In-situ observation of liquid immiscibility in the Fe-O-S system at high pressure using an X-ray radiographic technique

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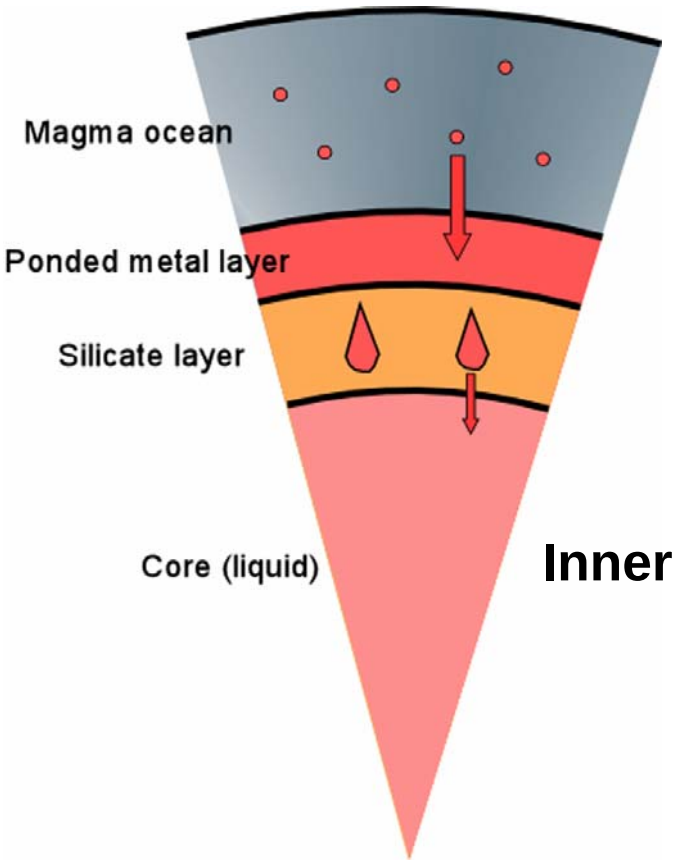
Liquid immiscibility in the Earth‘s core?

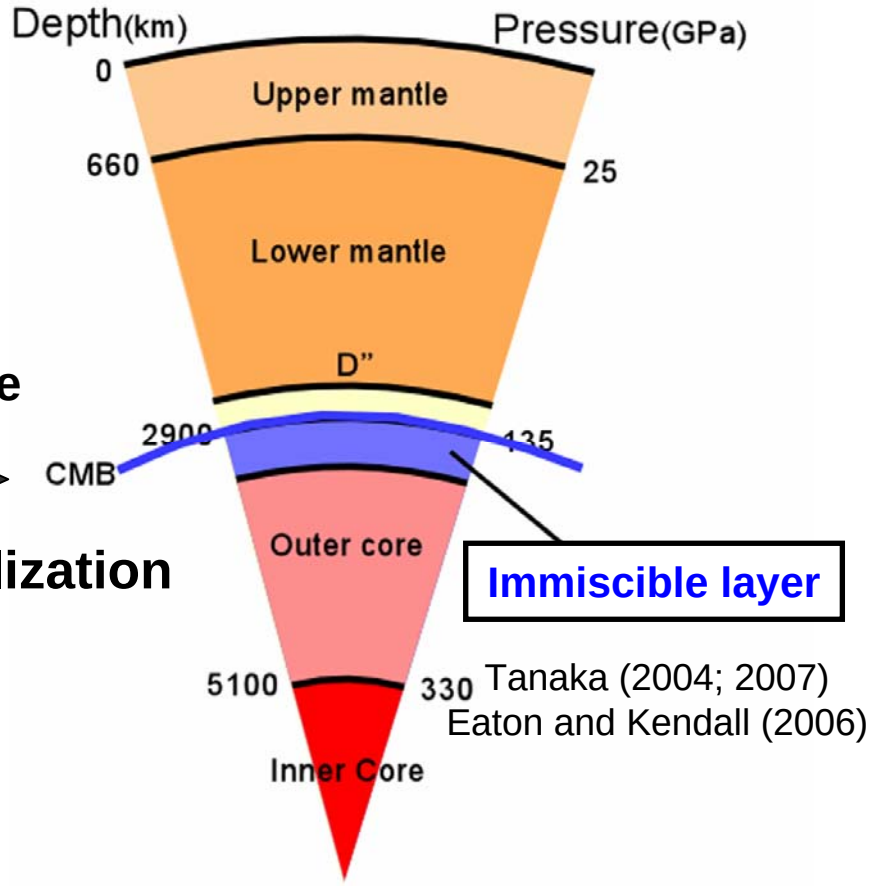
Presence of a thin layer in the outermost core?



During core formation,
Light elements dissolved in liquid iron.

T_{core} decrease

Inner core crystallization



Tanaka (2004; 2007)
Eaton and Kendall (2006)

Immiscibility develops?

Light element combinations in the core

Fe+	*H*	*C*	*O*	*Si*	*S*
H					
C	Unknown				
O	Unknown	Unknown			
Si	Unknown	Possible	Unlikely		
S	Unknown	Possible	Possible	Unlikely	

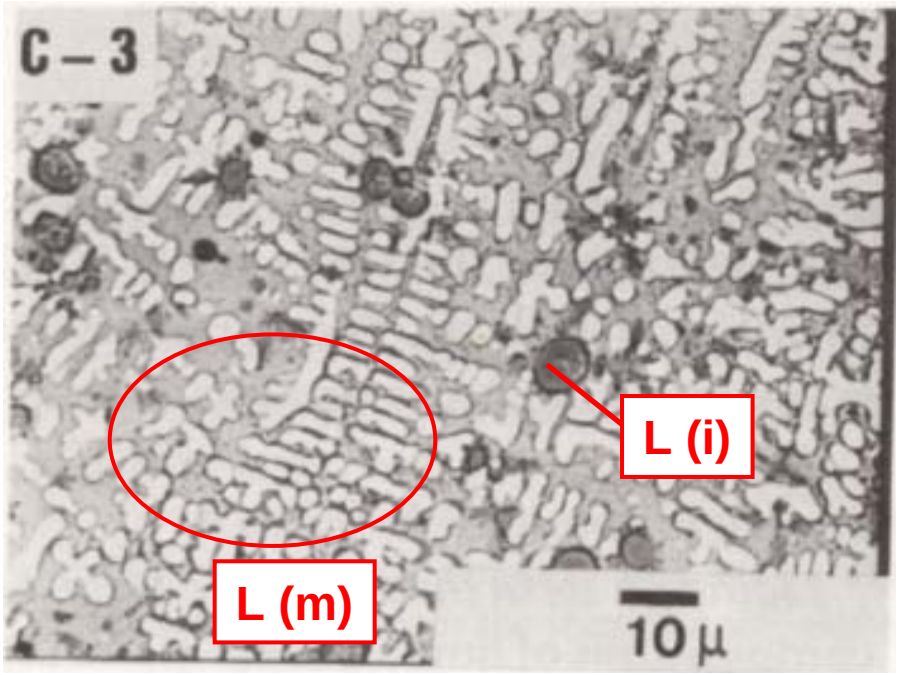
Li and Fei (2003)

- Liquid immiscibility gap

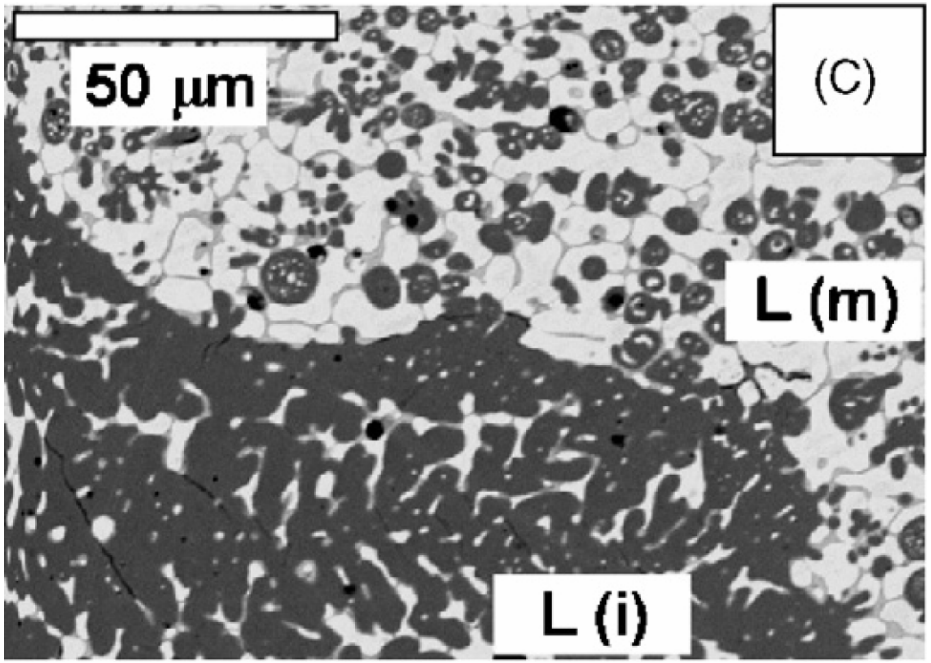
  Fe-S-Si system (Sanloup and Fei 2004)
  Fe-O-S system (Urakawa et al. 1987; Tsuno et al. 2007a)
  Fe-S-C system (Urakawa et al. 2005)

- Based on the textural observation and chemical analysis of the recovered samples.

Previous Fe-O-S experiments



Urakawa et al. (1987)

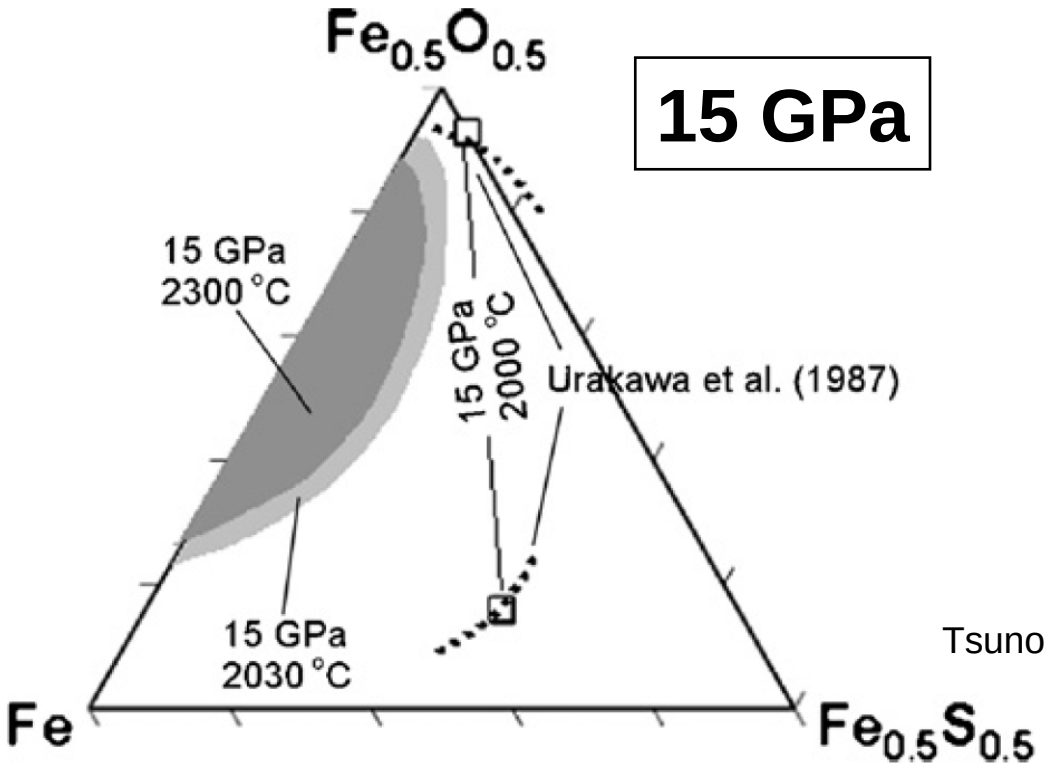


Tsuno et al. (2007a)

L (m): Fe-S metallic liquids
L (i): Fe-O ionic liquids

Difference in textural interpretation of quench products

Purpose of this study



Tsuno et al. (2007a)

• Difference of liquid immiscibility gap could be due to difference in textural interpretation of quench products.

• Our goal is therefore to observe liquid immiscibility in-situ at high P and T, and determine precise liquid immiscibility gaps

Experimental methods

High pressure apparatus: Kawai-type multianvil presses
1500-ton (SPEED-1500) on BL04B1 beamline (SPring-8)
700-ton (MAX-III) on BL14C2 beamline (KEK-PF)
3000-ton (SPIRIT-3000) at Tohoku University

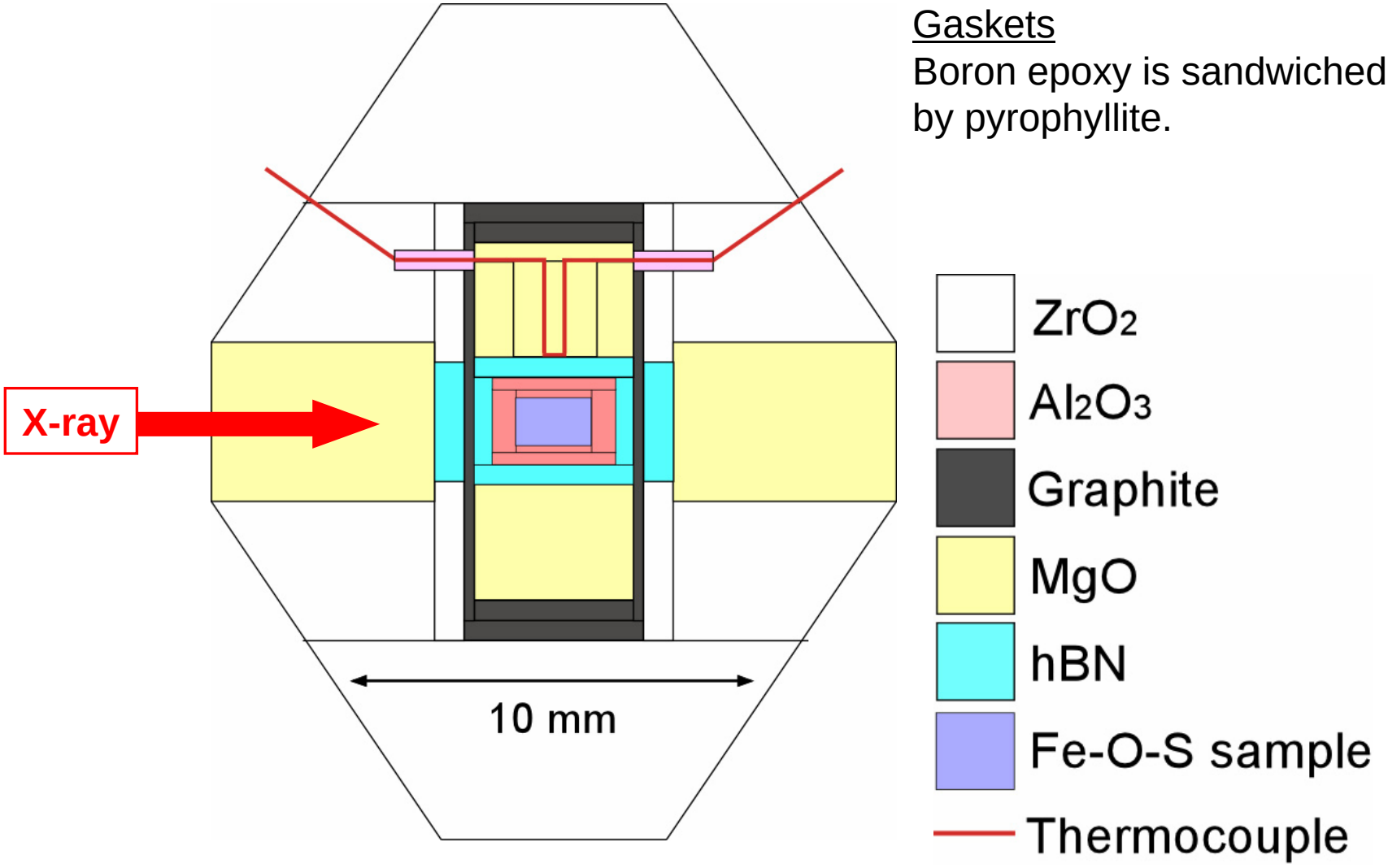
X-rays: White X-ray (SPring-8)
35 keV monochromatic X-ray (KEK-PF)

Pressure calibration: equation of state of hBN

Starting materials: mixtures of Fe, FeS, and $Fe_{0.91}O$

Experimental conditions: 3 GPa, up to 2203 K

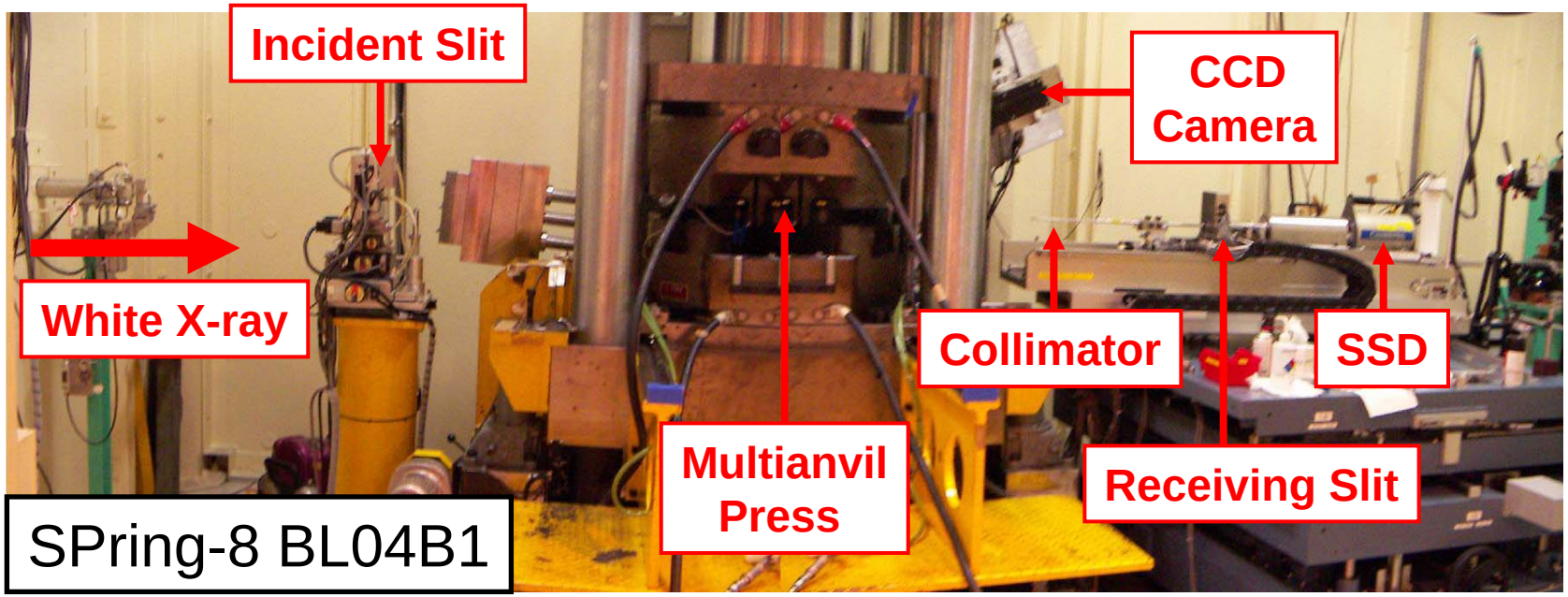
Cell Assembly (TEL 12 mm)

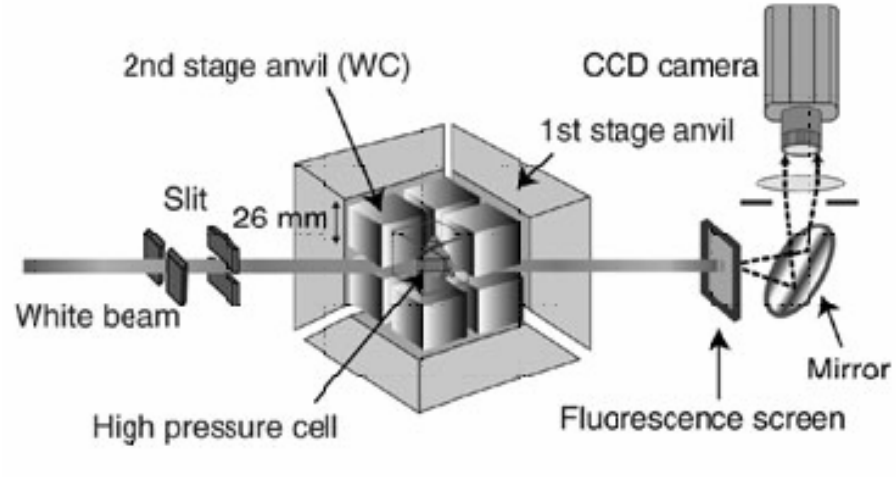


Gaskets

Boron epoxy is sandwiched by pyrophyllite.

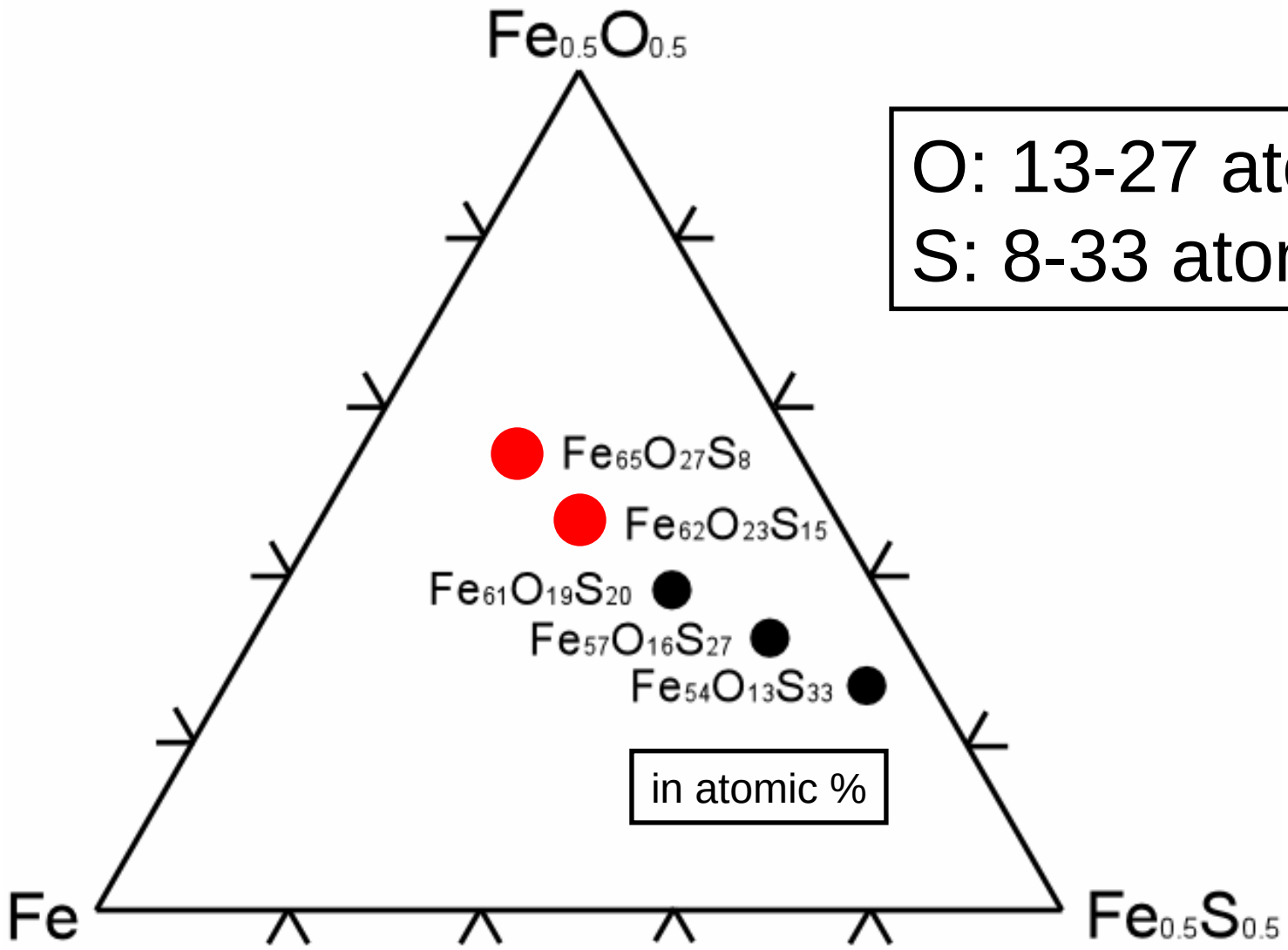
Beamlines





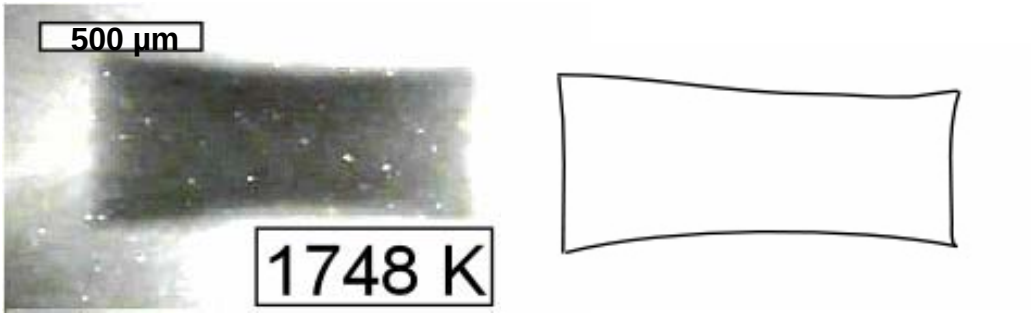
Funakoshi et al. (2002)

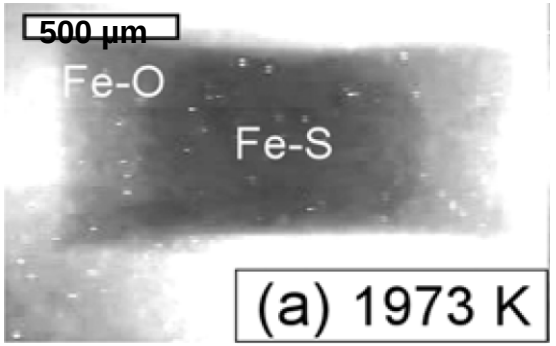
Starting compositions

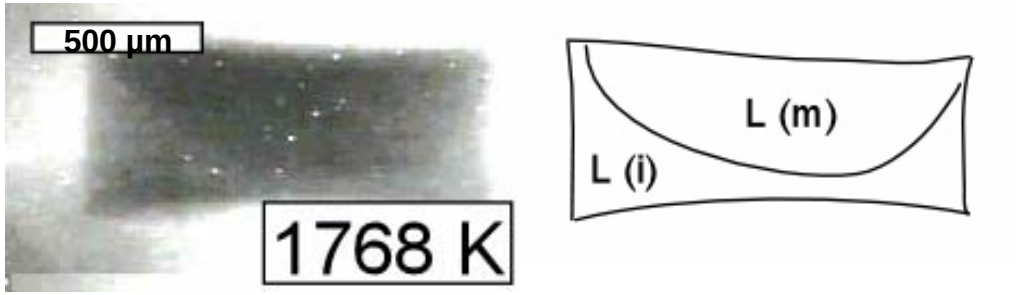


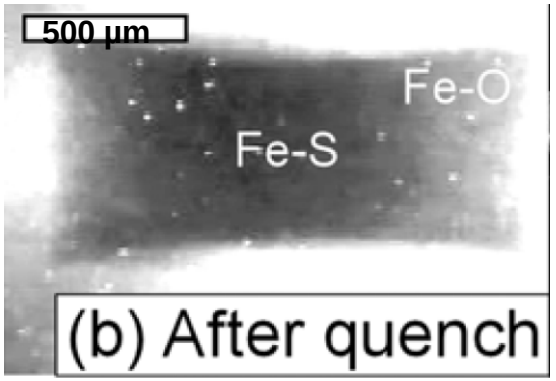
O: 13-27 atomic %
S: 8-33 atomic %

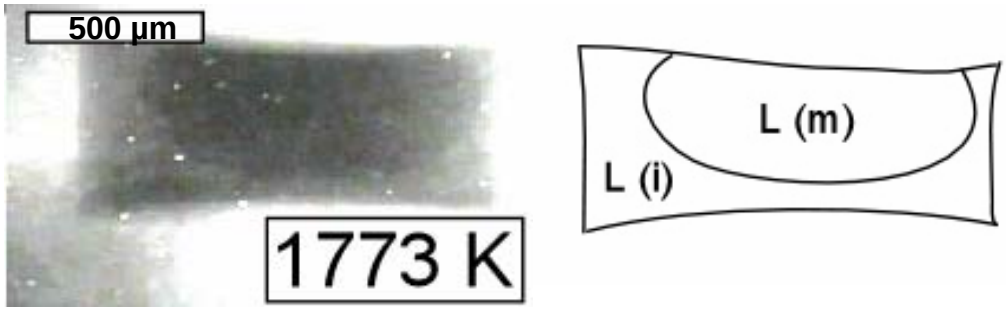
Radiography results (1): $Fe_{65}O_{27}S_8$





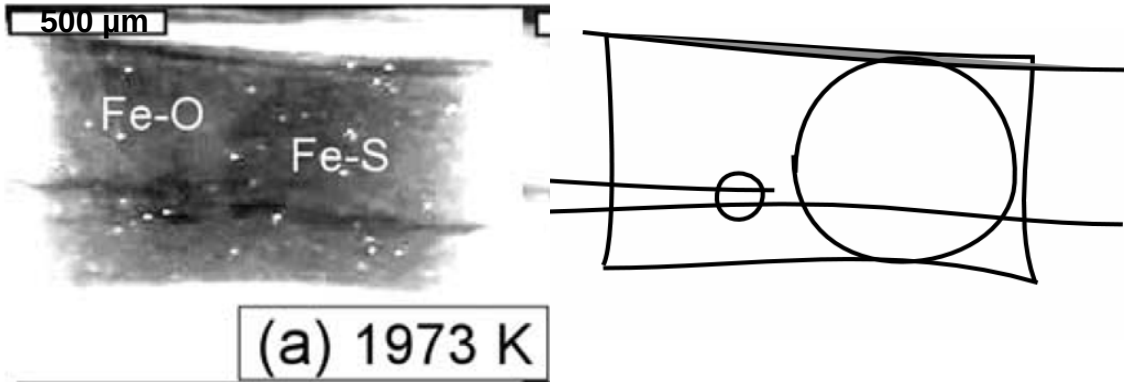


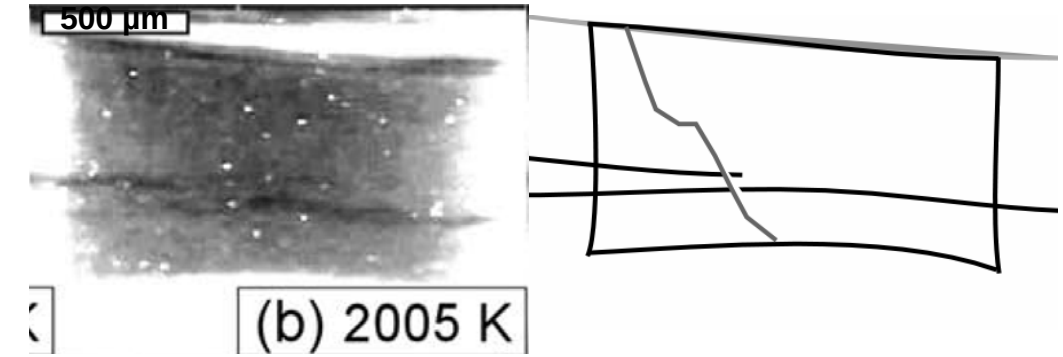


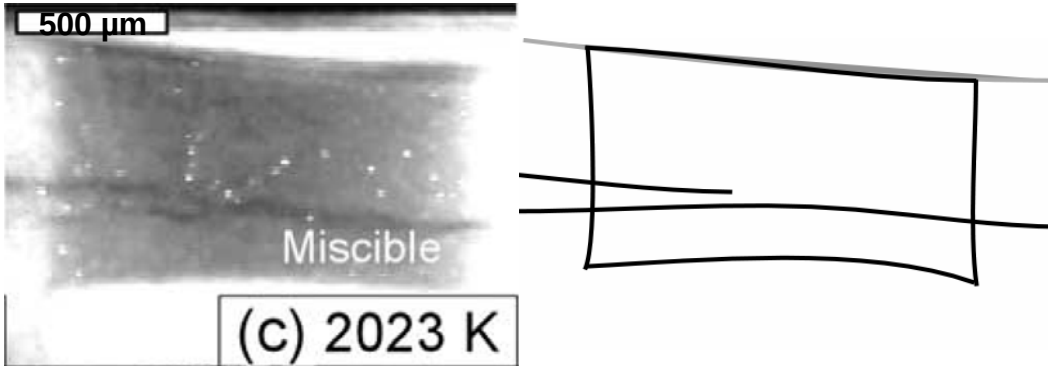


Immiscible liquids were quenched at room T.

Radiography results (2): $Fe_{65}O_{27}S_8$

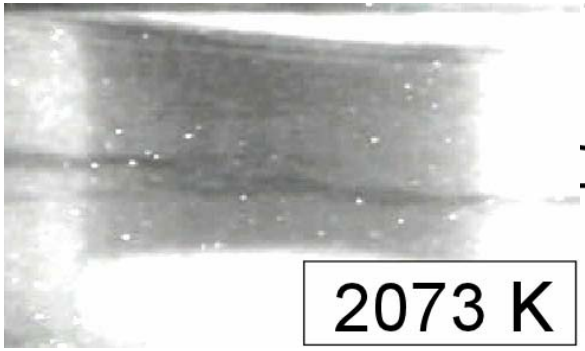


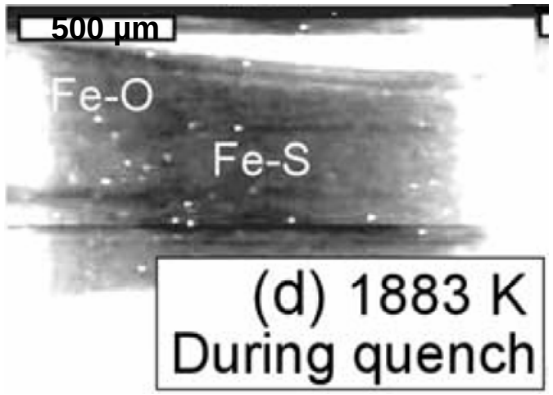


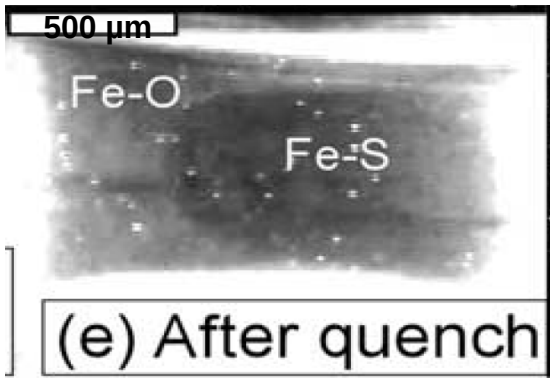


Immiscible liquids disappered and a miscible liquid was formed.

Radiographic images(a-c)
Tsuno et al. (2007b)







Two separated phases appeared from a miscible liquid during quenching.

Radiographic images(d-e)
Tsuno et al. (2007b)

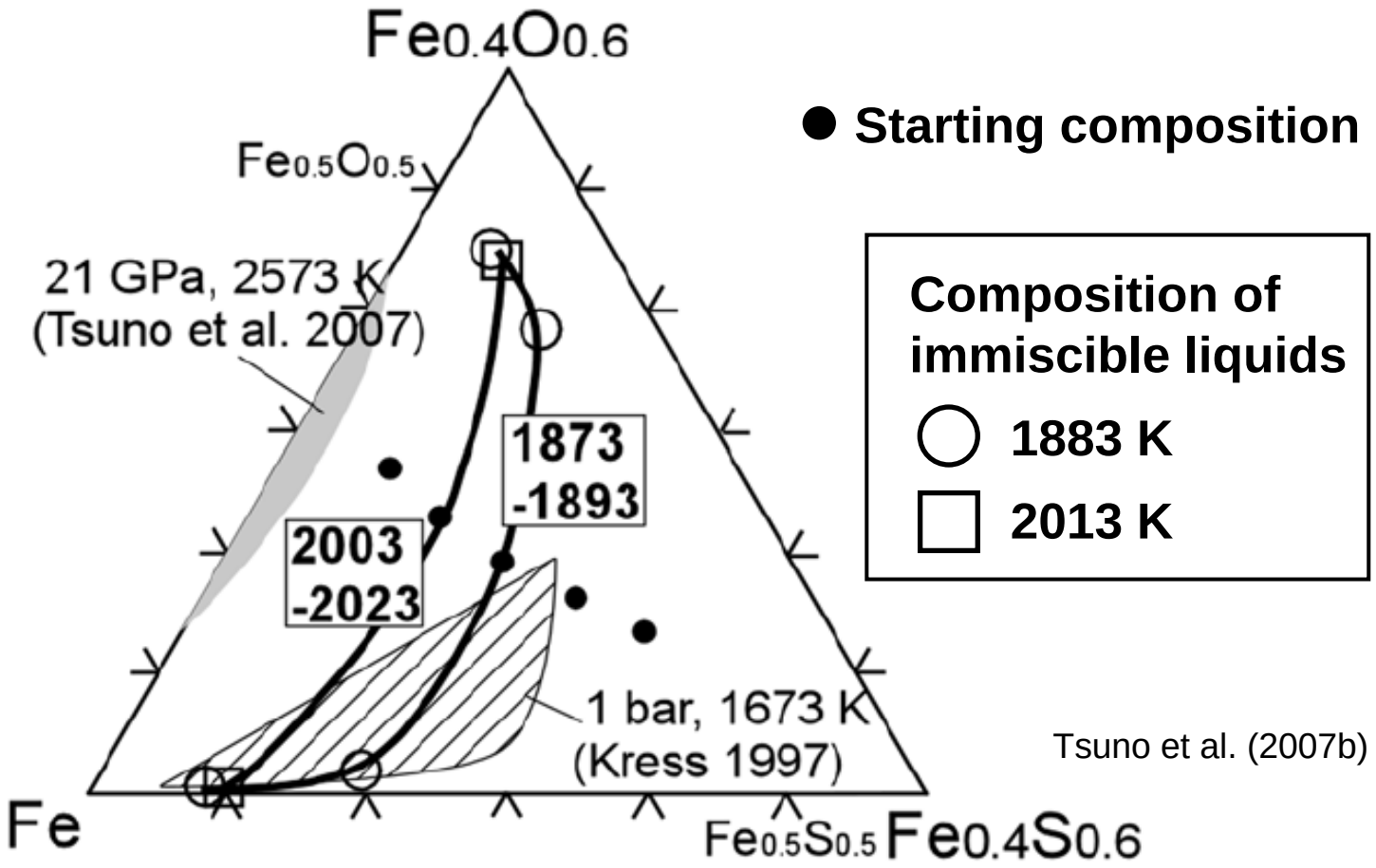
Importance of in-situ observation

• Fe-S and Fe-O liquid phases observed in quenched run products can be interpreted as either

(a) quenched immiscible phases, or
(b) exolution from miscible liquid.

• In-situ observations at high P and T necessary to determine immiscibility gap in Fe-light element systems.

Liquid immiscibility gap at 3 GPa



Liquid immiscibility gap shrinks with increasing temperature.

Summary

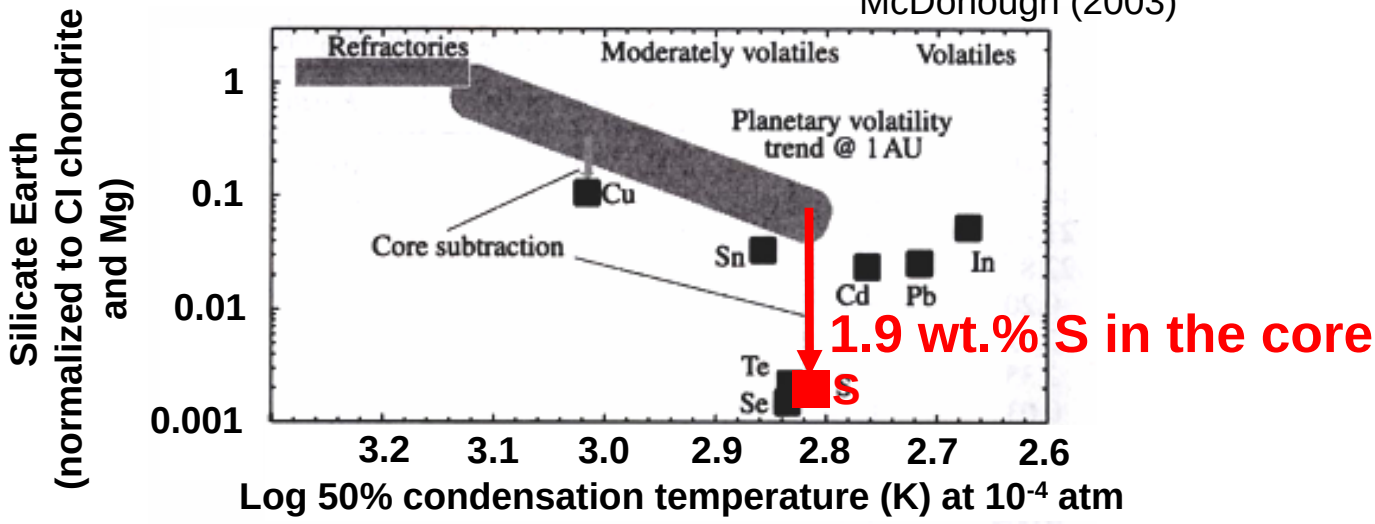
- In-situ observations of immiscible and miscible liquids in the Fe-O-S system were performed using an X-ray radiographic method.
- Immiscible and miscible liquids at high P and T, and quench process were observed.
- Liquid immiscibility gap decreases with increasing temperature at 3 GPa.
- X-ray radiographic technique is useful in solving questions of liquid immiscibility.

Contents

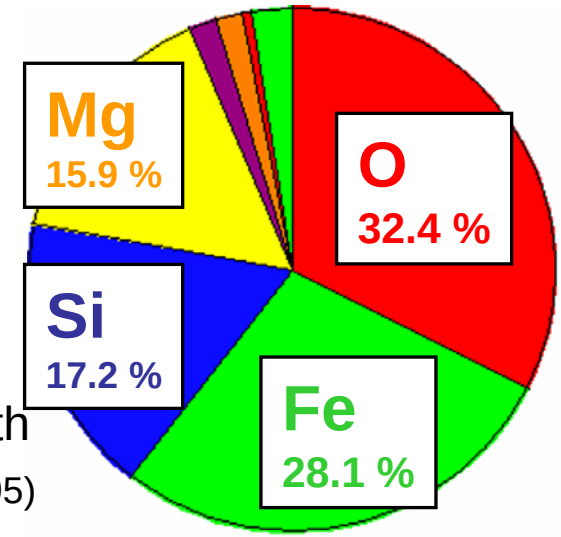
Significance of S and O in the core

(1) S: 1.9 wt.% in the outer core

McDonough (2003)



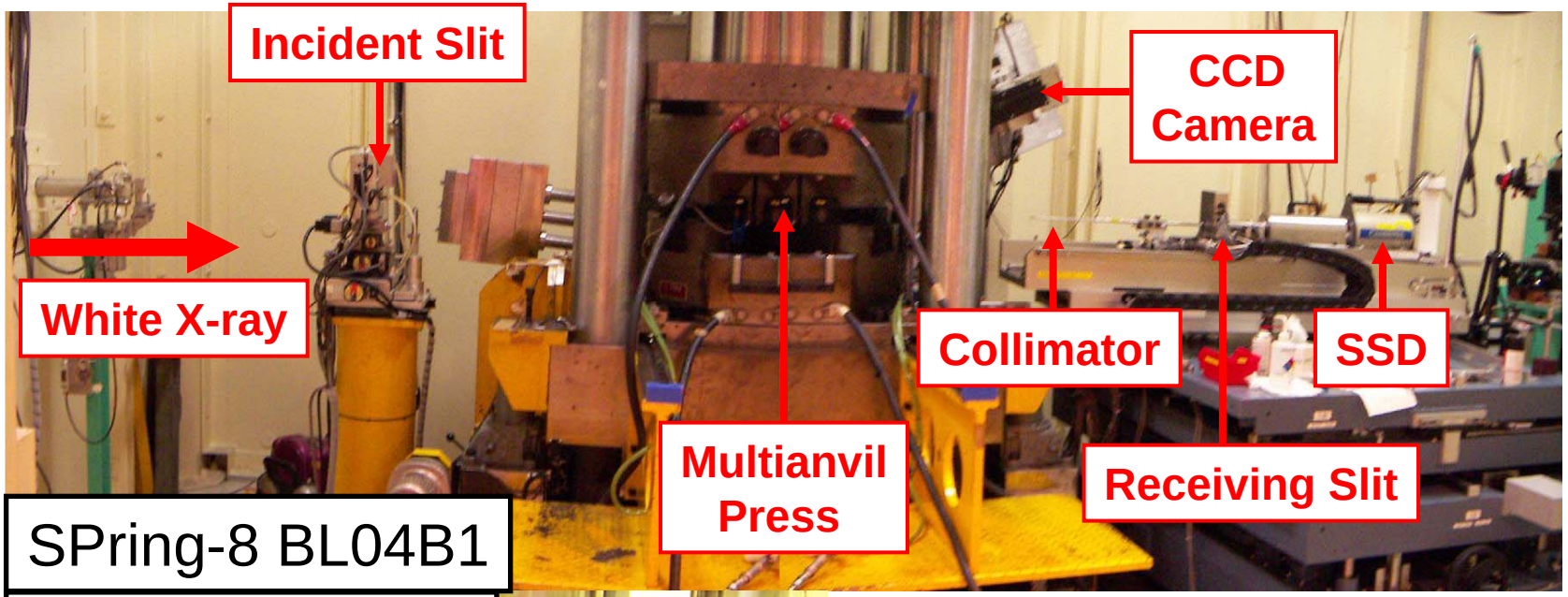
(2) O: most abundant in the bulk Earth



Bulk composition of the Earth

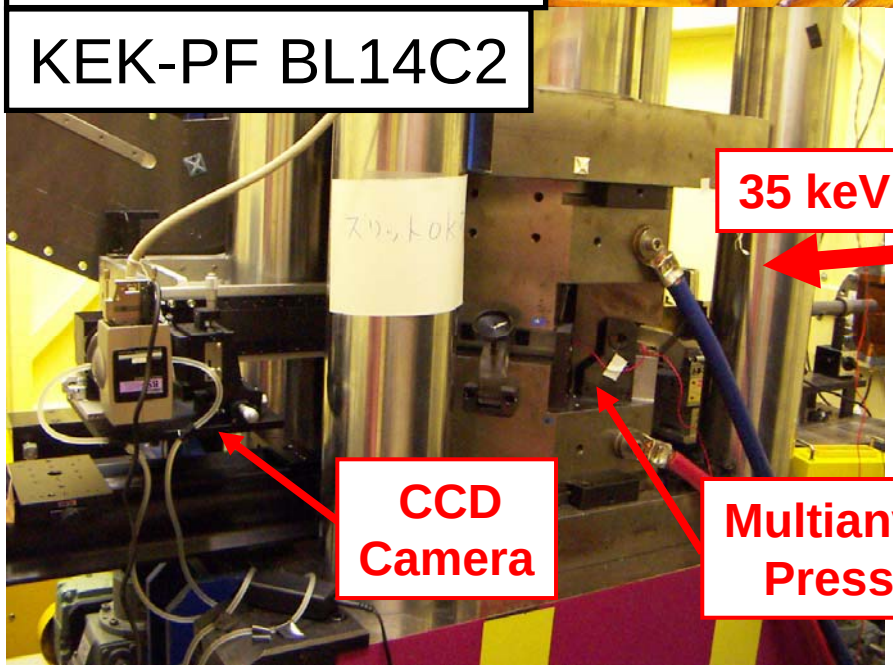
Allegre et al. (1995)

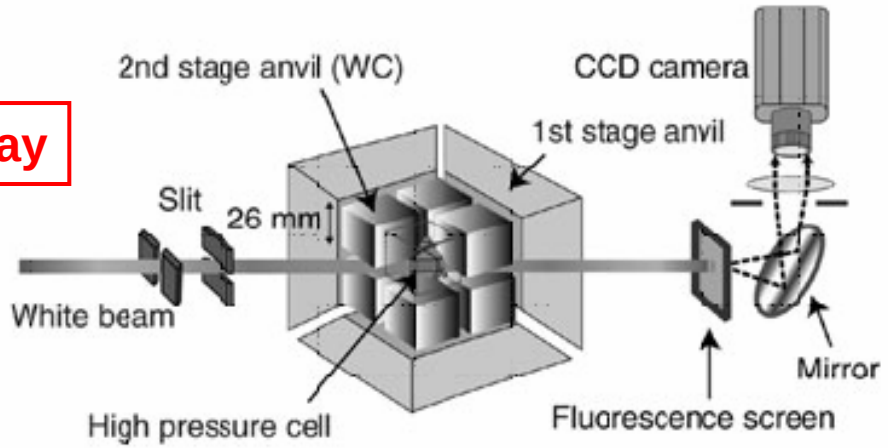
Beamlines in SPring-8 and KEK-PF



SPring-8 BL04B1

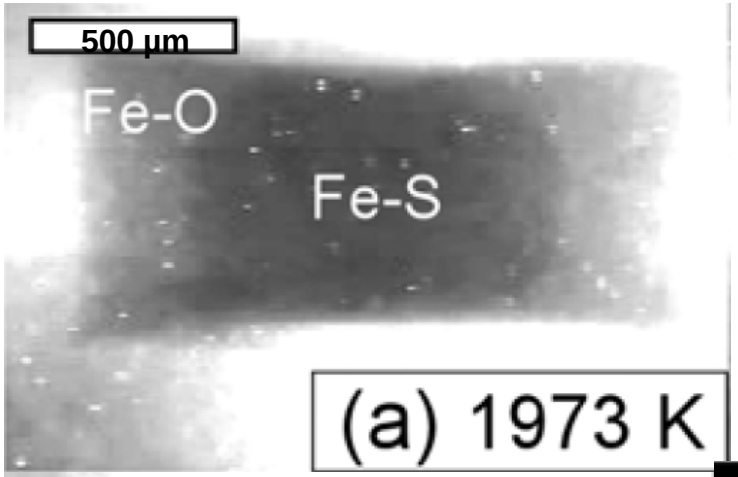
KEK-PF BL14C2



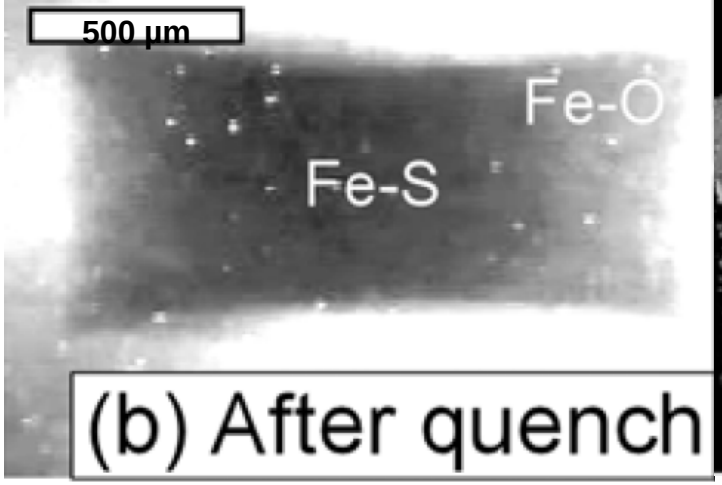


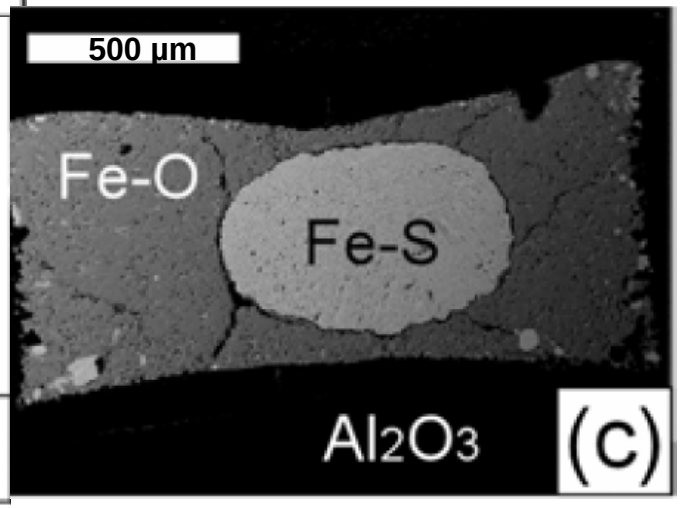
Funakoshi et al. (2002)

Increasing temperature



Immiscible melts can be quenched as two separated phases.

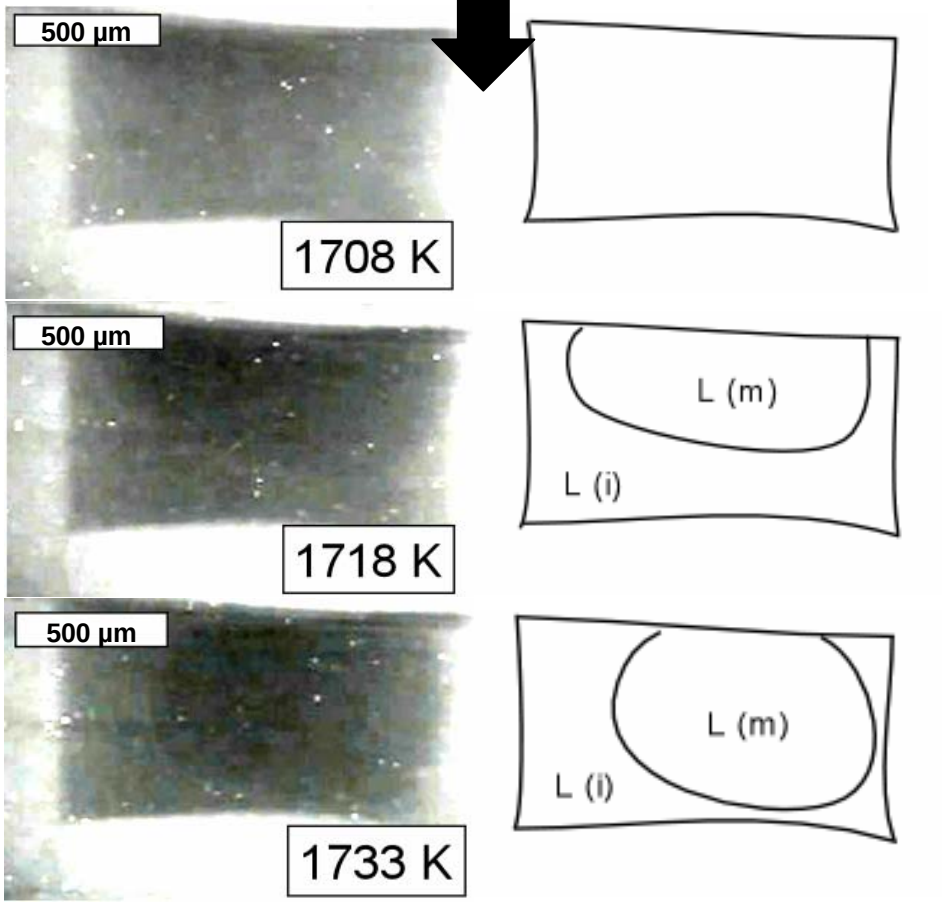


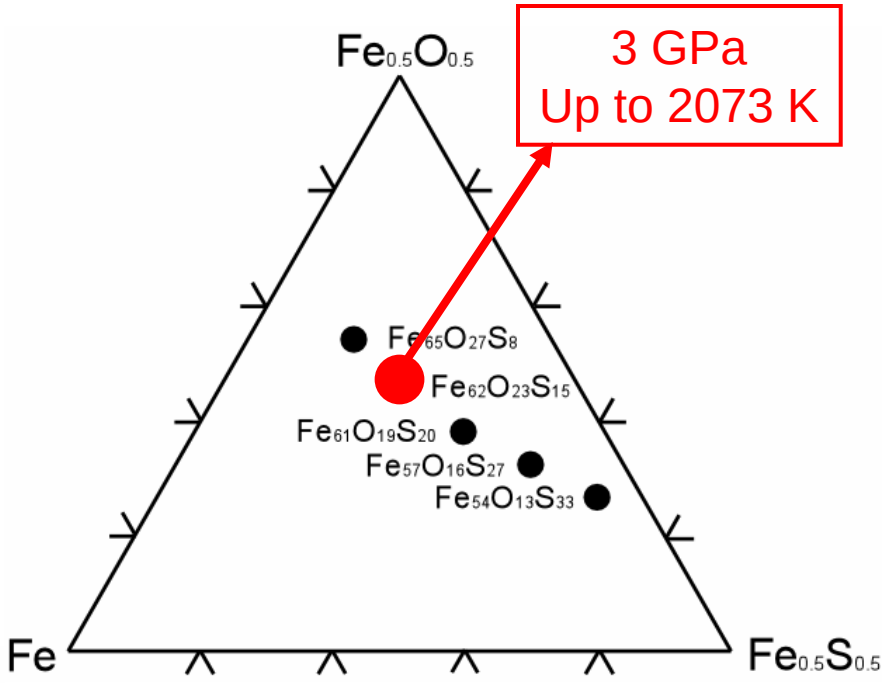


Tsuno et al. (2007b)

Radiography results (2): $Fe_{65}O_{27}S_8$

Room temperature





Liquid immiscibility gap in the Fe-O-S system at 3 GPa