Liquid silicate equation of state: Using shock waves to understand the properties of the deep Earth

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ABSTRACT

The equations of state (EOS) of several geologically important silicate liquids have been constrained via preheated shock wave techniques. Results on molten Fe_2SiO_4 (fayalite), Mg_2SiO_4 (forsterite), $CaFeSi_2O_6$ (hedenbergite), an equimolar mixture of $CaAl_2Si_2O_8$-$CaFeSi_2O_6$ (anorthite-hedenbergite), and an equimolar mixture of $CaAl_2Si_2O_8$-$CaFeSi_2O_6$-$CaMgSi_2O_6$ (anorthite-hedenbergite-diopside) are presented. This work represents the first ever direct EOS measurements of an iron-bearing liquid or of a forsterite liquid at pressures relevant to the deep Earth (> 135 GPa). Additionally, revised EOS for molten $CaMgSi_2O_6$ (diopside), $CaAl_2Si_2O_8$ (anorthite), and $MgSiO_3$ (enstatite), which were previously determined by shock wave methods, are also presented.

The liquid EOS are incorporated into a model, which employs linear mixing of volumes to determine the density of compositionally intermediate liquids in the CaO-MgO-Al_2O_3-SiO_2-FeO major element space. Liquid volumes are calculated for temperature and pressure conditions that are currently present at the core-mantle boundary or that may have occurred during differentiation of a fully molten mantle magma ocean.

The most significant implications of our results include: (1) a magma ocean of either chondrite or peridotite composition is less dense than its first crystallizing solid, which is not conducive to the formation of a basal mantle magma ocean, (2) the ambient mantle cannot produce a partial melt and an equilibrium residue sufficiently dense to form an ultralow velocity zone mush, and (3) due to the compositional dependence of Fe^{2+} coordination, there is a threshold of Fe concentration (molar $X_{Fe} \leq 0.06$) permitted

in a liquid for which its density can still be approximated by linear mixing of end-member volumes.

TABLE OF CONTENTS

Acknowledgements iii
Abstract iv
Table of Contents vi
List of Tables and Figures viii

Chapter I

Introduction I-1
References I-4

Chapter II

Multi-technique equation of state for Fe_2SiO_4 melt and the density of Fe-bearing silicate melts from 0-161 GPa II-1
Abstract II-2
Introduction II-3
Methods II-6
1-atm double-bob Archimedean methods II-6
Sink/float methods II-7
Shock wave methods II-8
Sample synthesis and preparation of preheated (1573 K) shots II-8
Preparation of room temperature (300 K) shots II-11
Experimental setup II-11
Results II-13
Density and ultrasonic results at ambient pressure II-14
Sink/float results II-14
Shock wave results II-14
Comparison to previous data II-14
Solid Hugoniot shocked to liquid / $\chi 2$ test of weighted values II-17
Grüneisen parameter II-17
Thermal equation of state fitting II-20
Correction and re-analysis of silicate liquids II-26
Implications II-26
Mixing of oxide volumes at high pressure and temperature; application to a magma ocean liquidus II-26
Buoyancy in the current temperature regime; application to the solidus and ULVZ II-32
Conclusions II-35
Acknowledgements II-36
References II-37

Chapter III

Direct shock compression experiments on pre-molten Mg_2SiO_4 and progress towards a consistent high-pressure equation of state for $CaO\text{-}MgO\text{-}Al_2O_3\text{-}SiO_2\text{-}FeO$ liquids III-1

Abstract III-2
Introduction III-3
Methods III-5
Sample preparation of preheated (2273 K) shots III-5
Experimental setup III-6
Results III-8
Linear Hugoniot III-8
Grüneisen parameter III-10
Thermal equation of state fitting III-12
Revised Equations of State for $MgSiO_3$ and CaAl2Si_2O_8 liquids III-14
Enstatite, $MgSiO_3$ III-14
Anorthite, $CaAl_2Si_2O_8$ III-15
Discussion III-18
Sound speed of Mg_2SiO_4 liquid III-18
Isentropes for a full mantle magma ocean III-20
Evaluating the partial melt hypothesis for
Ultralow velocity zones III-23
Conclusions III-30
Acknowledgements III-32
References III-33

Chapter IV

Preheated shock liquids Hd, An-Hd-Di, An-Di: a test for linear
mixing at high pressure and temperature IV-1
Abstract IV-2
Introduction IV-3
Methods IV-4
Sample preparation IV-4
Experimental setup IV-6
Results IV-7
Hedenbergite ($CaFeSi_2O_6$) liquid IV-8
An-Hd liquid IV-10
An-Hd-Di liquid IV-10
Discussion IV-11
Linear mixing assumptions IV-11
Glass and 1-bar melt data IV-12
Tests of linear mixing IV-16
Conclusions IV-19
Acknowledgements IV-21
References IV-22

LIST OF TABLES AND FIGURES

Chapter II *Page*
Table 1: Double-bob density measurements..II-41
Table 2: Shock compression data II-42
Table 3: Parameters used..II-43
Table 4: Equation of state fits for molten Fe_2SiO_4 ....II-43
Table 5: BM/MG fits for silicate liquid II-44
Table 6: Major oxide proportions for model mantle II-44

Figure Captions...II-45
Figure 1: Comparison of previous sink/float and shock wave results ...II-49
Figure 2: Schematic of shock wave arrival selection II-50
Figure 3: Double-bob density linear fit...II-51
Figure 4: Density-pressure diagram of sink/float results II-52
Figure 5: U_S-u_p preheated fayalite Hugoniot II-53
Figure 6: Grüneisen parameter of liquid and solid silicates II-54
Figure 7: *P*-*ρ* preheated fayalite Hugoniot...II-55
Figure 8: Model mantle isentropic temperature profiles.......................II-56
Figure 9: Silicate liquid densities along a modern geotherm................II-57
Figure 10: Density of liquid mixtures for ULVZ II-58

Chapter III *Page*
Table 1: Shock compression data...III-38
Table 2: Parameters used..III-38
Table 3: Equation of state fits for molten Mg_2SiO_4.............................III-39
Table 4: Equation of state fits for molten silicate liquids.....................III-39

Figure Captions...III-40
Figure 1:Modeled sound speed parameter space..................................III-43
Figure 2: U_S-u_p preheated forsterite Hugoniot.....................................III-44
Figure 3: Grüneisen parameter of liquid silicates.................................III-45
Figure 4: *P*-*ρ* preheated fayalite Hugoniot...III-46
Figure 5: $MgSiO_3$ Hugoniot dataset...III-47
Figure 6: Estimates of Mg_2SiO_4 liquidus III-48
Figure 7: Silicate liquid and solid densities along a geotherm.............III-49
Figure 8: Re-modeled mantle isentropic temperature profiles.............III-50
Figure 9: Partial melting of ULVZ composition III-51

Chapter IV *Page*
Table 1: Shock compression data... IV-25
Table 2: Parameters used.. IV-26

Table 3: Equation of state fits for molten $CaFeSi_2O_6$........................... IV-26
Table 4: Equation of state fits for molten An-Hd................................. IV-27
Table 5: Equation of state fits for molten An-Hd-Di IV-27

Figure Captions... IV-28
Figure 1: U_S-u_p preheated $CaFeSi_2O_6$ Hugoniot.................................. IV-31
Figure 2: P-ρ preheated $CaFeSi_2O_6$ Hugoniot..................................... IV-32
Figure 3: U_S-u_p preheated An-Hd Hugoniot.. IV-33
Figure 4: P-ρ preheated An-Hd Hugoniot IV-34
Figure 5: U_S-u_p preheated An-Hd-Di Hugoniot IV-35
Figure 6: P-ρ preheated An-Hd-Di Hugoniot....................................... IV-36
Figure 7: Hd mixing model IV-37
Figure 8: Comparison of An-Hd mixing models.................................. IV-38
Figure 9: Comparison of An-Hd-Di mixing models IV-39
Figure 10: Comparison of mantle mixing models................................ IV-40