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Supporting Information for

Viscosity of Fe-Ni-C Liquids up to Core Pressures and Implications for Dynamics of Planetary Cores

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Additional Supporting Information (Files uploaded separately)

Introduction

The supporting information includes 4 figures, 3 tables and 1 movie. Figure S1 shows the sketch of the cell assembly for viscosity measurement. Figure S2 and S3 show the viscometry data of all investigated pressure points. Figure S4 shows the convergence of viscosity in FPMD calculation. Table S1 summarizes the viscosity measurements of Fe-(Ni)-light element in this and previous studies. Table S2 and S3 give the data of viscosity measurements and calculations in this study. Movie S1 shows an example of the floating sphere experiments.

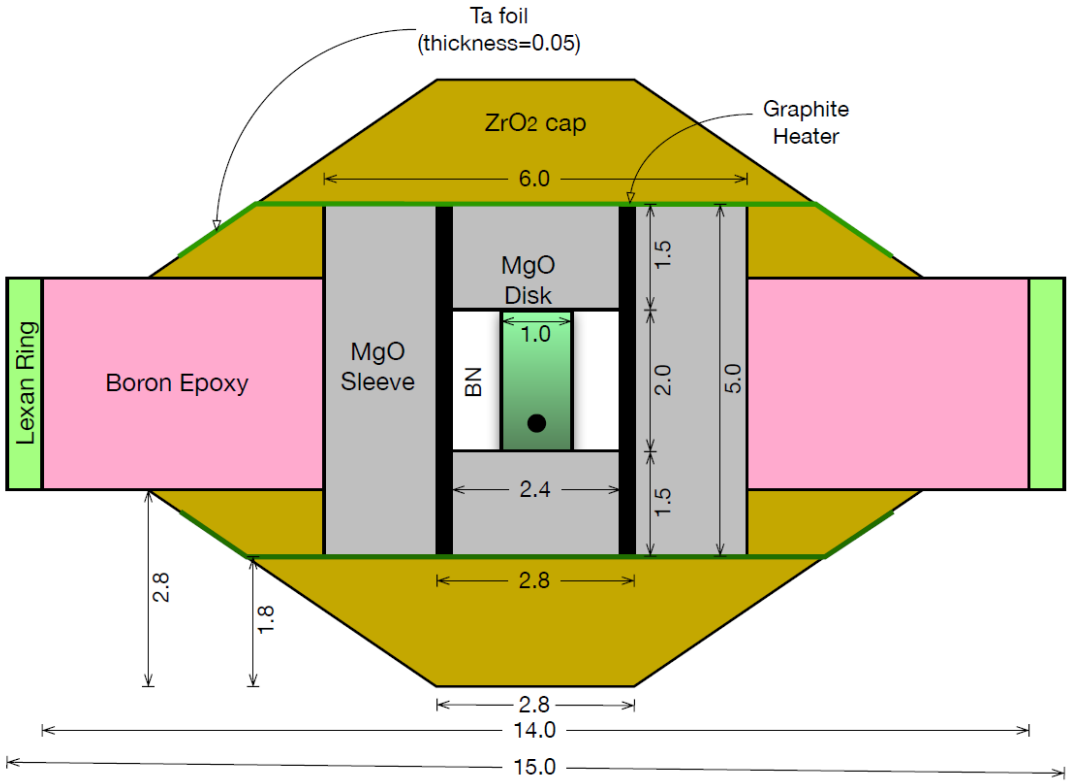

Figure S1. Sketch of the cell assembly for viscosity measurement in the Paris-Edinburgh Press at 16-BM-B [*Kono et al.*, 2014]. The green part in the center is the sample and the black sphere inside is the ruby sphere.

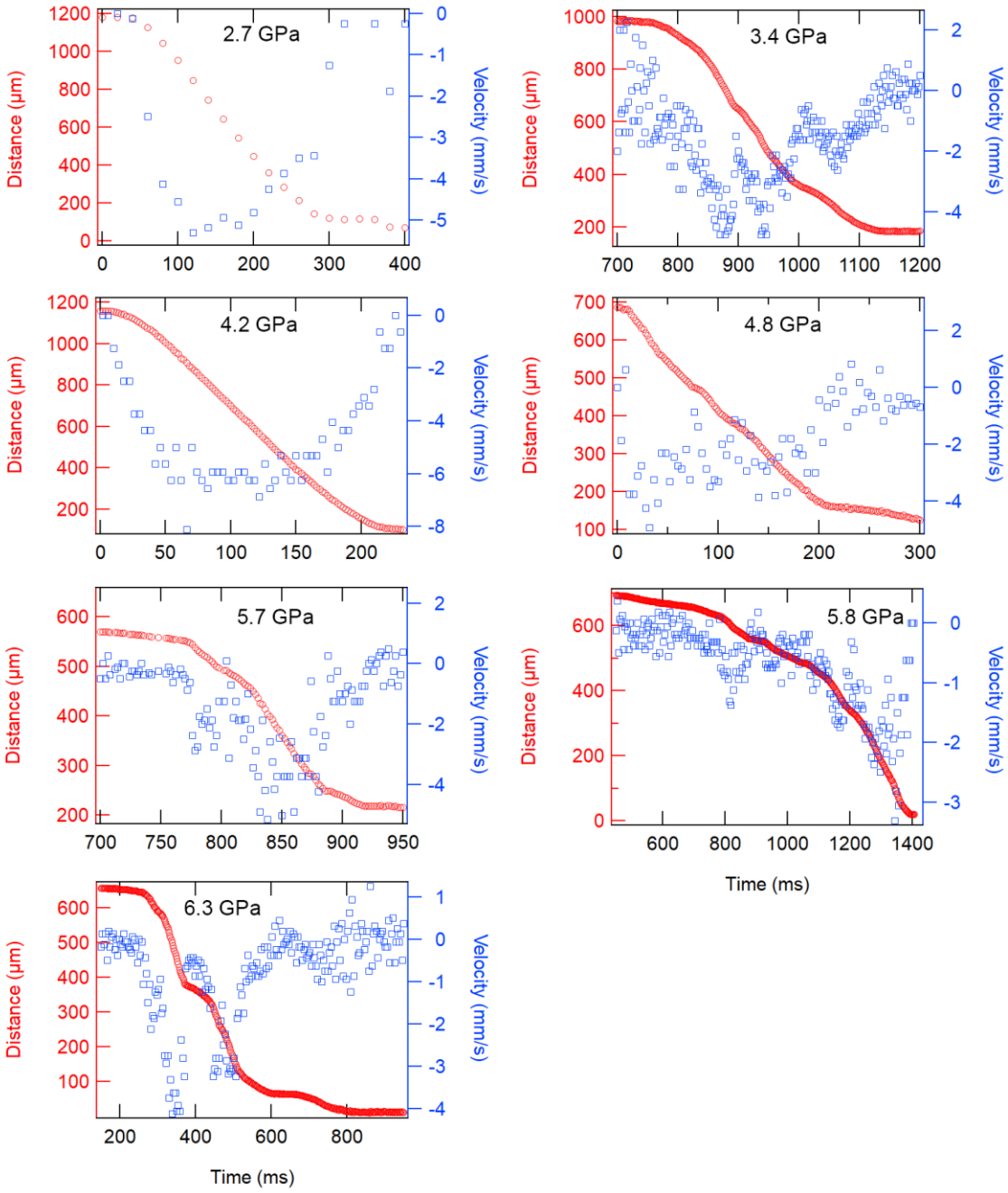

Figure S2. The distance-time (left axis) and converted velocity–time (right axis) relation for all $Fe_{90}Ni_{10}$-3 wt.%C viscometry measurements. The frame rate is 500 frame/s except that at 2.7 GPa, which is at 50 frame/s. Some velocities are calculated combining two frames to reduce data scattering. The absence of some data points in the curve (e.g. ~750 ms at 5.7 GPa) is due to the failure of locating sphere coordinates by the sphere tracking software. The absence does not influence the determination of terminal velocity. At 5.8 GPa, the highest velocity was reached at position too close to the end of the capsule, thus the terminal velocity may be higher than the measured one, which means the calculated viscosity may be overestimated.

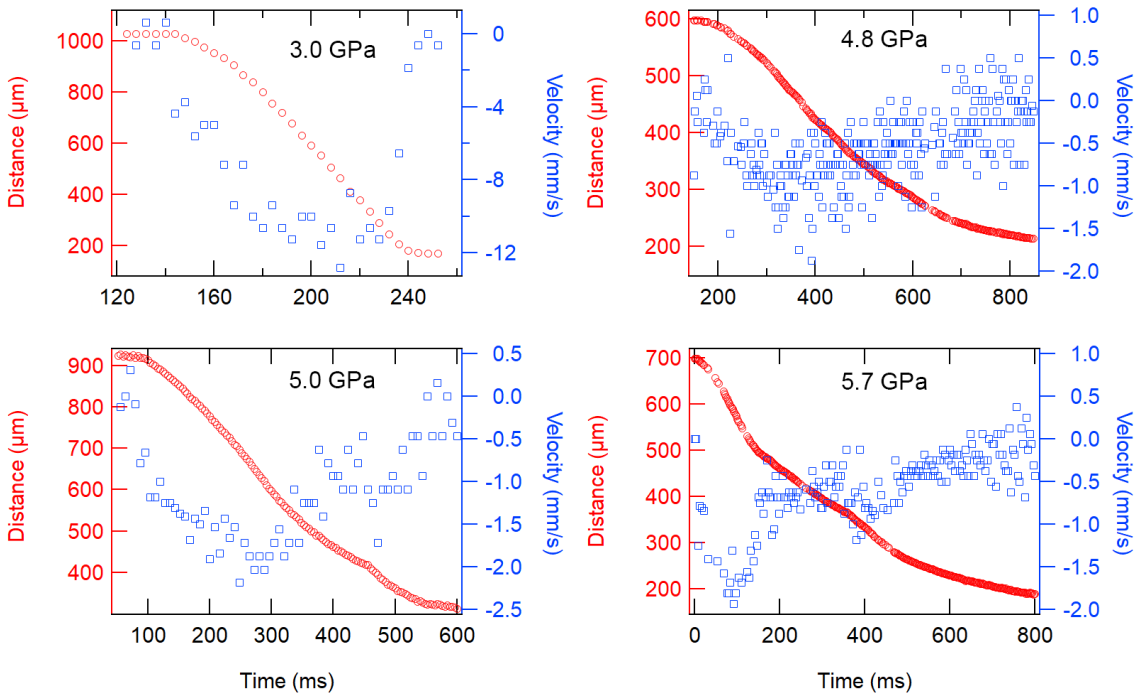

Figure S3. The distance-time (left axis) and converted velocity–time (right axis) relation for all $Fe_{90}Ni_{10}$-5 wt.%C viscometry measurements. The frame rate is 500 frame/s except that at 3.0 GPa, which is at 250 frame/s. Some velocities are calculated combining two frames to reduce data scattering. At 4.8 GPa, the velocity shows a very small convex with terminal velocity significantly lower than those of 5.0 and 5.7 GPa close to it. Given its relatively smooth motion, additional forces from the wall and end may interfere its early acceleration process, resulting the terminal velocity underestimated and the viscosity overestimated.

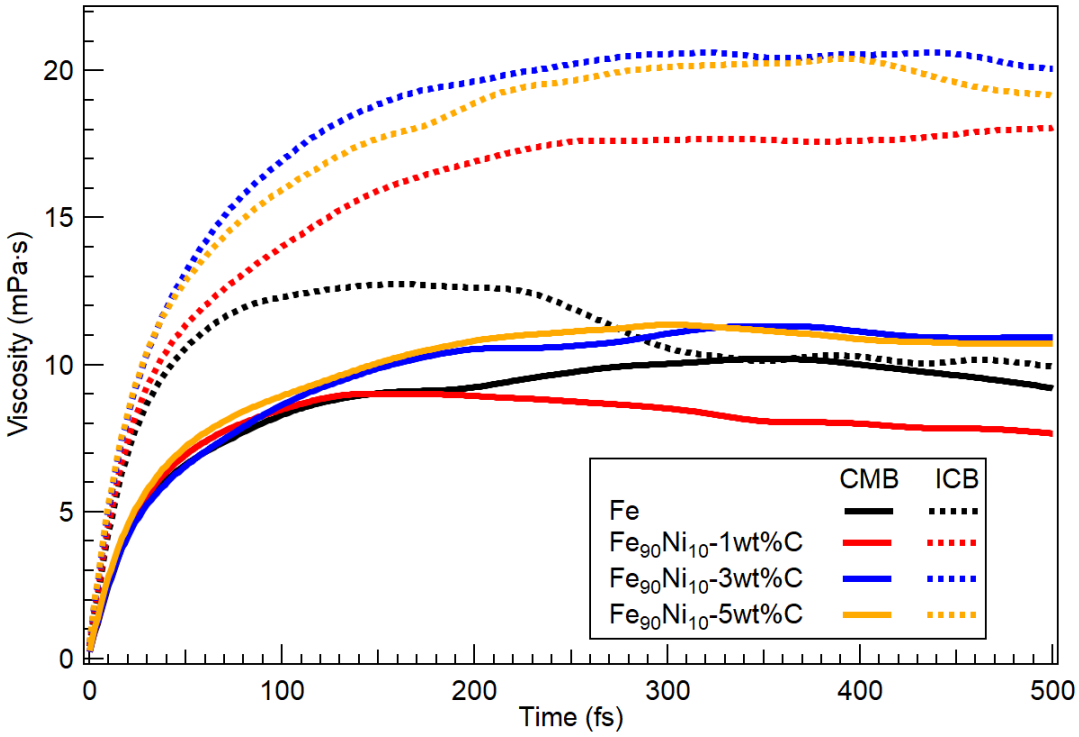

Figure S4. Convergence of viscosity of Fe and $Fe_{90}Ni_{10}$-C liquids with 1, 3 and 5 wt% C as a function of time at CMB (135 GPa, 4050 K) and ICB (330 GPa, 5530 K) conditions.

Table S1. Viscosity measurements of Fe-(Ni)-light element alloys.

Composition	Pressure range (GPa)	Method	Source
$Fe_{90}Ni_{10}$-3C	1.8-6.3	X-ray radiography	this study
$Fe_{90}Ni_{10}$-5C	3-5.7	X-ray radiography	this study
Fe-27S	2-5	falling sphere	LeBlanc & Secco 1996
FeS	0.5-5	X-ray radiography	Dobson et al. 2000
Fe-S(eutectic)	1.5-5.5	X-ray radiography	Dobson et al. 2000
Fe-27S	1.5-6.9	X-ray radiography	Terasaki et al. 2001
Fe-FeS	5.0-6.9	X-ray radiography	Urakawa et al. 2001
Fe-10S	1.5-4.0	X-ray radiography	Secco et al. 2002
Fe-8.5S	2.4-6.0	X-ray radiography	Rutter et al. 2002a
Fe	1.6-5.5	X-ray radiography	Rutter et al. 2002b
Fe	2.8-7.0	X-ray radiography	Terasaki et al. 2002
$Fe_{86}C_{14}$	3.0-4.5	X-ray radiography	Terasaki et al. 2006
$Fe_{78}S_{22}$	8.6-16.1	X-ray radiography	Terasaki et al. 2006
FeS	0.7-1.7	X-ray radiography	Perrillat et al. 2010
Fe	1.6-6.4	X-ray radiography	Kono et al. 2015
FeS	1.2-6.3	X-ray radiography	Kono et al. 2015

Table S2. Viscosities of Fe-Ni-C liquids from Paris-Edinburgh Press Experiments.

Pressure (GPa)	Viscosity (mPa·s)	Pressure (GPa)	Viscosity (mPa·s)
$Fe_{90}Ni_{10}$-3 wt%C		$Fe_{90}Ni_{10}$-5 wt%C	
1.8	8.2(4)	3.0	4.7(2)
2.7	9.8(5)	4.8	35.9(20)*
3.4	12.1(6)	5.0	25.6(14)
4.2	8.3(4)	5.7	27.0(16)
4.8	17.9(11)		
5.7	14.4(7)		
5.8	24.7(11)*		
6.3	16.1(8)		

Note: The temperature is 1973 K for all data points.

Sources of uncertainty: Uncertainty of liquid density (~0.05 g/cm^3) results in ~1.5% uncertainty of viscosity; Uncertainty of sphere density (~0.003 g/cm^3) results in ~0.1% uncertainty; Uncertainty of temperature (50 K) results in ~0.02 g/cm^3 uncertainty in the difference between liquid and sphere density, ~0.6% uncertainty of viscosity; Uncertainty of sample diameter (0.004 mm) and height (0.004 mm) results in ~0.4% and <0.1% uncertainty; Uncertainty of ruby sphere diameter (0.004 mm) results in ~1.7% uncertainty. Terminal velocity determination results in 0.1-0.5 mPa·s uncertainty, depending on the data quality.

*These viscosities may represent upper limits of the true viscosities in these two measurements. Details in Figure S2 & S3.

Table S3. Viscosities of Fe and Fe-Ni-C liquids from FPMD calculations

Conditions	Viscosity (mPa·s)			
	Fe	$Fe_{90}Ni_{10}$-1wt%C	$Fe_{90}Ni_{10}$-3wt%C	$Fe_{90}Ni_{10}$-5wt%C
CMB 135 GPa 4050 K	9.7(4)	8.7(3)	10.7(4)	11.0(3)
ICB 330 GPa 5530 K	12.7(2)	17.3(5)	20.1(5)	19.4(8)

Movie S1. An example of the floating sphere experiment for viscosity measurement at 1.8 GPa and 1973 K. The movement of the ruby sphere (light color ball) upon melting was recorded by a high-speed X-ray camera at a frame rate of 500 frame/s. The movie is 10x slower (50 frame/s) for better observation.