SHOCK WAVE EXPERIMENTS ON IRON SULFIDE AND SULFUR IN PLANETARY CORES

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The possible importance of sulfur in planetary cores is widely recognized. Thus, an understanding of the melting relations of iron and iron sulfides is important to models of planetary interiors. A study was undertaken to constrain the melting of pyrrhotite ($Fe_{.87}S$) and relate it to core formation.

In the present experiments, 7 samples of pyrrhotite (Table 1) with varying porosities were shocked to pressures of 3.7 to 24 GPa. The shocked material was recovered and studied with optical and electron microscopy. Shock temperatures for the samples were determined from porous Hugoniots calculated from existing equation of state data (1,2). The results, combined with the zero-pressure liquidus of $Fe_{.87}S$, constrain the melting curve to the region shown in Figure 1. Also shown are an experimental melting curve for Fe from Liu (3) and an experimental-plus-theoretical melting curve for the Fe-FeS eutectic from Usselman (4). It is expected that the melting curve of troilite (FeS) at high pressures would be similar to that of pyrrhotite. Further note should be taken of the experimental evidence that the composition of the eutectic material becomes more Fe-rich with increasing pressure (4).

If these data are applied to the interior of a planet during accretion, the result is that we expect potentially core-forming melts to be more sulfur-rich during early accretion when internal pressures are lower. Figure 2 shows plots of temperature vs. radius of a planet which undergoes only accretional heating with no internal heat transport. Also shown are estimates of internal pressure profiles for several instantaneous planetary radii. Comparison of P-T combinations from this figure with the melting curves indicates that the first melting of Fe in the presence of FeS will occur relatively near the surface when the radius is about 1300 to 2000 km. As the planet grows and pressures at a given temperature and radius increase, more Fe-rich materials will melt. Also, FeS and Fe which are isolated from one another will begin to melt. At high pressures, pure FeS will melt at temperatures which may be much lower than those for Fe, as compared to lower pressures. In reality, however, the inner portions of a planet are expected to eventually reach high temperatures, melting both Fe and FeS, and equilibration with the surrounding material may occur offsetting any effect the lower melting point of FeS might have. On the whole, the total melt in the planet will probably tend toward more Fe-rich compositions as a planet grows. If the core of a planet reflects a "freezing in" of this trend at some point, then the cores of smaller bodies will tend to have higher sulfur contents.

Complications such as equilibration of migrating melts with surrounding materials or heat sources such as radioactivity and gravitational energy of differentiation have not been considered

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here, although they are sure to have sizeable effects on the behavior of melting and melt migration. However, the principle presented here is important and should be considered in attempts to model the cores of planetary bodies.

References:

1) Brown J. M. et al. (1984) Jour. Geophys. Res. 89, 6041-6048.
2) Watt J. P. and Ahrens T. J. (1984) Jour. Geophys. Res. 89 7836-7844.
3) Liu L. (1975) Geophys. J. 43, 697-705.
4) Usselman T. M. (1975) Am. Jour. Sci. 275, 291-303.

Table 1. Shock wave experiments on pyrrhotite.

Shot	Porosity (%)	Pressure (GPa)	Temperature (K)	Melting*
858	0	23-24	550-1000	
868	28.3	11-13	1300-1650	
877	33	23-24	1800-2300	X
878	33.3	11-13	1500-1800	
879	34.8	3.5-4.5	500-750	
880	34.6	7.5-8.5	1000-1300	
881	33	16-17	1600-2200	X

* Excludes shear band and other local melting events not related to Hugoniot temperatures. Determined on the basis of textural criteria developed for this study.

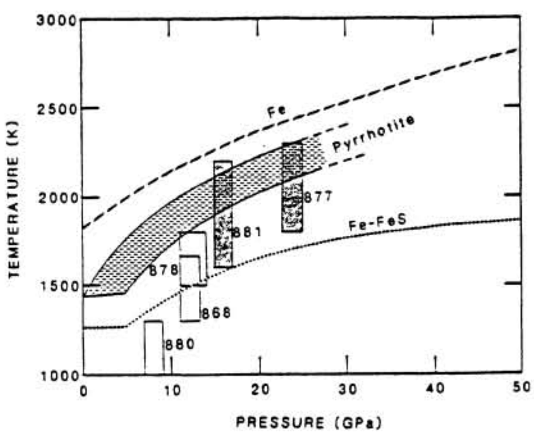

Figure 1. Shot data and the inferred region of melting for pyrrhotite and melting curves for Fe and Fe-FeS eutectic (from 3, 4). Shaded boxes represent samples which melted.

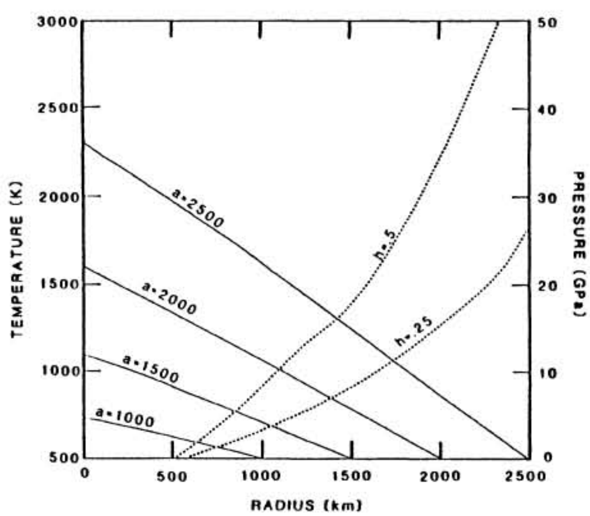

Figure 2. Temperatures (dotted lines) in a planet which retains fraction h of its accretional heat and pressure profiles (solid lines) for instantaneous planetary radii a in km.

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