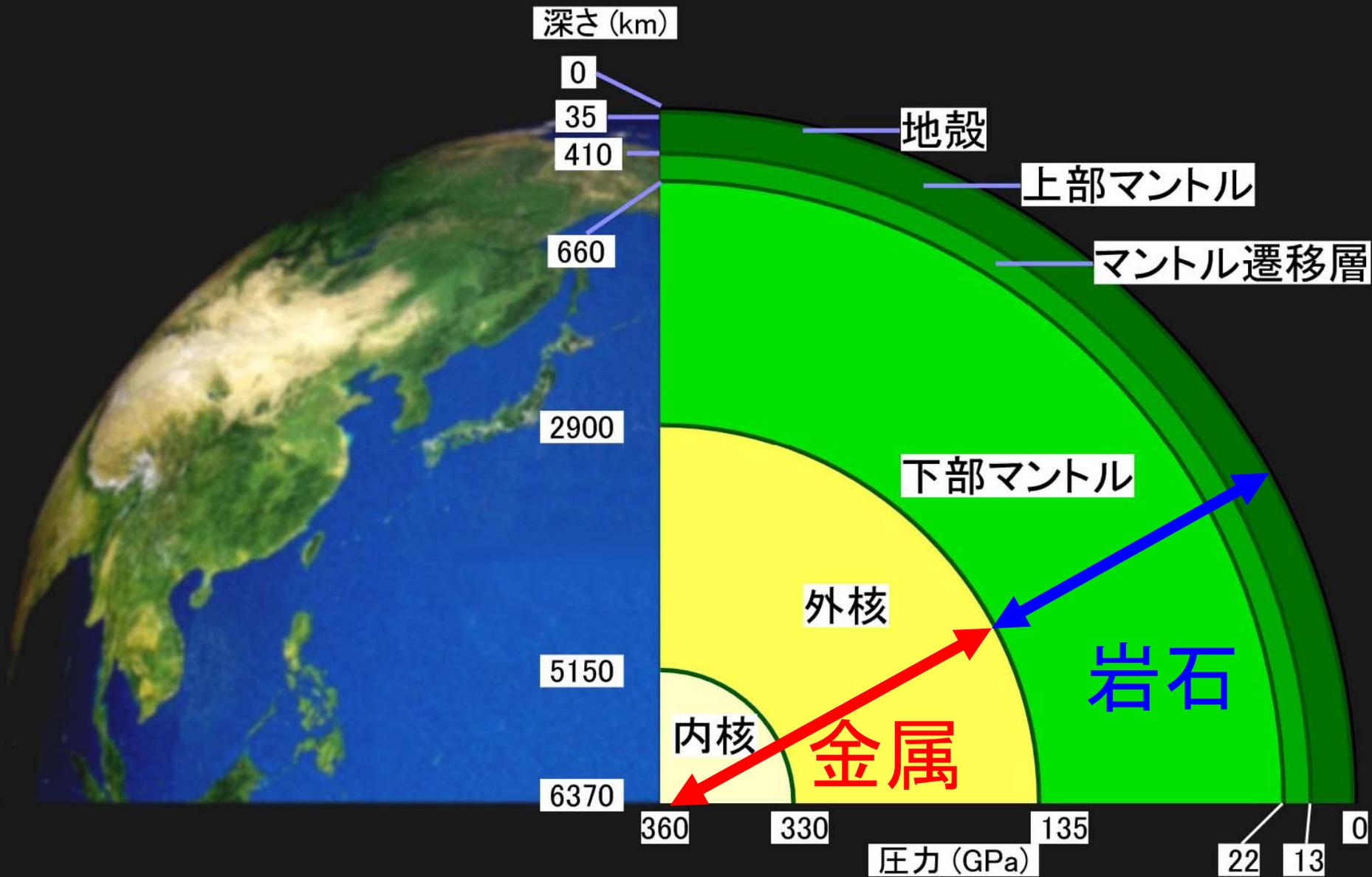


高圧力下でのX線イメージング による地球惑星物質の研究

鈴木昭夫(東北大・理)

地球内部は高圧高温の世界



地震波トモグラフィーによる地球内部構造

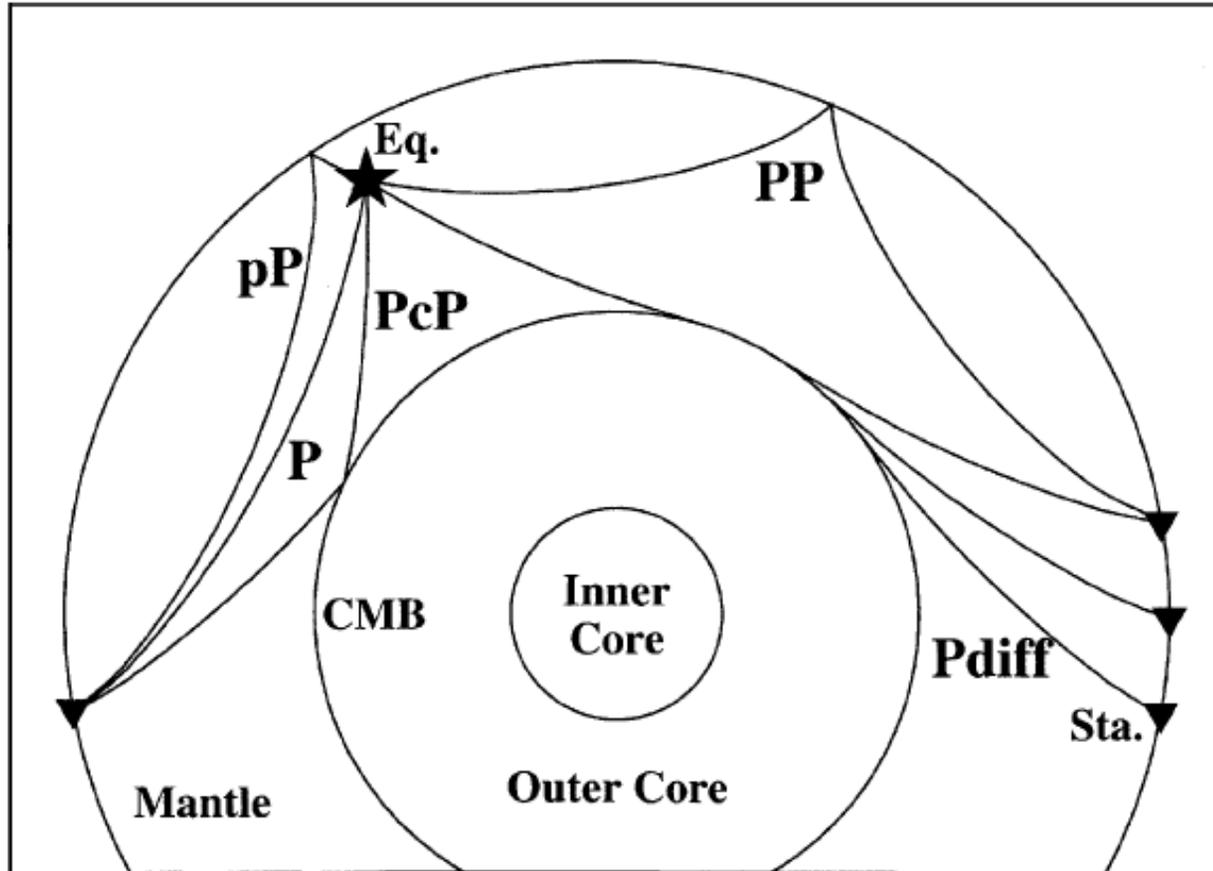
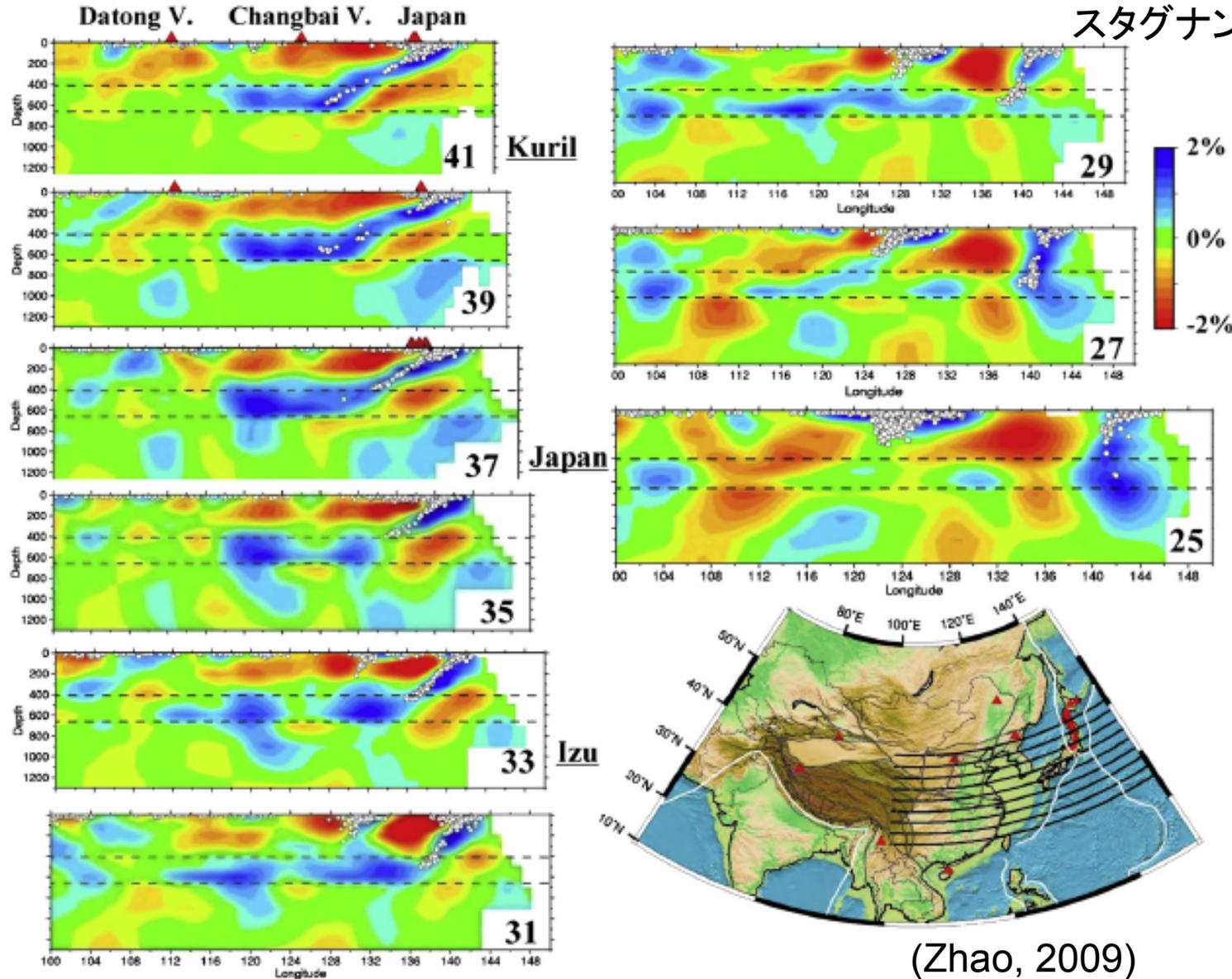


Fig. 2. Schematic illustrations of the seismic rays used in this study. The rays are direct P waves, depth phases (pP), surface reflected waves (PP), core reflected waves (PcP), and core diffracted waves (Zhao, 2004) (Pdiff).

地震波トモグラフィーによる地球内部構造

沈み込む海洋プレート
スタグナントスラブ(メガリス)

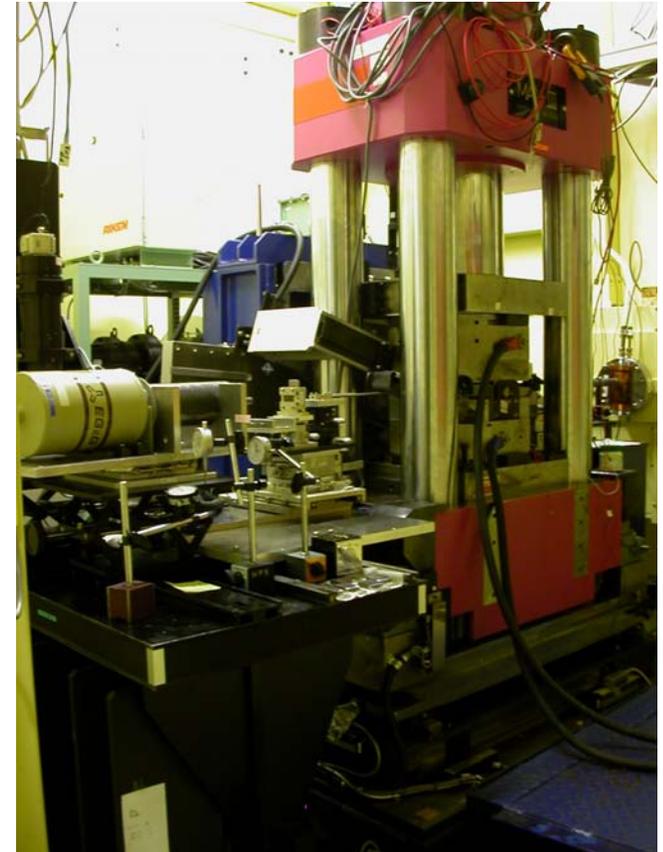
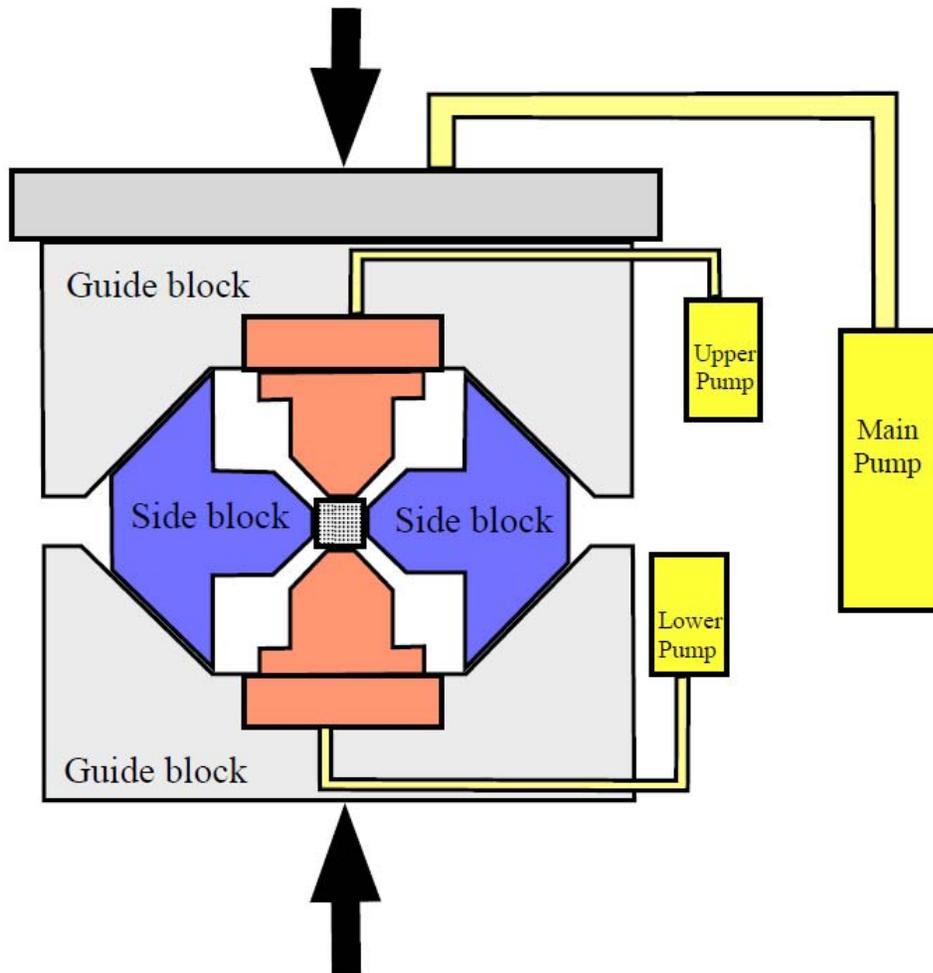


(Zhao, 2009)

New deformation apparatus

Deformation cubic anvil press (D-CAP)

MAX-III



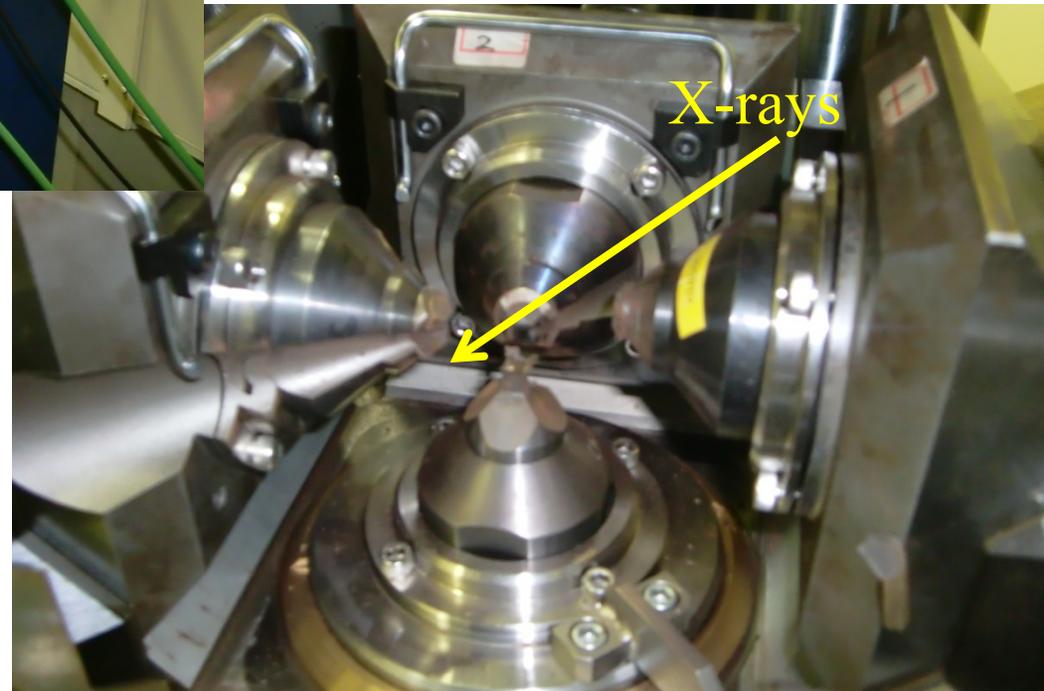
Two differential rams can be controlled independently of the main ram.

New deformation apparatus

D-CAP@Photon Factory

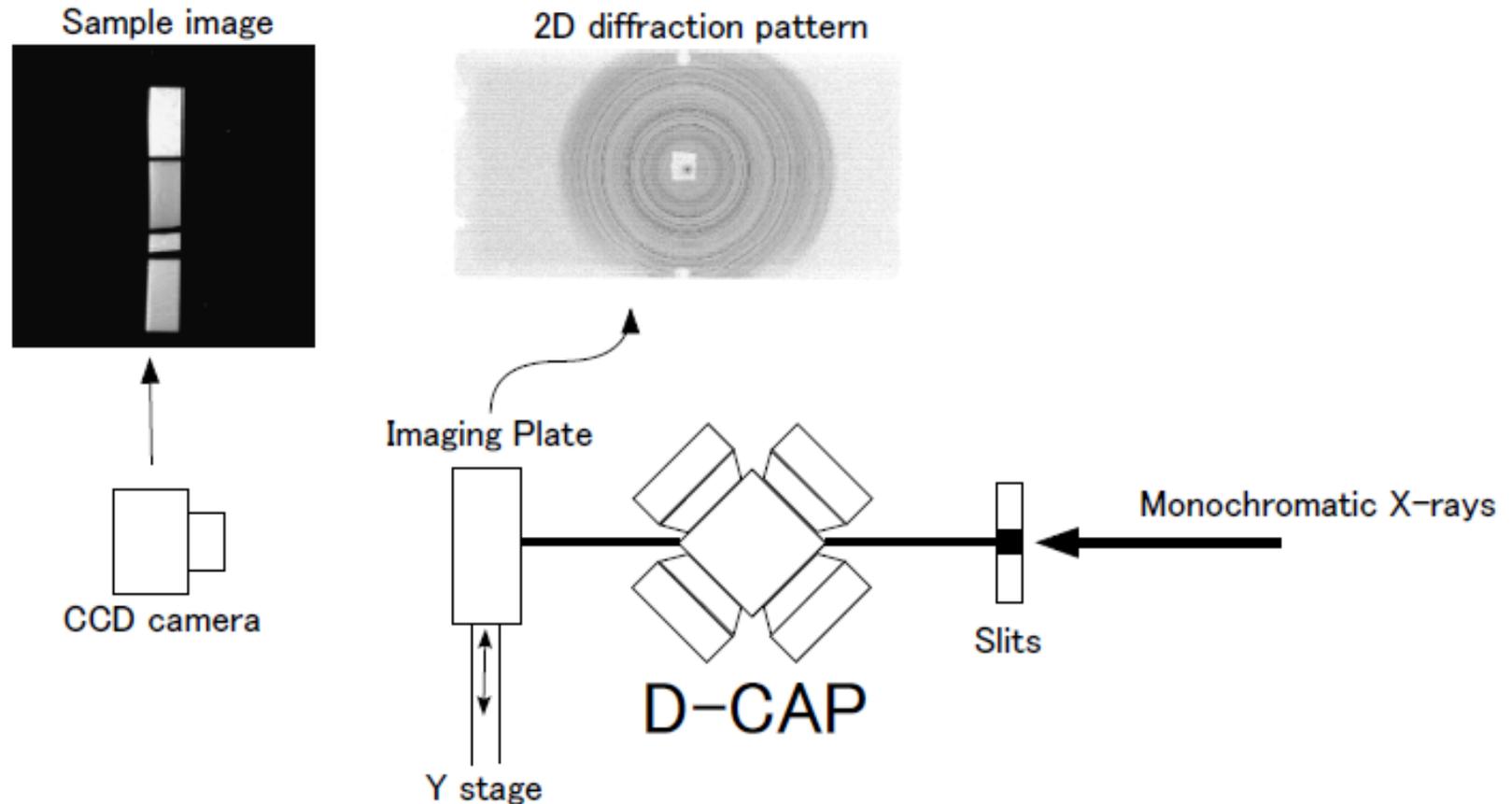


MAX-IIIに組み込んだ
D-CAP変形実験装置



Stress and strain measurements

X-rays diffraction and imaging system at the 14C2 PF-KEK



Strain: transmitted X-rays imaging of samples

Stress: X-rays diffraction peak shifts (distortion of Debye rings)

Strain measurement

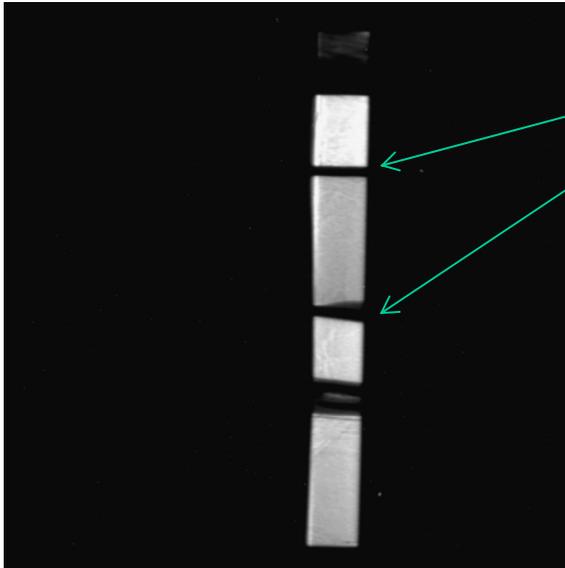
measure time change of length between two gold foils

Strain marker; Au foil

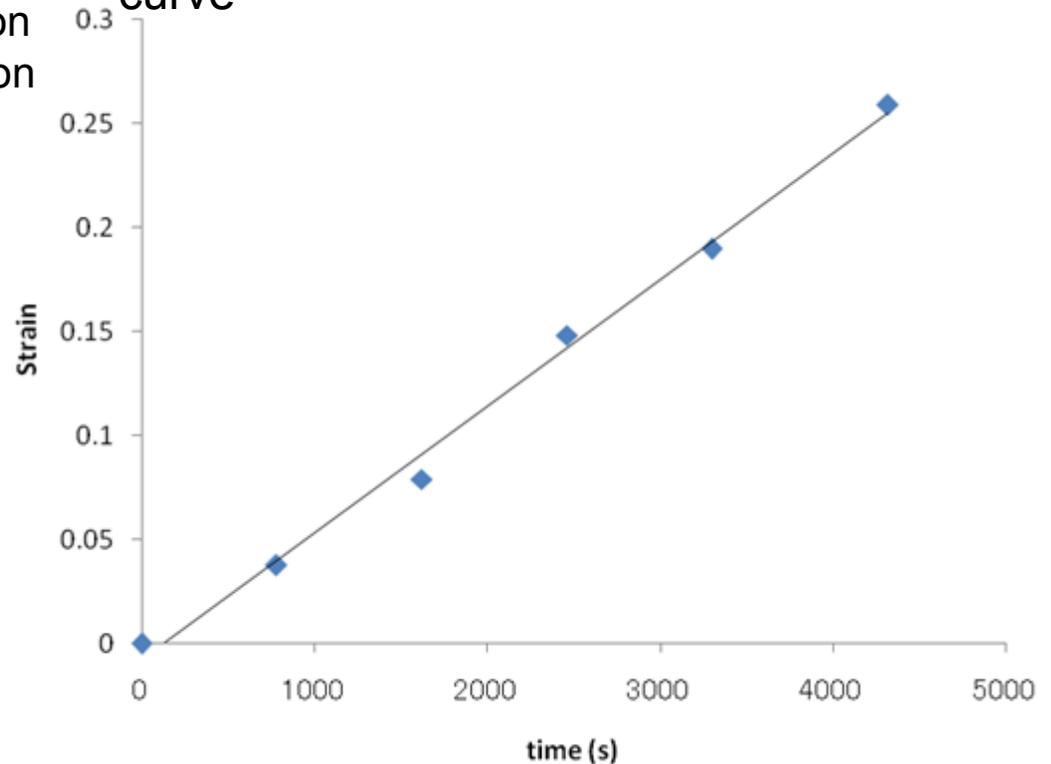
Strain $\varepsilon_{\text{total}}$; $(l_0 - l)/l_0$

l_0 ; sample length before deformation

l ; sample length during deformation



Strain rate; the slope of the strain-time curve



Strain rate become basically constant.

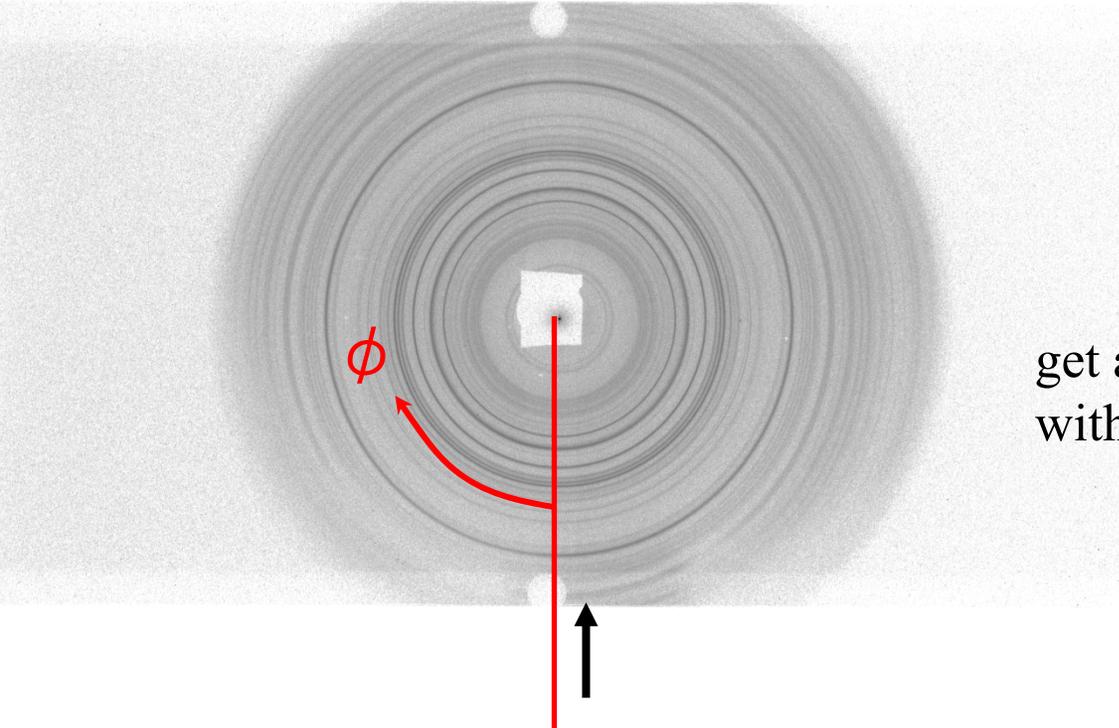
Stress measurement

Lattice strain: $\varepsilon(\phi, hkl)$

$$\varepsilon(\phi, hkl) = \varepsilon_p - \varepsilon_t(hkl)(1 - 3 \cos^2 \phi)$$

ϕ : azimuth angle, ε_p : hydrostatic strain, ε_t : differential lattice strain

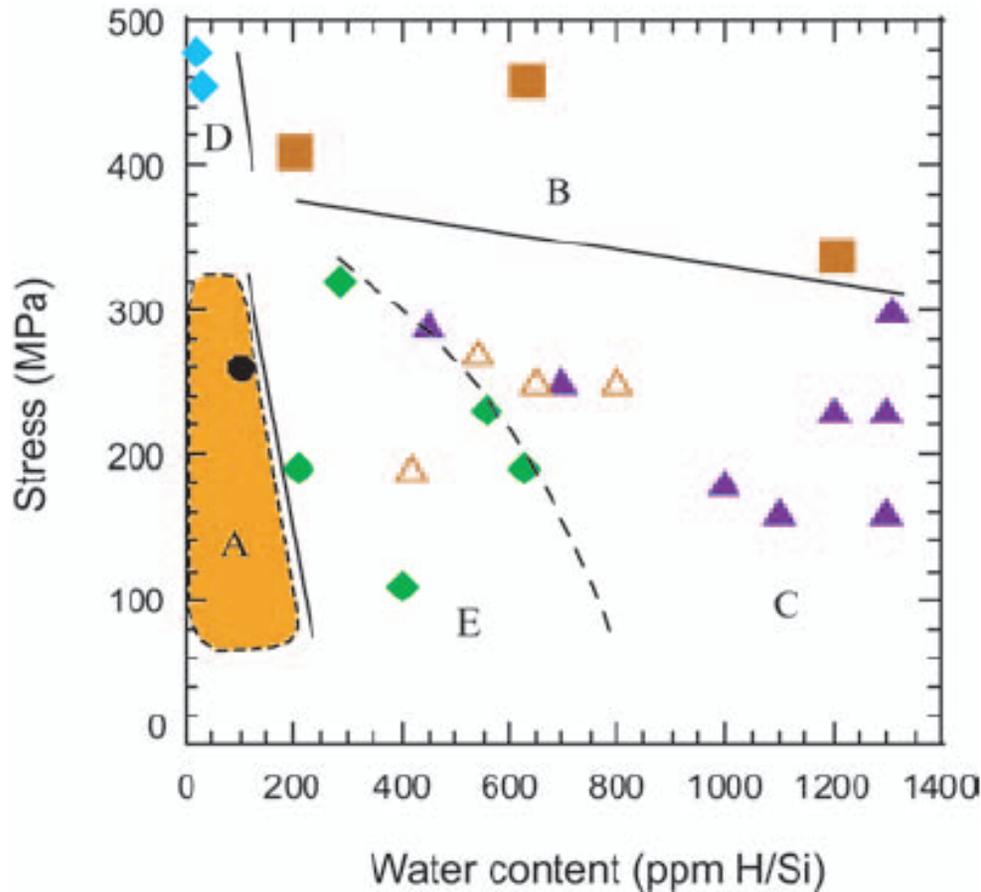
↓ compression direction



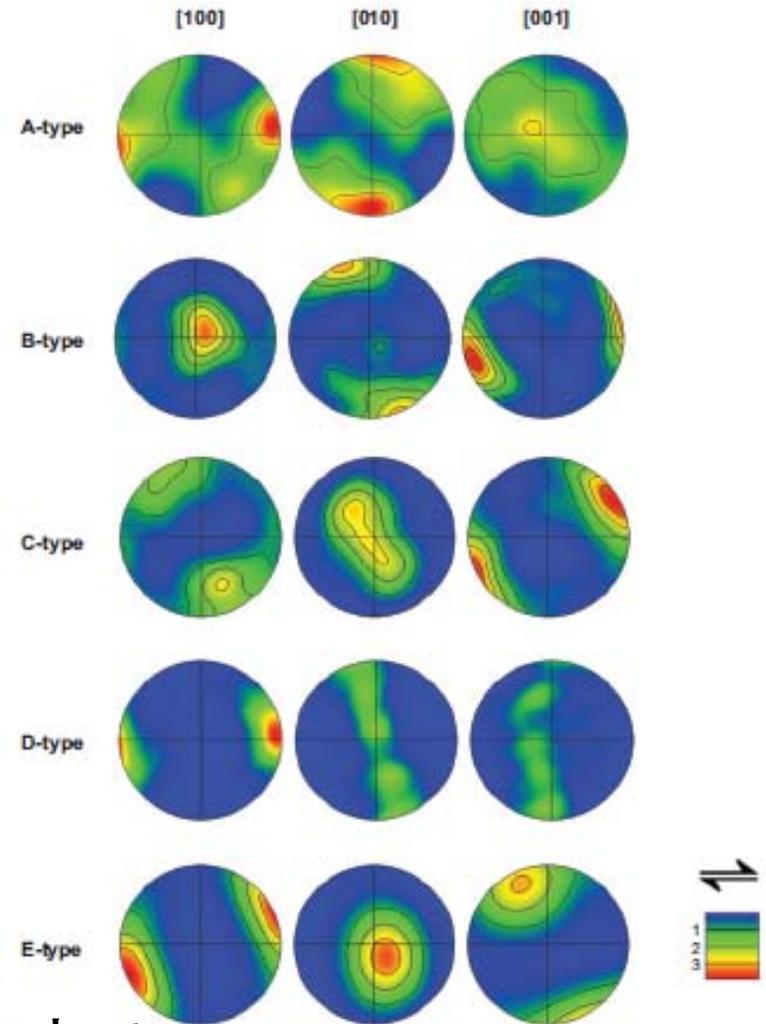
$$\varepsilon = \frac{d_0 - d}{d_0}$$

get a series of 1-D diffraction patterns with respect to 15° of azimuth angle

選択配向パターンが変化する



カンラン石



地震波異方性の観測結果と比較することで
マントル内の流動特性が予想できる

Jung et al. (2004)

地球形成期における液体の役割

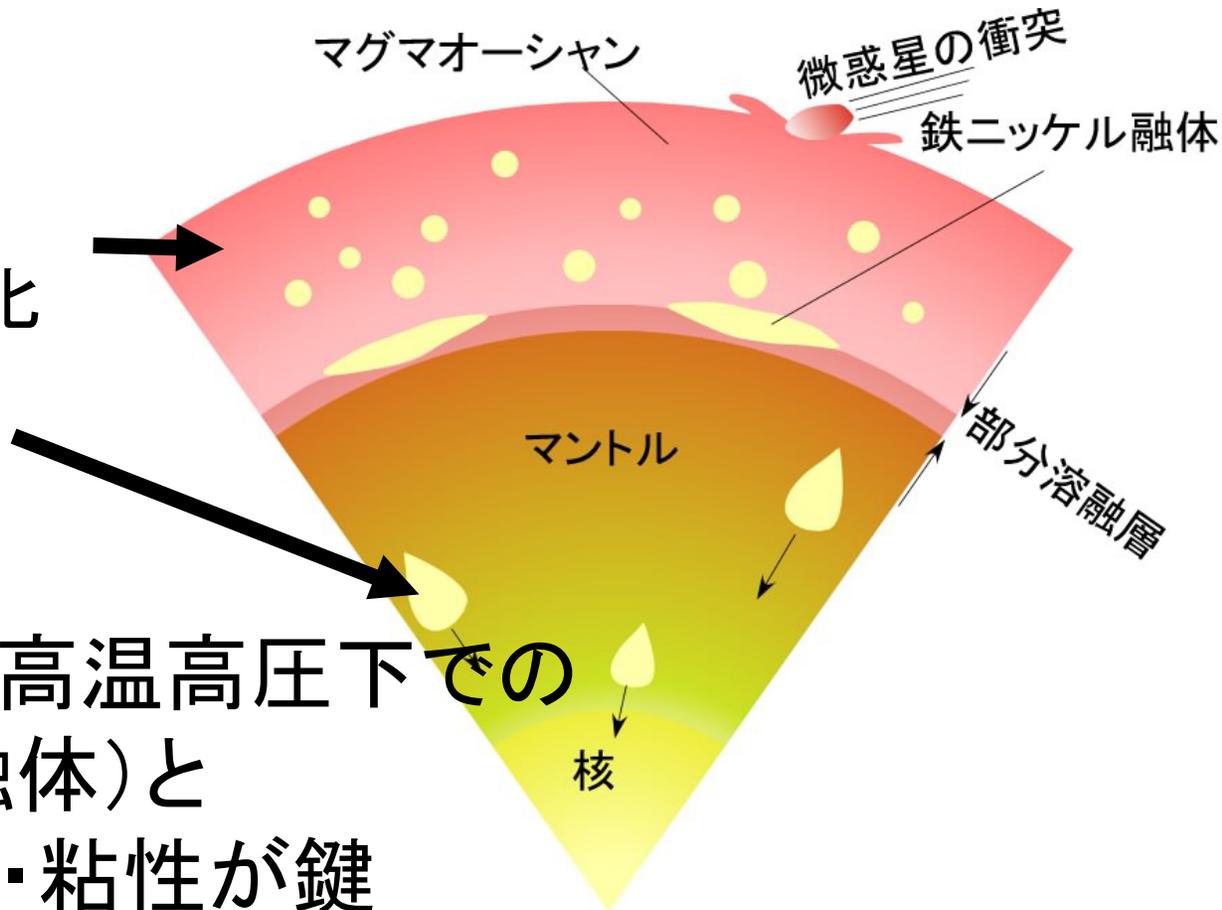
地球・惑星の形成期，進化過程
＝液体の挙動が重要な役割を果たす

形成期の地球

マグマオーシャン
→マンツルの分化

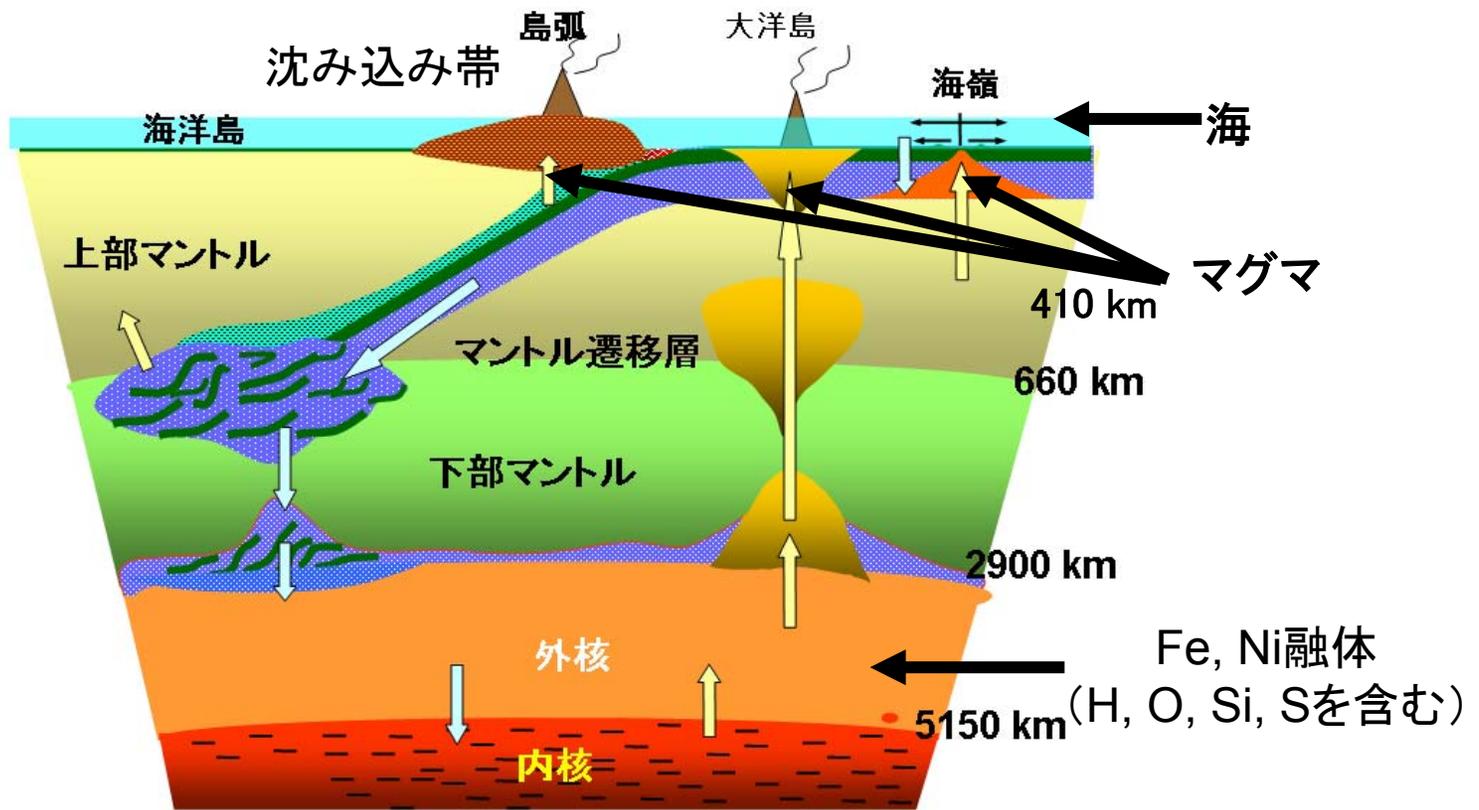
金属融体の分離
→核の形成

地球深部環境＝高温高压下での
マグマ（珪酸塩融体）と
金属融体の密度・粘性が鍵

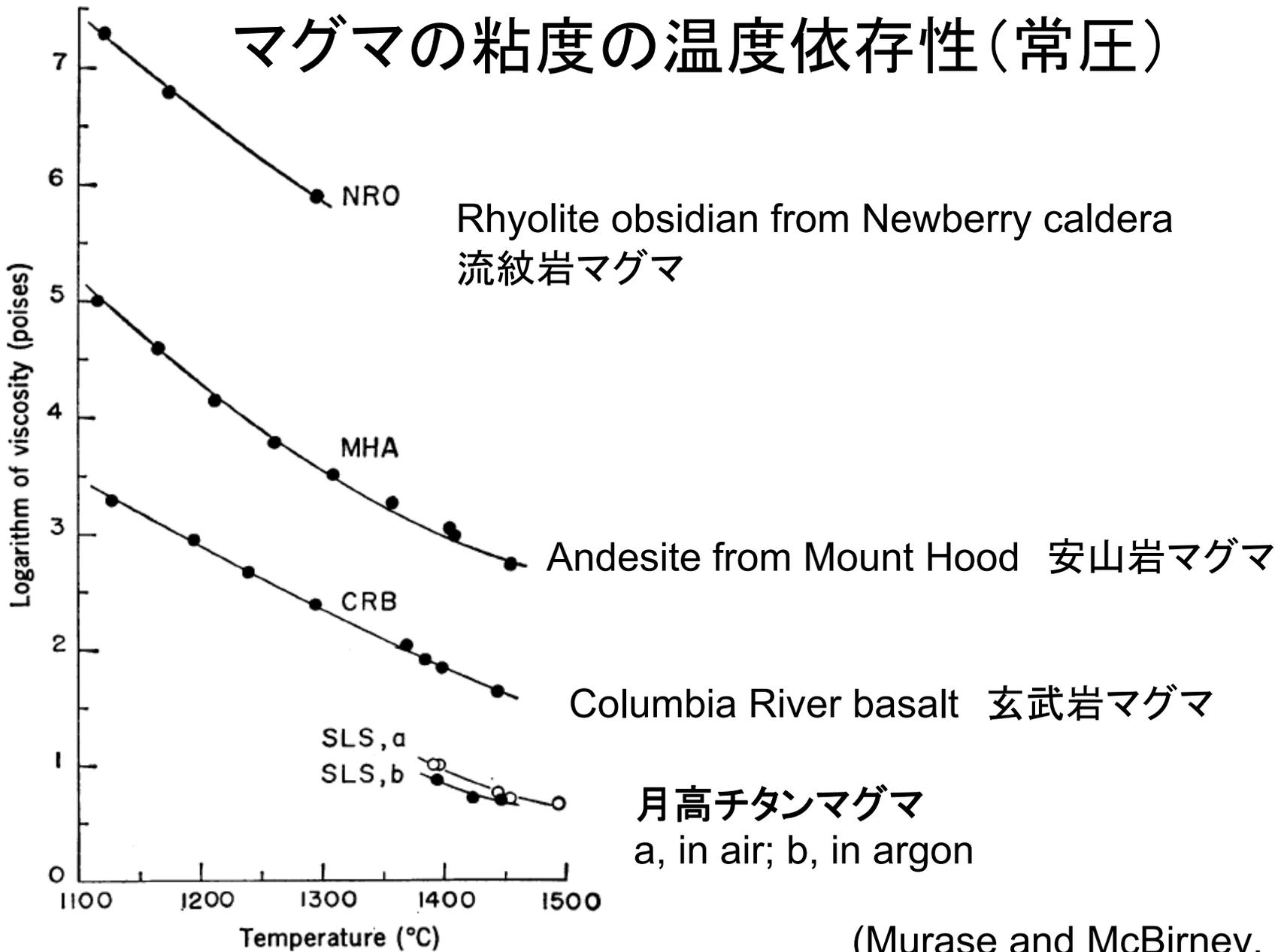


現在の地球

現在の地球にも、様々な融体がある
地球の形成、進化の過程には、融体の役割が重要



マグマの粘度の温度依存性(常圧)



(Murase and McBirney, 1970)

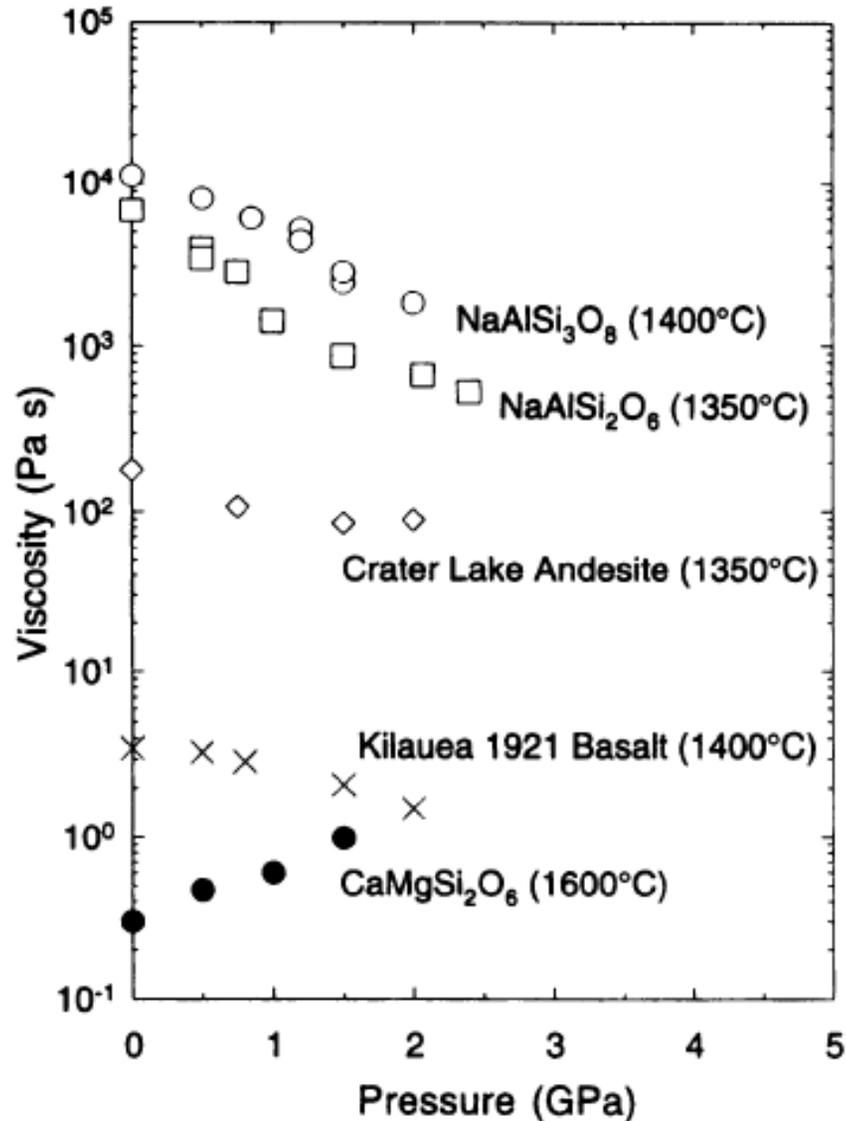
マグマ(珪酸塩融体)の粘度の圧力依存性

$$\frac{d\eta}{dP} > 0$$

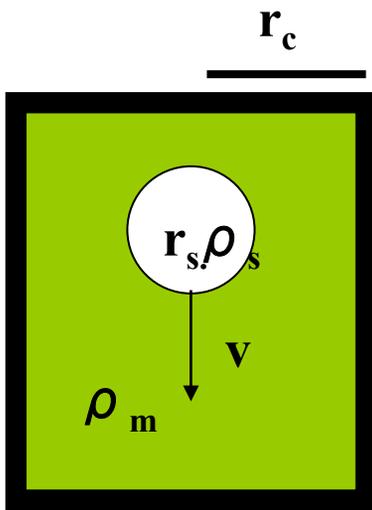
$$\frac{d\eta}{dP} < 0$$



融体の構造に関係？



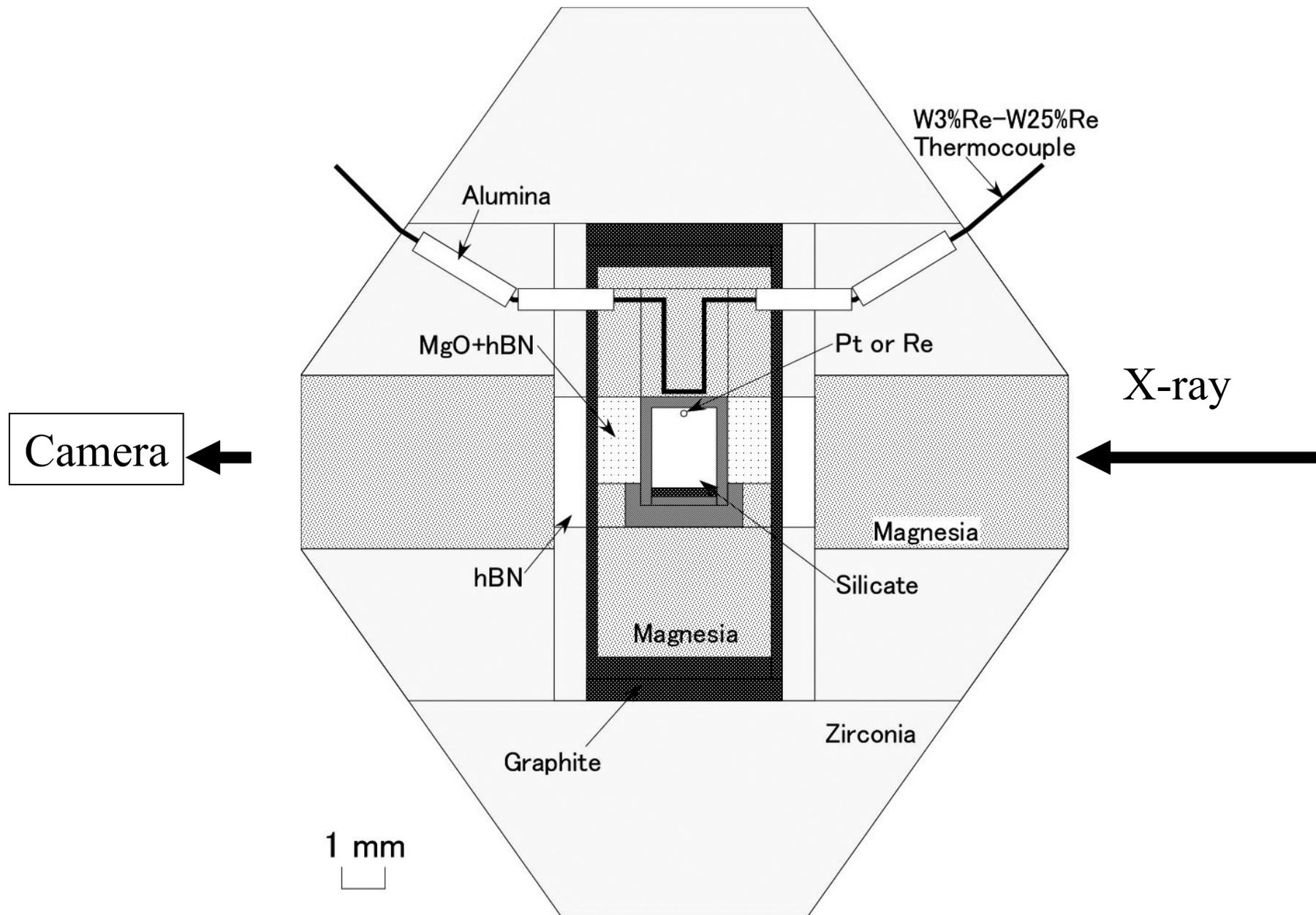
落球法による粘度測定



Stokes' equation with Faxén correction for wall effect

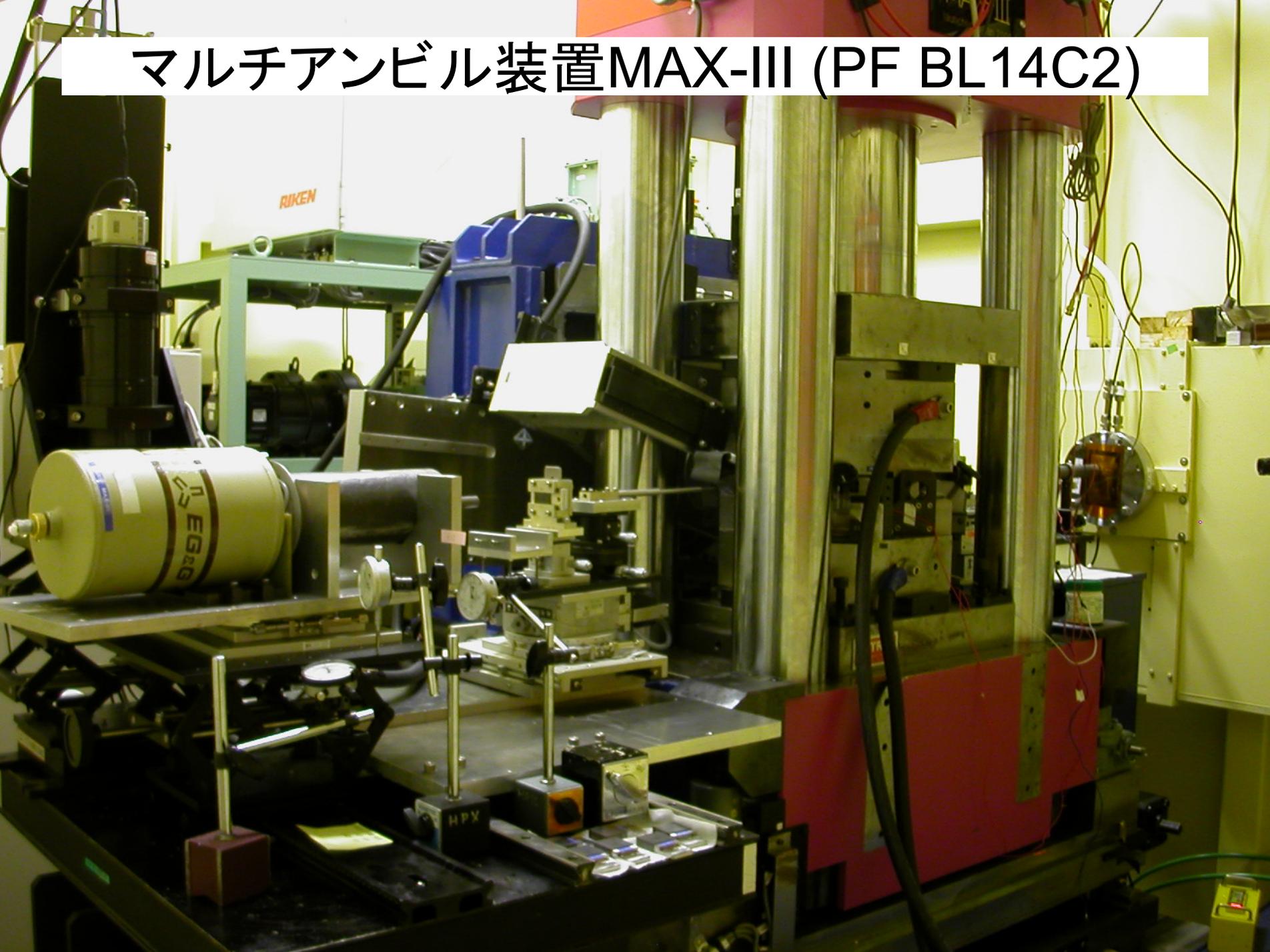
$$\eta = \frac{2r^2 g \Delta \rho}{9v} \left[1 - 2.104 \left(\frac{r}{R} \right) + 2.09 \left(\frac{r}{R} \right)^3 - 0.95 \left(\frac{r}{R} \right)^5 \right]$$

g , the acceleration due to gravity; r , the radius of the falling sphere;
 $\Delta \rho$, the density difference between the sphere and the melt; v , the falling velocity; R , the inner radius of the container

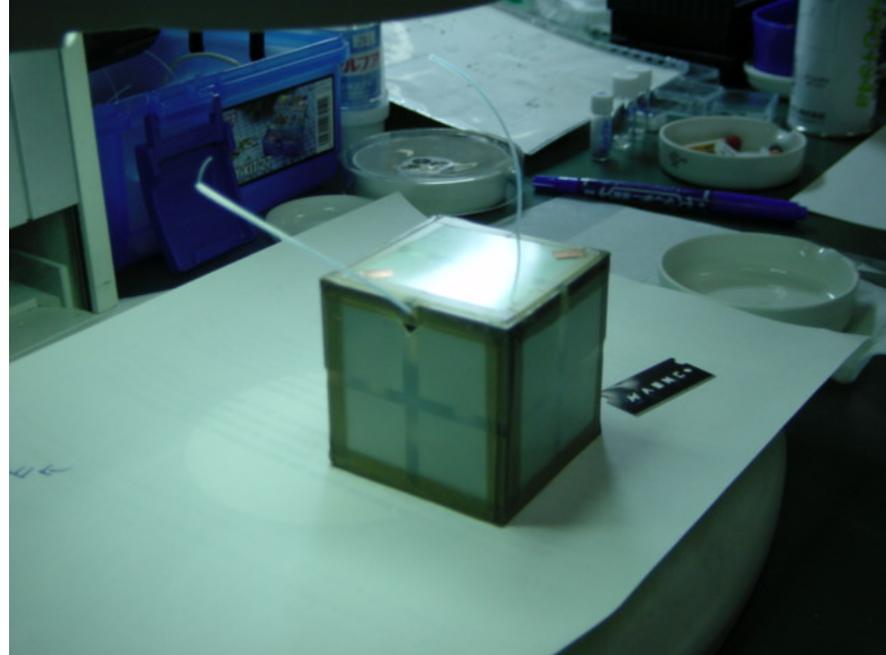


粘度測定用高压セル

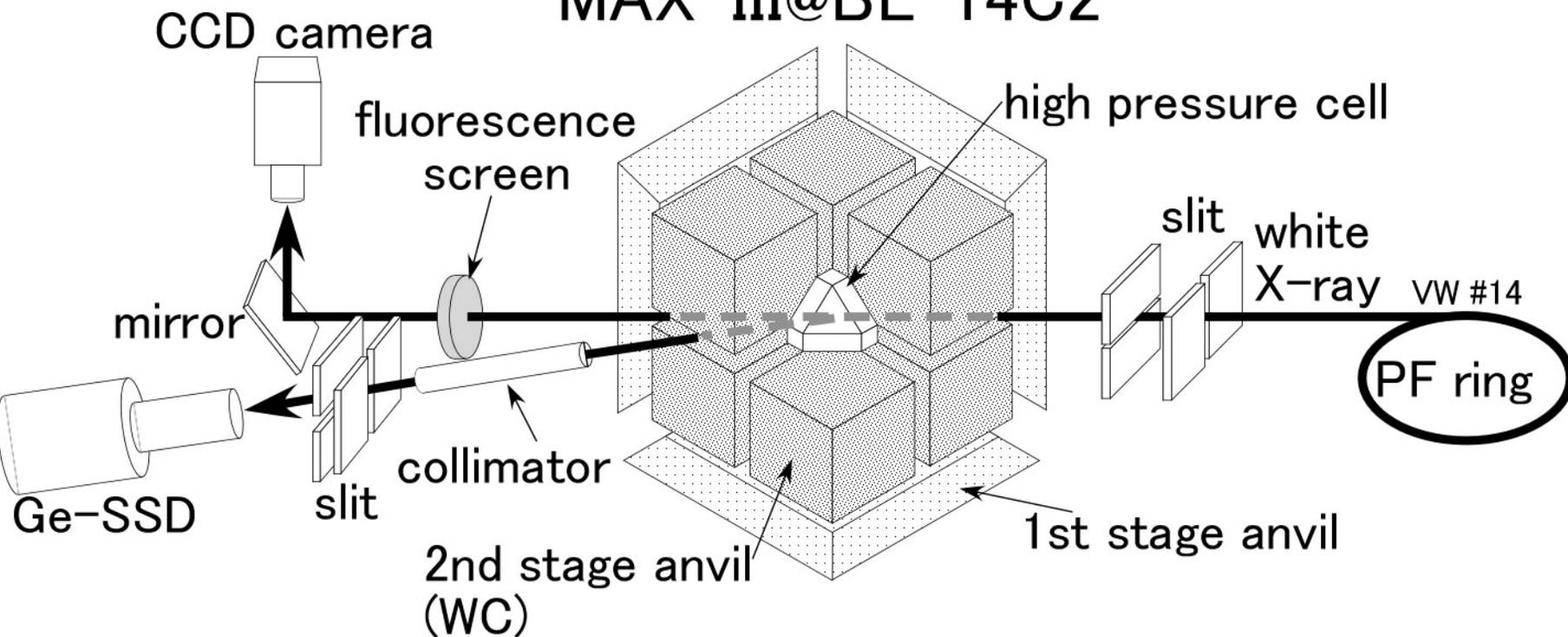
マルチアンビル装置MAX-III (PF BL14C2)



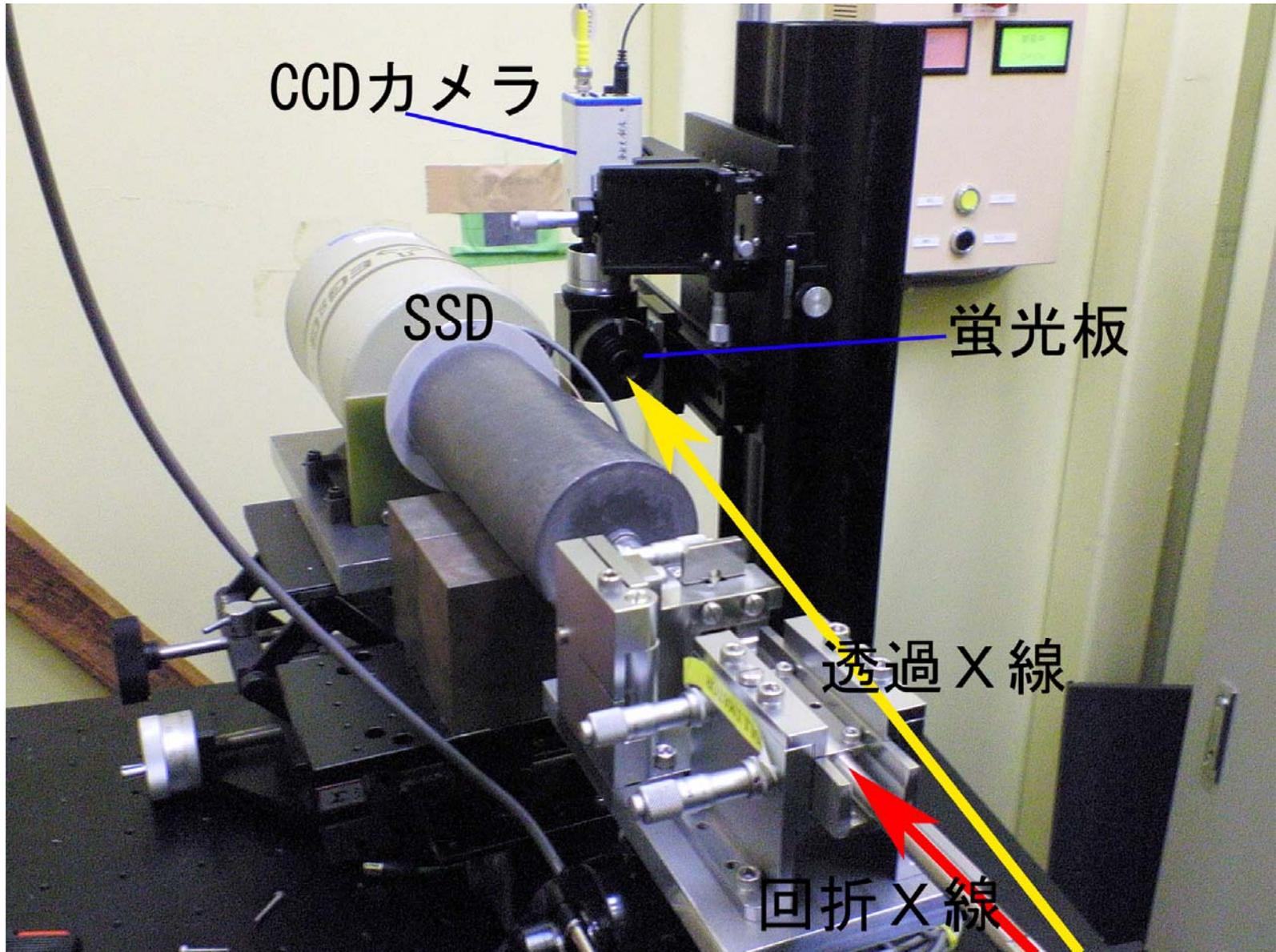
白色X線を用いたイメージング
システムの模式図
@Photon Factory, BL-14C2



MAX-III@BL-14C2



白色X線を用いたイメージングのシステム @Photon Factory, BL-14C2



NaAlSi₂O₆メルト中を落下する白金球

↑ UP

NaAlSi₂O₆ melt

Pt sphere

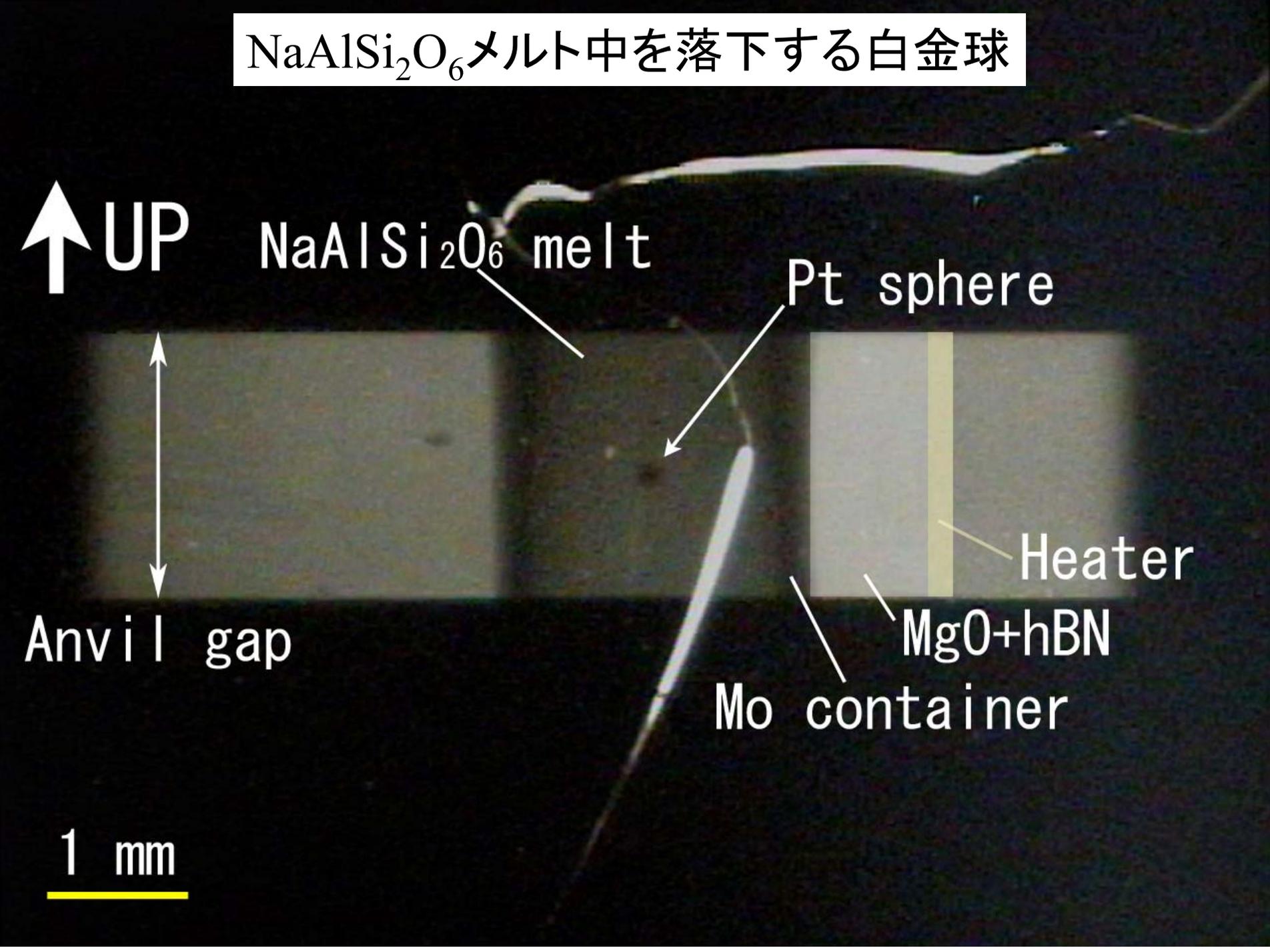
Anvil gap

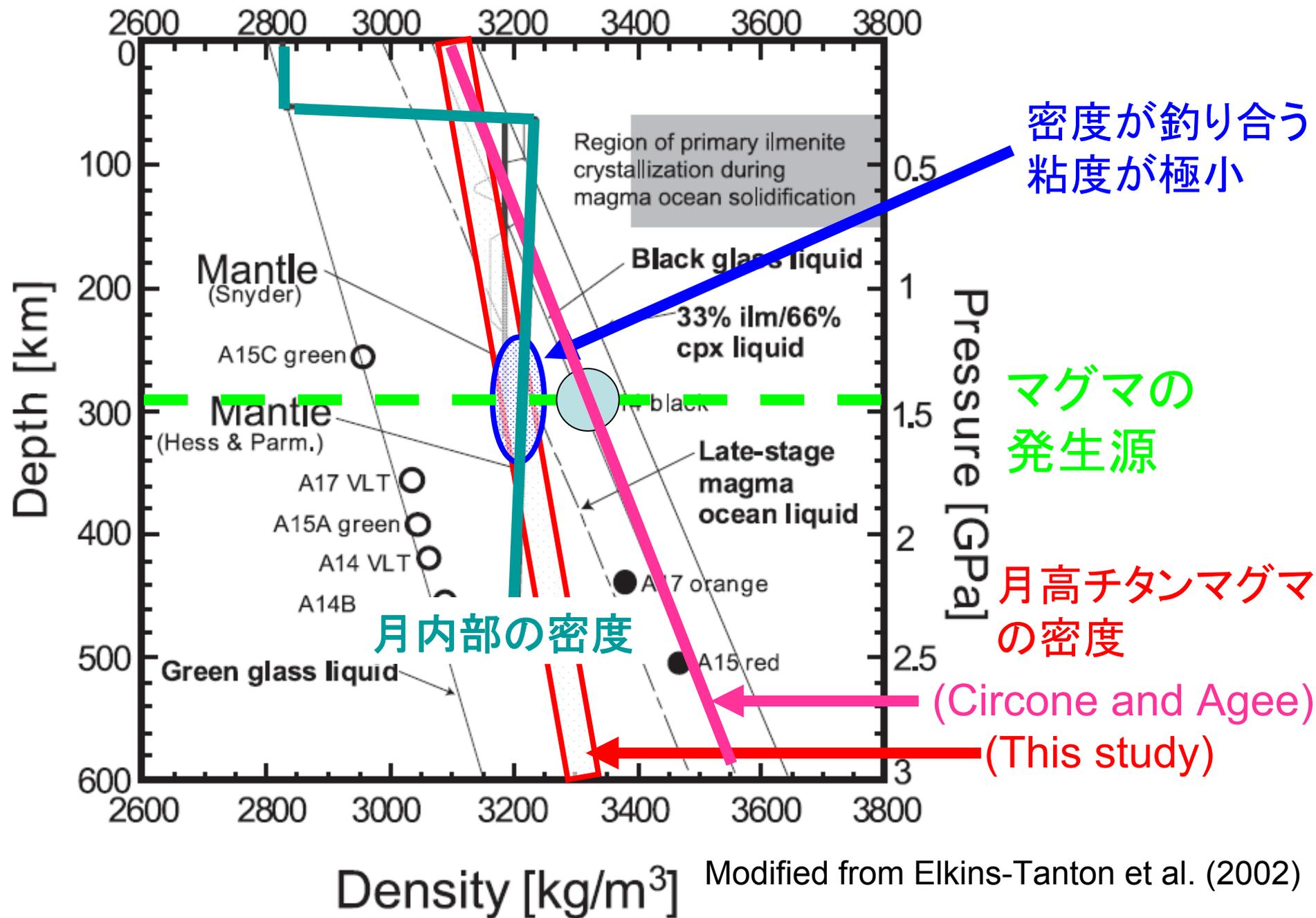
Heater

MgO+hBN

Mo container

1 mm





密度が釣り合う
粘度が極小

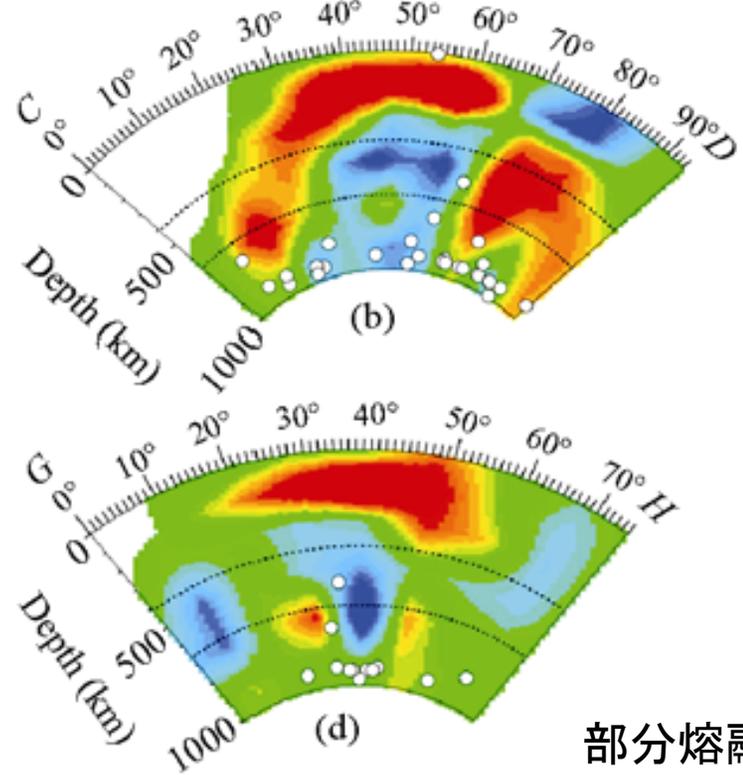
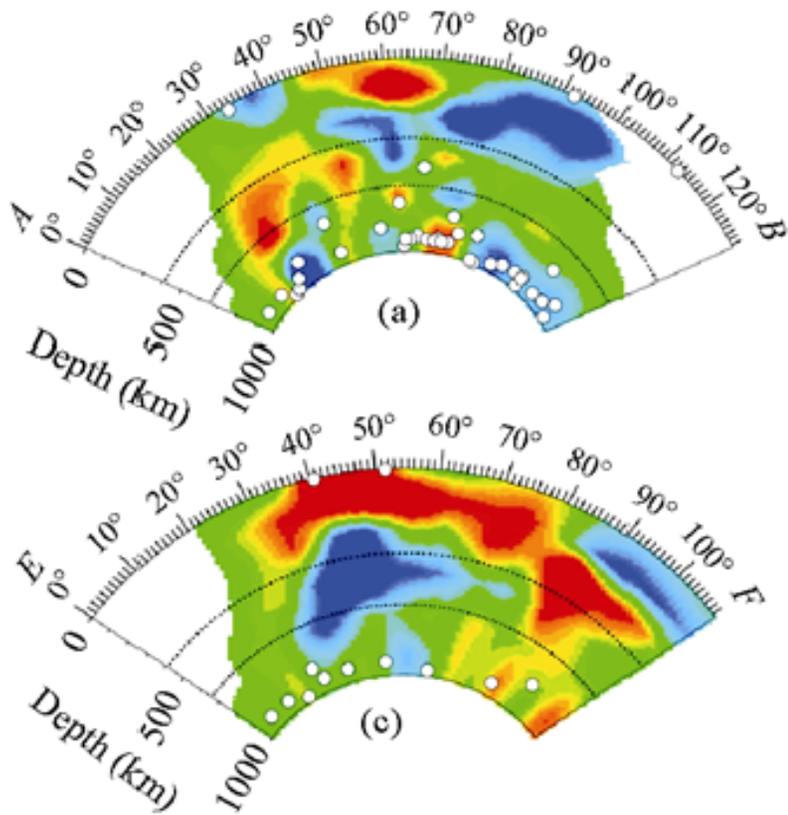
マグマの
発生源

月高チタンマグマ
の密度

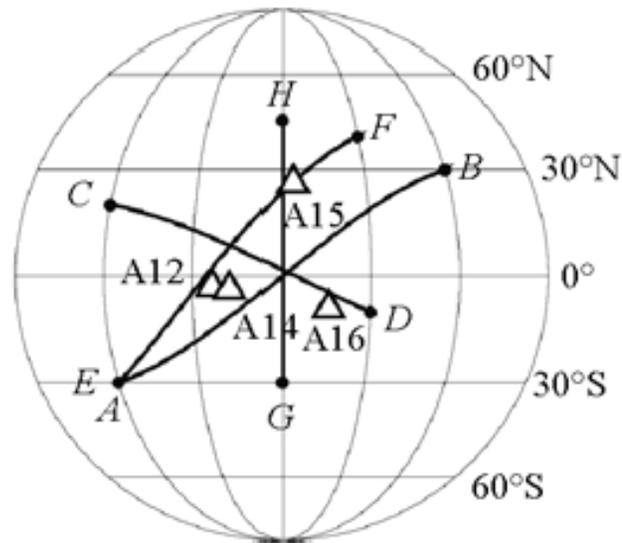
(Circone and Agee)

(This study)

月内部の密度



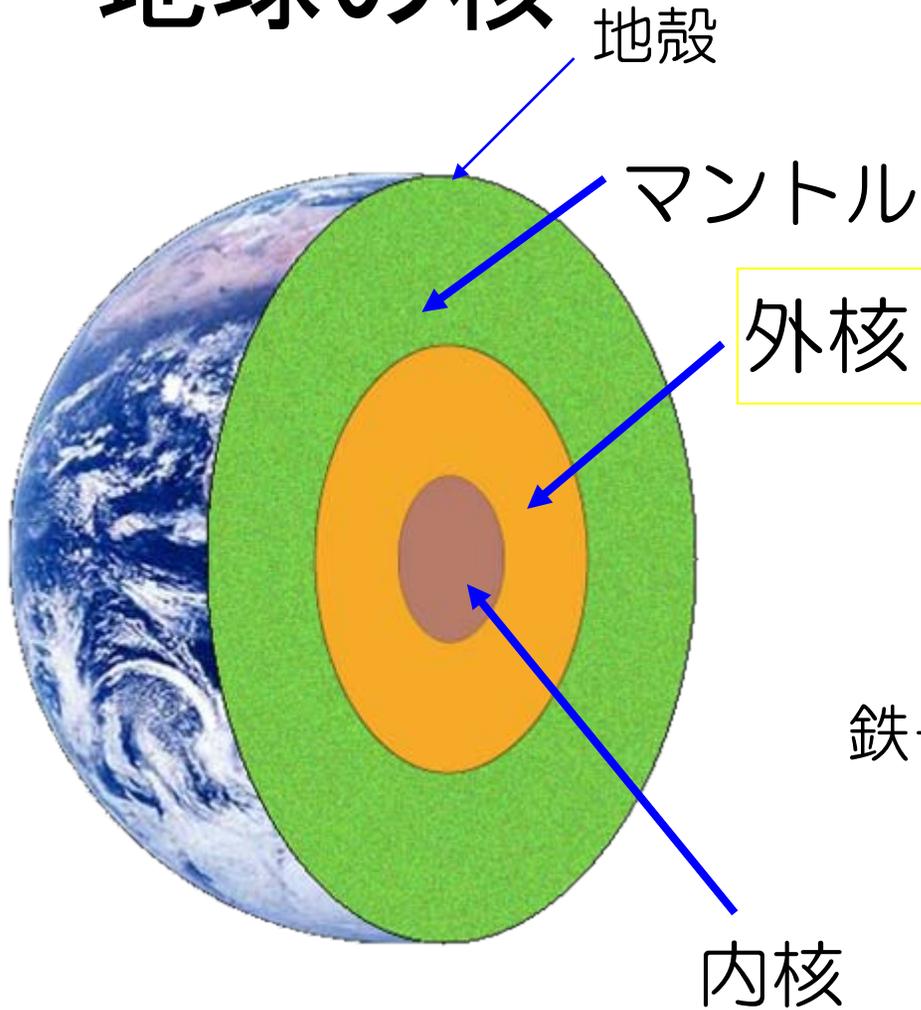
部分熔融層？



月震波トモグラフィーによる
月の内部構造
(S-wave)

(Zhao et al., 2008)

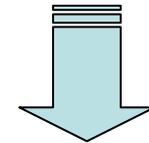
地球の核



地震波観測

- 地震波速度（縦波、横波速度）
- 密度

- 液体である
- 外核の密度は純鉄の密度に比べ約10wt%低い

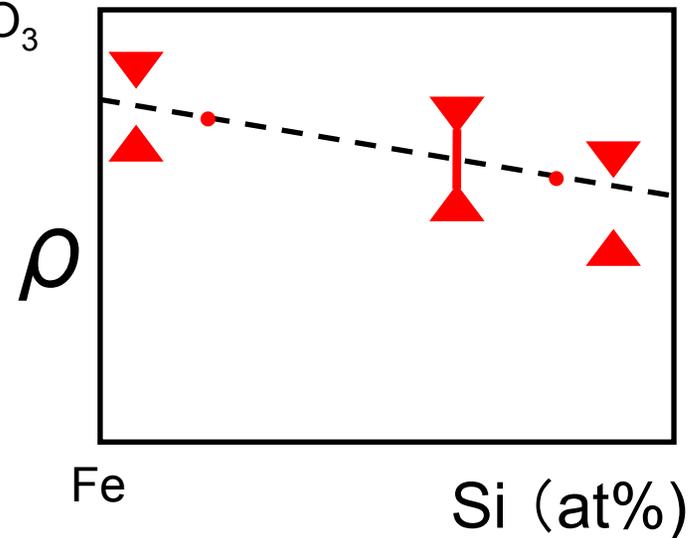
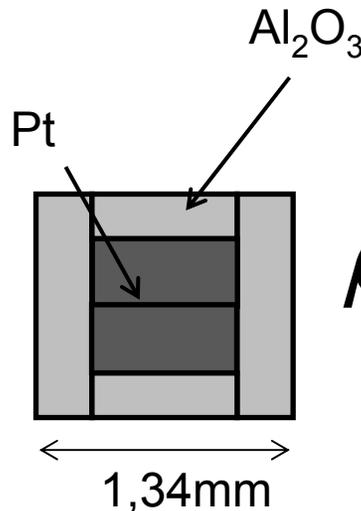
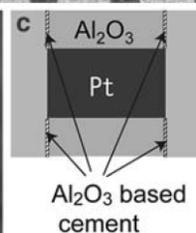
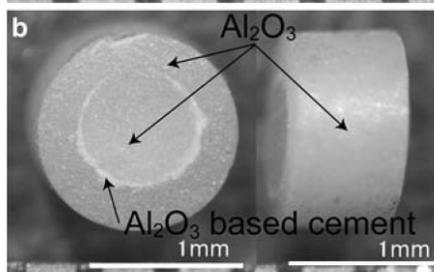
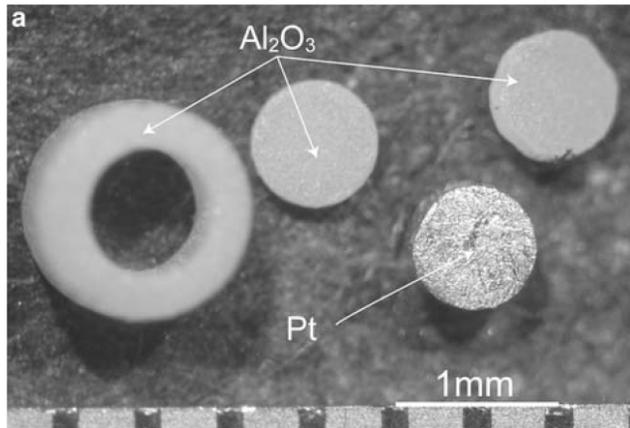
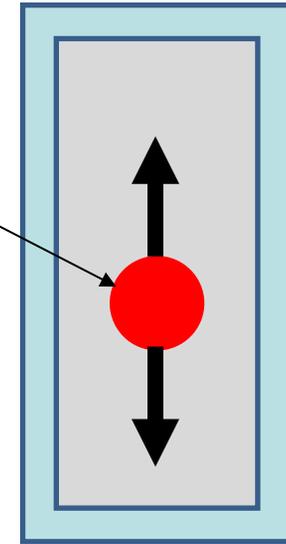


鉄＋ニッケル＋軽元素(H,C,O,Si,P,S)
(液体)

地球の外核を理解するためには鉄－軽元素合金融体の密度が重要

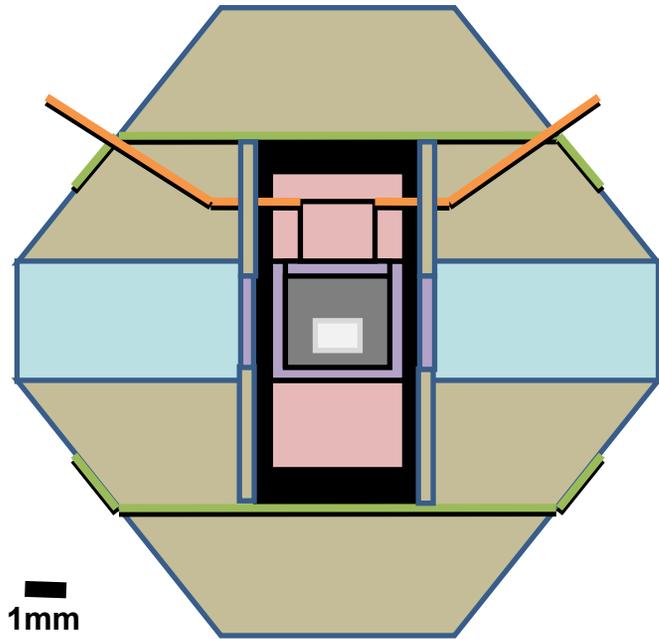
Fe-Si系メルトの密度測定

- 高圧セル内の密度マーカーの浮き沈みで試料の密度を判定



Nishida et al.(2008)

Fe-Si系メルトの密度測定



出発物質：Fe-Si合金粉末

(Si = 0 , 10 , 20 , 29 , 40 , 50 , 60 , 80 , 100 at%)

放射光を用いたその場観察実験

@Photon Factory :BL14C2

700 ton マルチアンビルプレス(MAXIII)

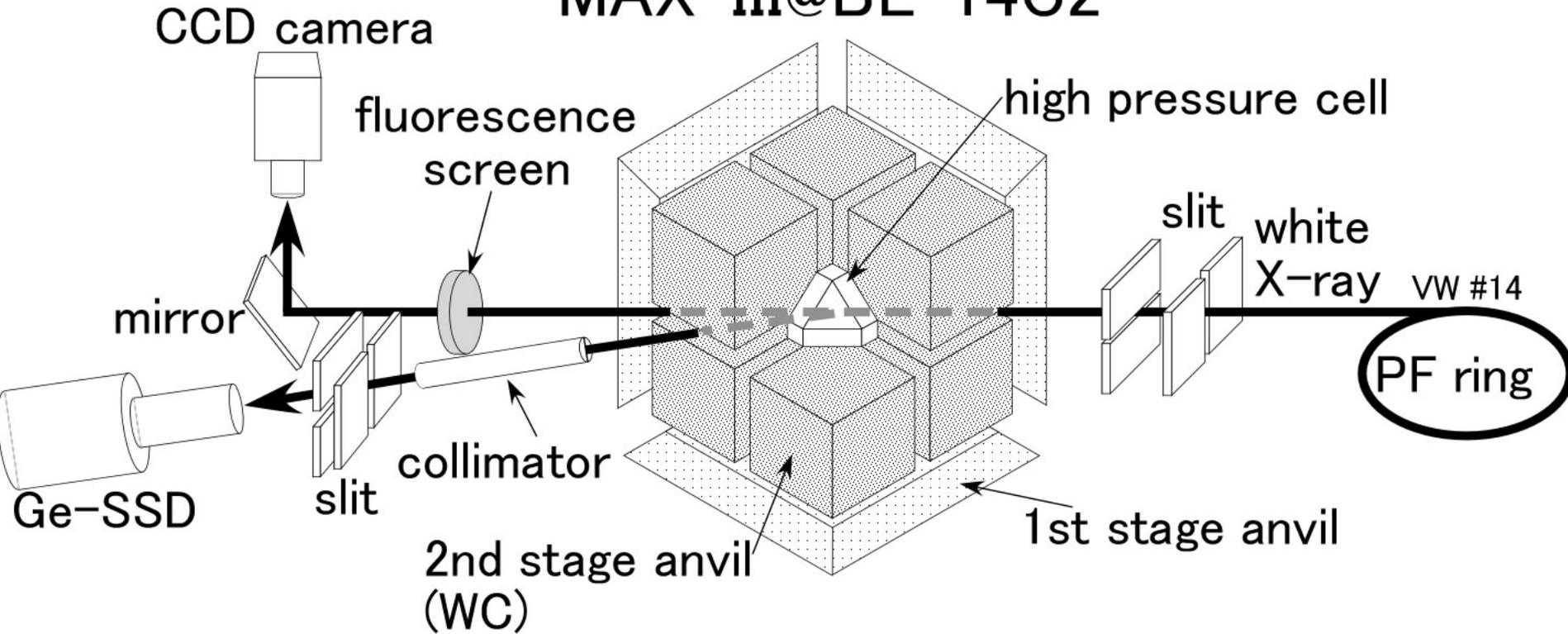
温度：1650 °C

圧力マーカー：hBN

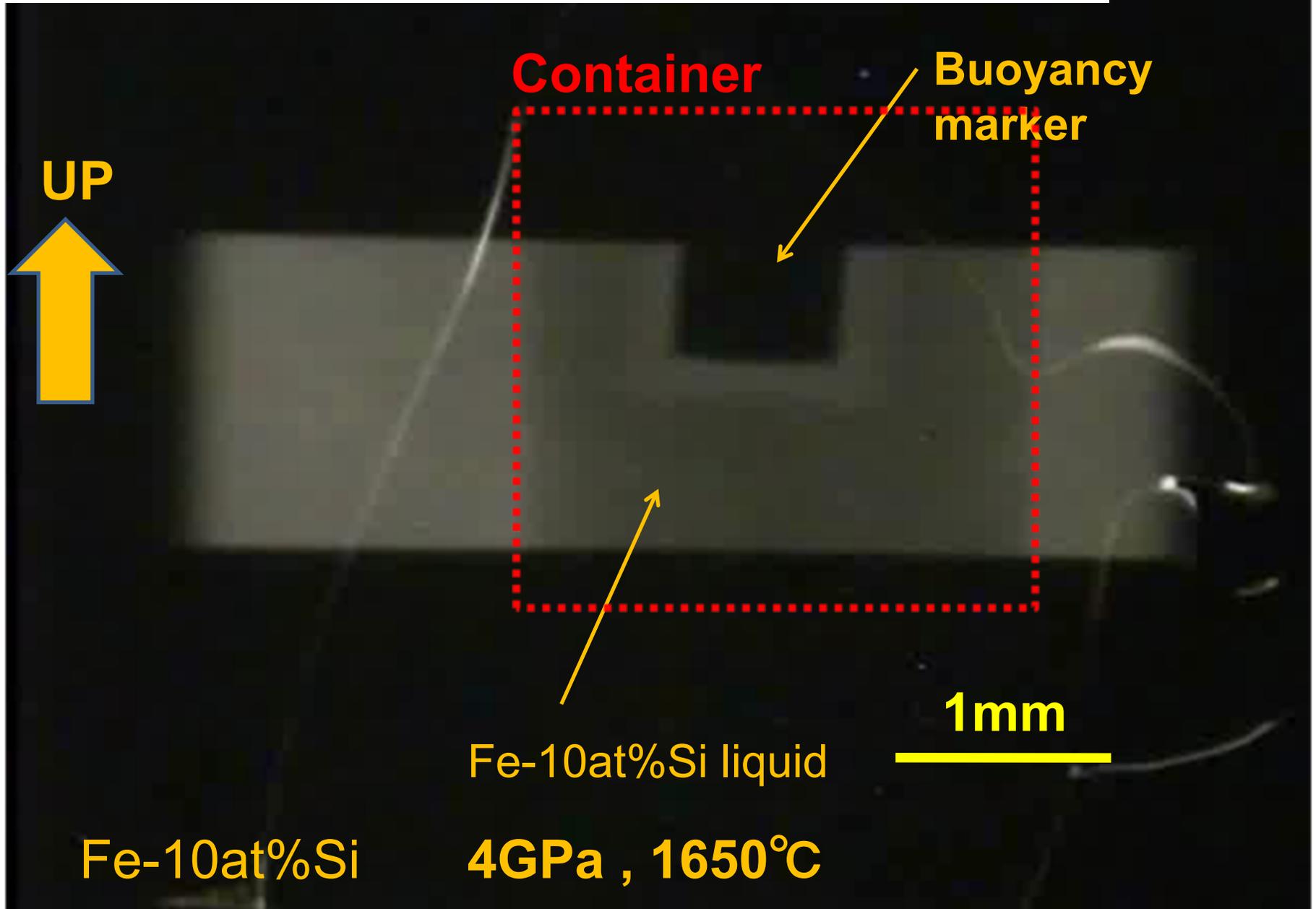
-  Boron epoxy
-  Sample (FeSi)
-  Zirconia
-  Magnesia
-  Boron nitride
-  Graphite
-  Molybdenum electrode
-  $W_{97}Re_3$ - $W_{75}Re_{25}$ Thermocouple

Photon FactoryのX線ラジオグラフィシステム

MAX-III@BL-14C2



In situ buoyancy test for density measurement



NE7A の建設



24. June, 2009

A photograph showing the construction site of NE7A on June 24, 2009. The site is a large, open industrial space with a concrete floor. A rectangular concrete structure is under construction, surrounded by orange traffic cones and red-and-white striped safety tape. A person in a purple shirt and white pants is standing on a metal platform within the structure. The background shows various industrial equipment and materials.



29. June, 2009

A photograph showing the construction site of NE7A on June 29, 2009. The concrete structure is more advanced than in the previous image. The area is still cordoned off with orange traffic cones and safety tape. A person is visible in the background near a whiteboard. The overall scene is a busy industrial construction environment.



26. July, 2009

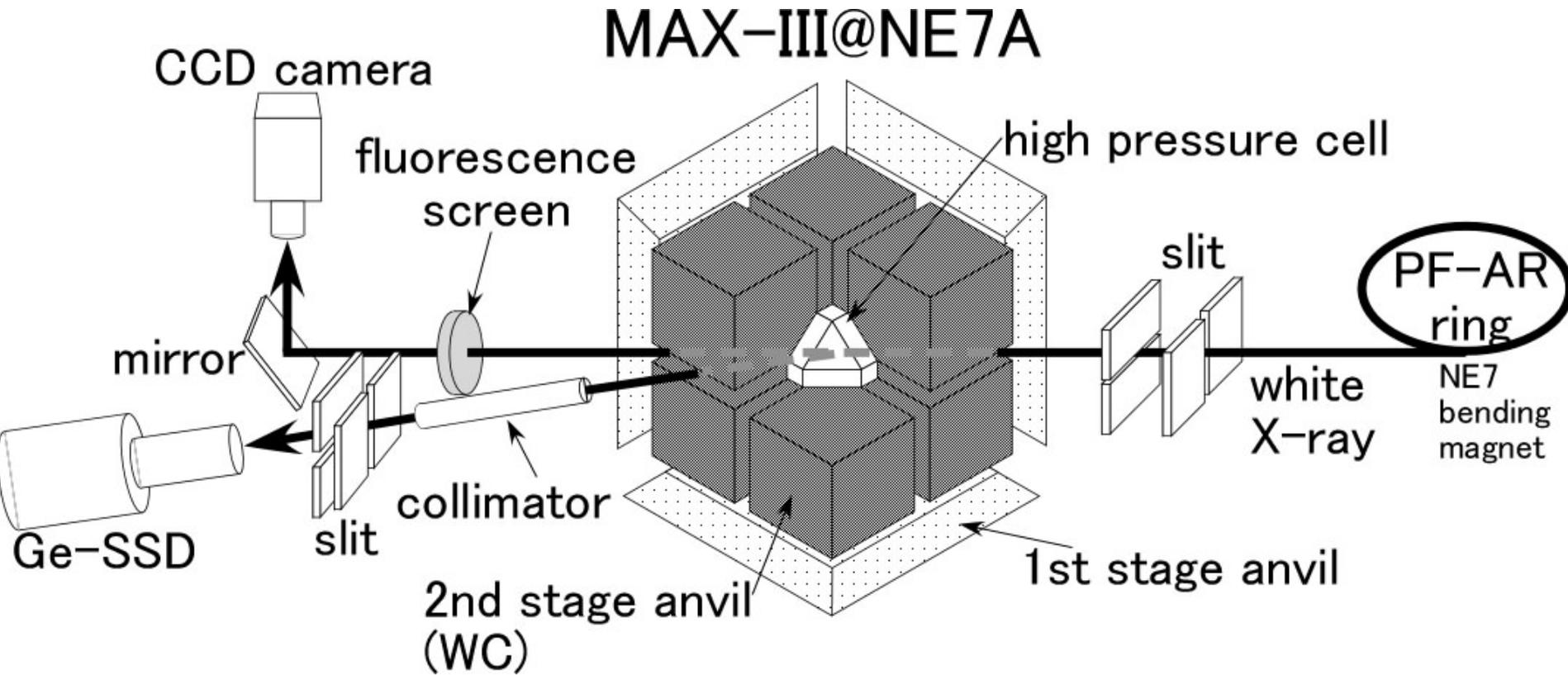
A photograph showing the construction site of NE7A on July 26, 2009. A large, yellow metal frame structure is the central focus, standing on a concrete floor. The frame is composed of vertical and horizontal beams, forming a grid-like structure. Orange traffic cones are placed around the base of the frame. The background shows the industrial interior with various equipment and materials.



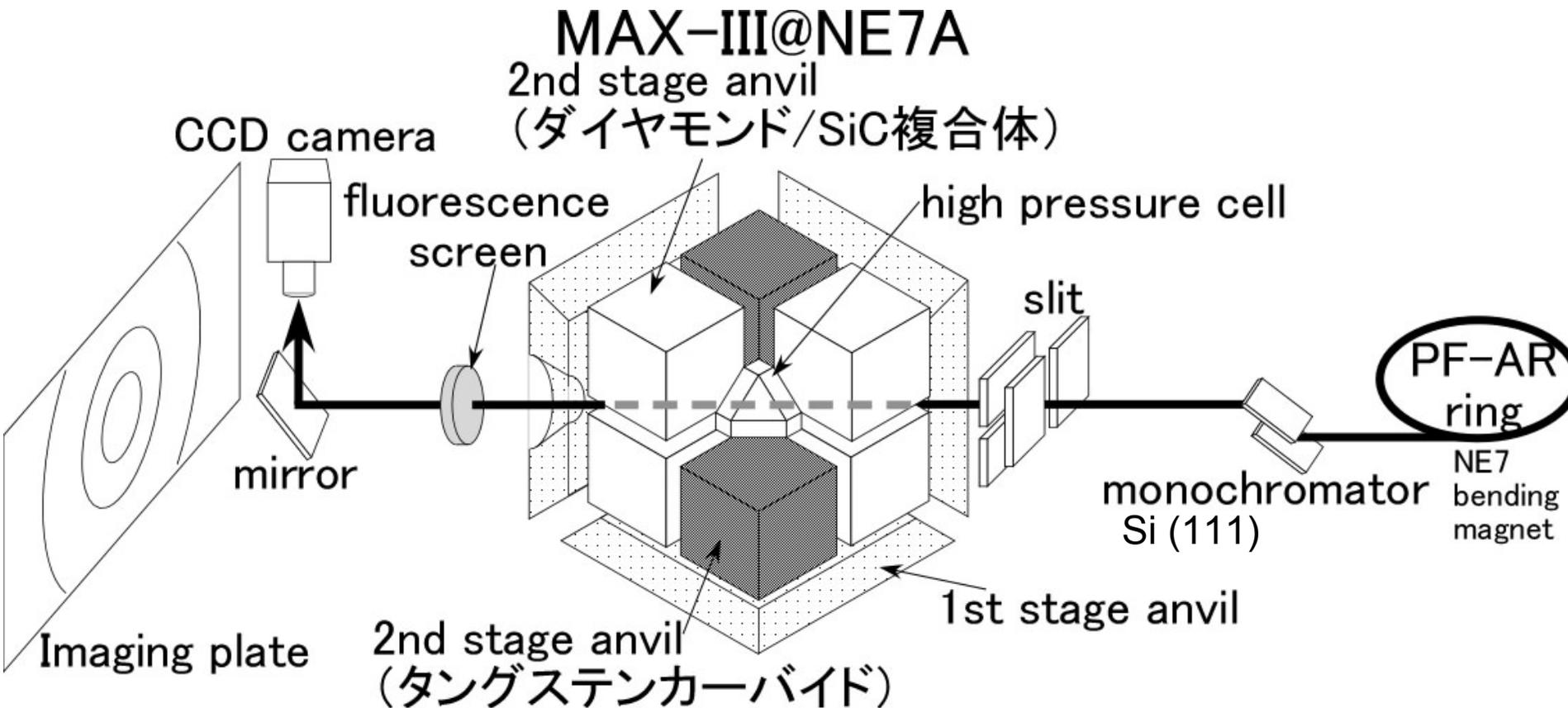
31. July, 2009

A photograph showing the construction site of NE7A on July 31, 2009. A large, light blue metal cabinet or enclosure is the central focus, standing on a concrete floor. The cabinet has a grid-like top structure. Orange traffic cones and safety tape are visible around the base of the cabinet. The background shows the industrial interior with various equipment and materials.

白色X線用イメージング・回折装置 (PF-AR NE7A)



単色X線用イメージング・回折装置 (PF-AR NE7A)



NE7A: 高圧高温下でのX線イメージングと変形 実験用ステーション (2009年11月共同利用開始)

- **白色X線を用いる実験** (高速CMOSカメラ + SSD)

落球法によるマグマや金属メルトの粘度測定 (鈴木(東北大))

その場観察浮沈法による金属メルトの密度測定 (立山(東北大))

液体の構造解析 (井上, 山田(愛媛大))

鉱物の相転移カインेटクス (小野(JAMSTEC))

- **単色X線(30-60 keV)を用いる実験**

(高解像度CCDカメラ + イメージングプレート)

X線イメージング吸収法による金属メルトの密度測定 (西田(東北大))

D-CAP装置を用いた鉱物の変形実験 (白石(東北大), 土井, 久保(九大), 西原(愛媛大))

相転移・粒成長カインेटクス(下宿, 久保(九大))