Understanding the Earth's Interior from Synchrotron Laboratory Studies

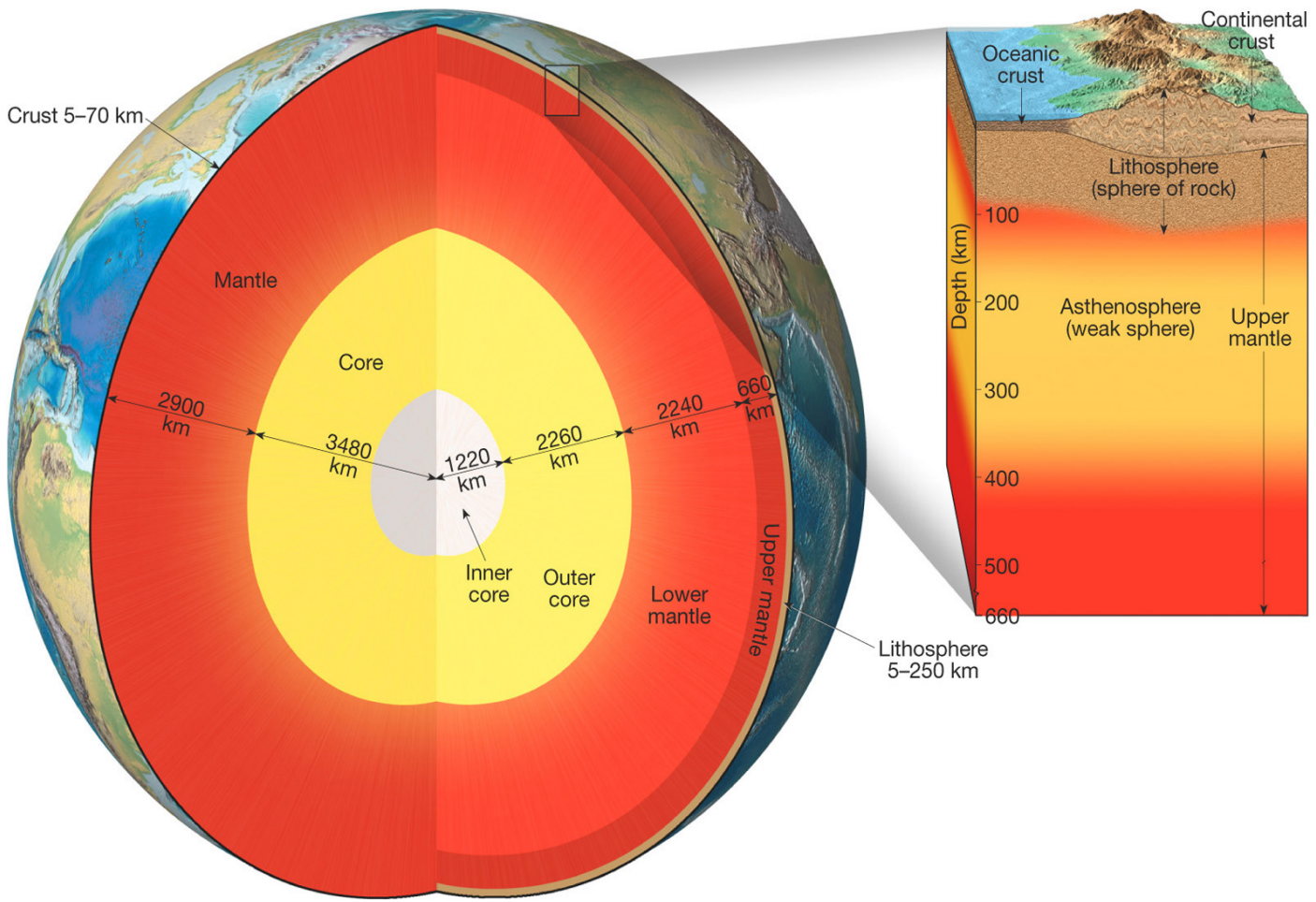
Broad Research Questions about the Earth:

- Formation
- Evolution
- Current Status
- Causes of Observed Natural phenomena

Key: Understanding properties of Earth materials

Main Challenge: Earth's interior accessibility

Views of Earth's layered structure



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Facts:

Pressure increases with depth

Temperature increases with depth

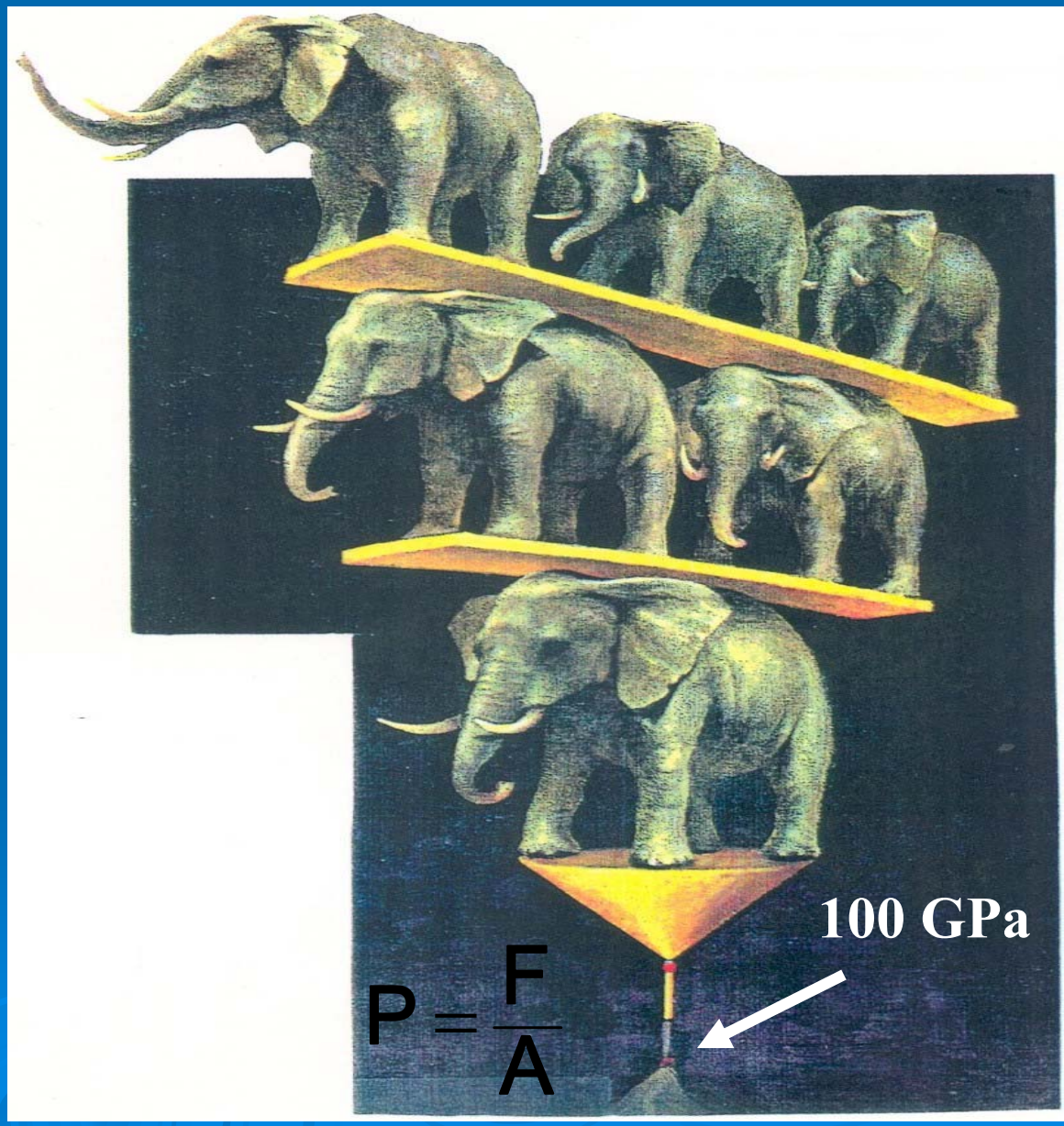
Pressure and Temperature Increase with Depth

At depth of 400 km

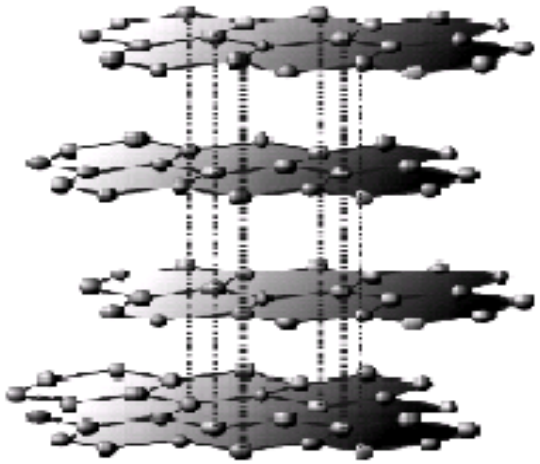
P ≈ 14 GPa (140,000 atm.)

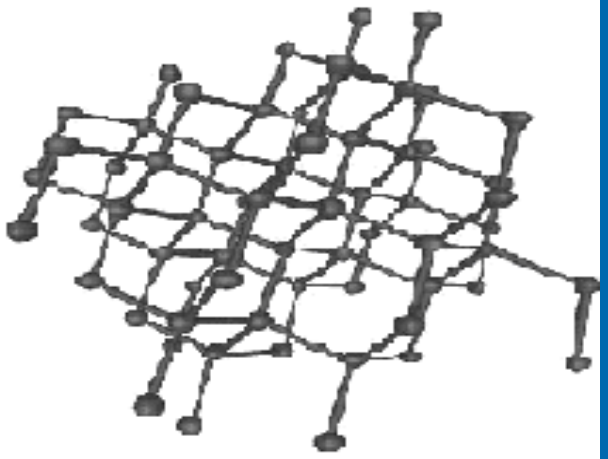
T ≈ 1400°C to 1700 K

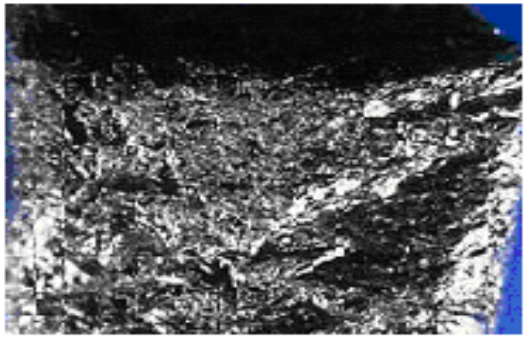
Changes in P and T cause changes in materials structures (properties)

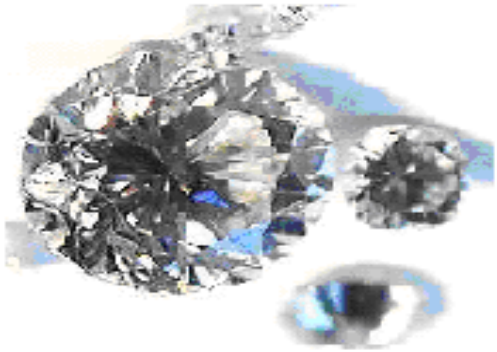


Graphite From to Diamond









Diamond Formation

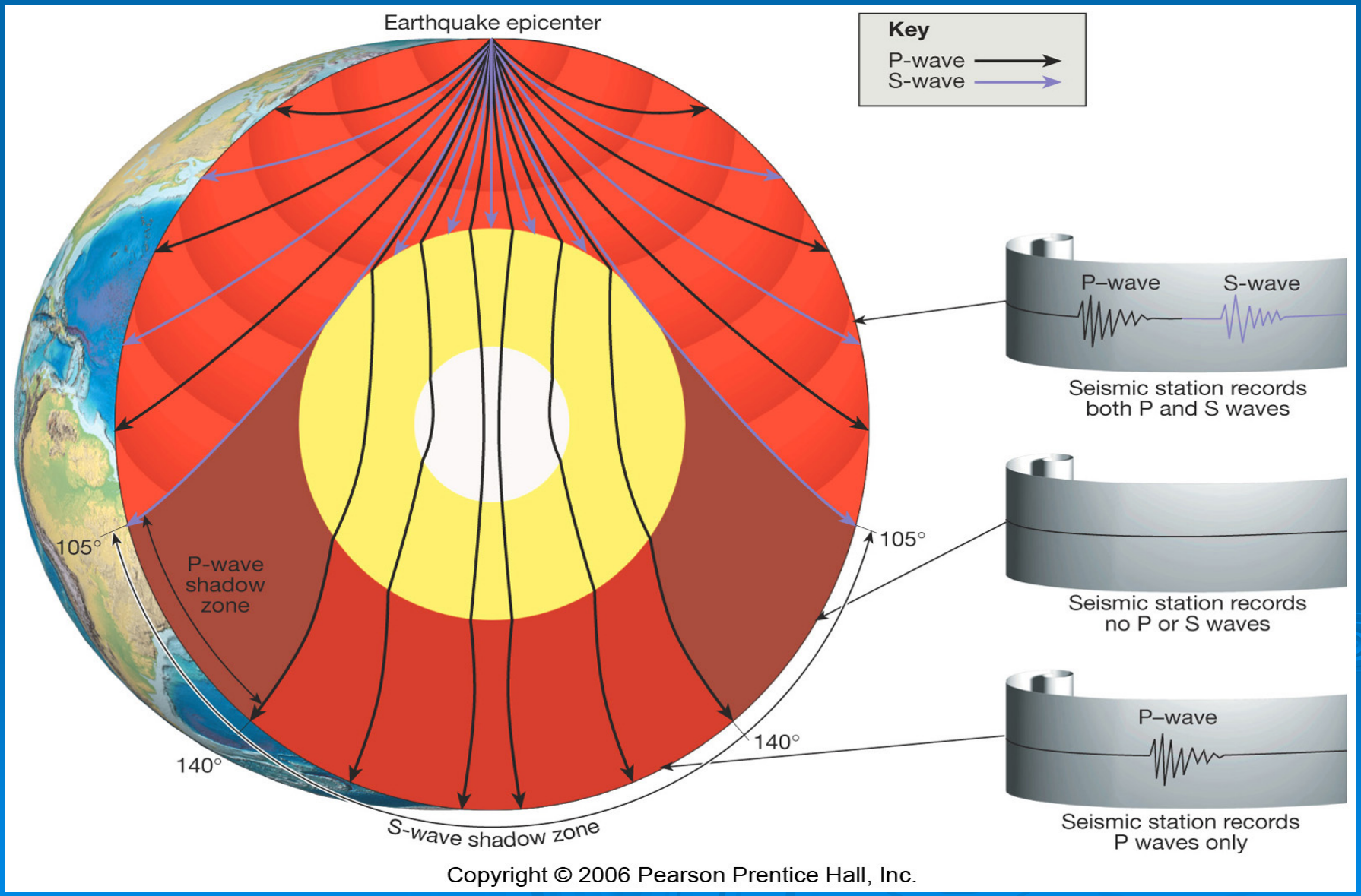
Depth
90 – 120 miles
(140 – 190 km)

P = 4.5 – 6 GPa
T = 900 – 1300°C
(1652-2372 F)

Dark, Soft, electrical conductor
Used in pencils, Used as dry lubricants

Hard, Transparent, Insulator, MP (3820K)
High Thermal Conductivity
Used for cutting tools, grinding/polishing

Possible Paths of Seismic Waves



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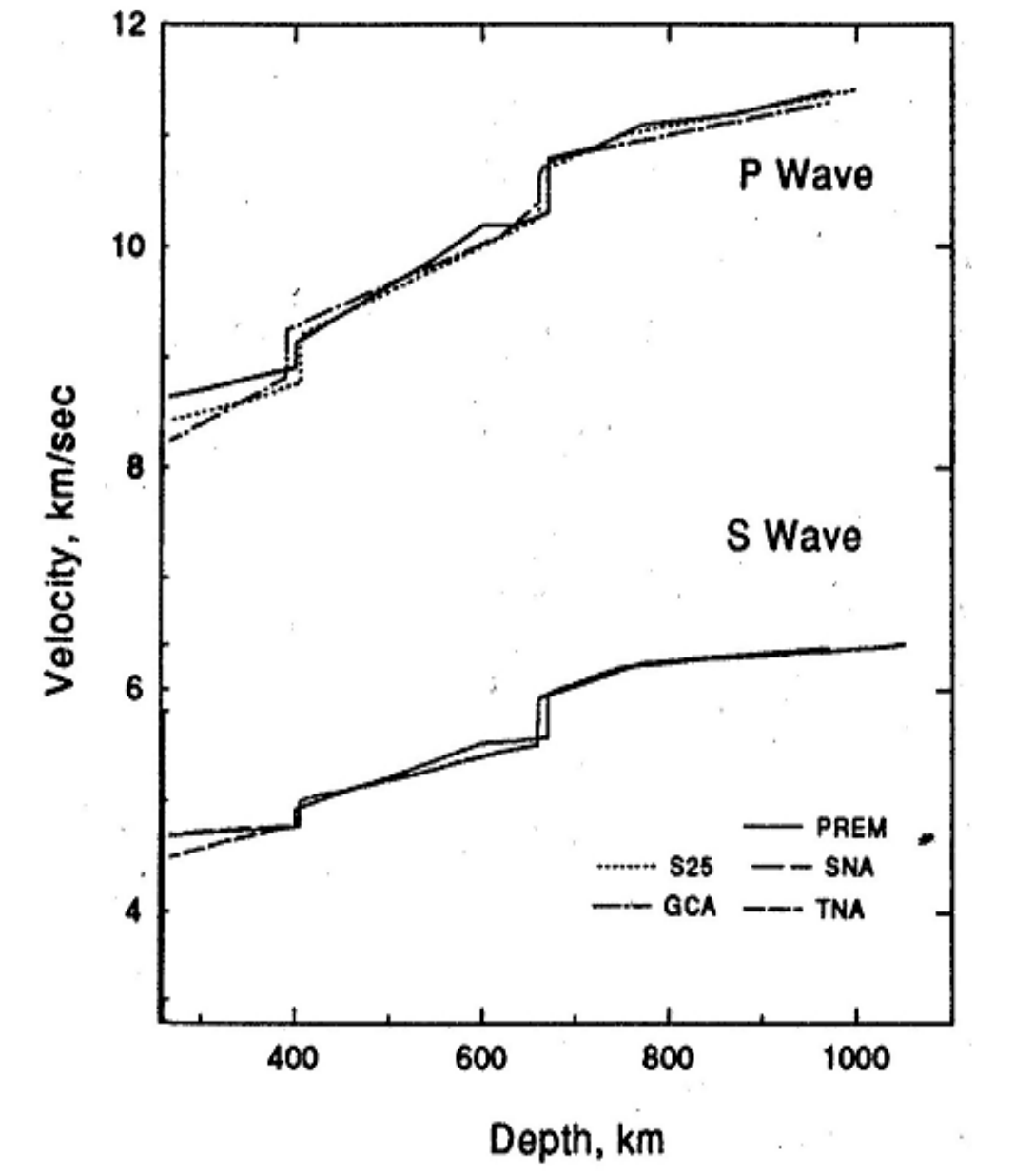
Seismic wave profiles for the Earth



Important features:

- *jumps in P and S waves at 410 and 660 km.*
- *high velocity gradients between discontinuities*

Transition Zone-

Region between 410 and 660 km

Research Focus

Research Goal: to understand Earth mineralogical composition of the Earth.

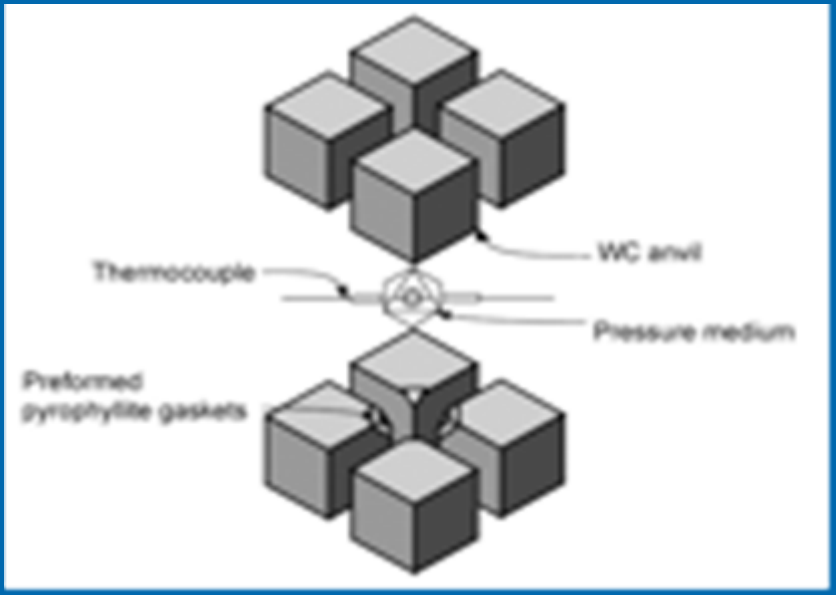
Samples: Synthetic mantle minerals synthesized under simulated P and T conditions.

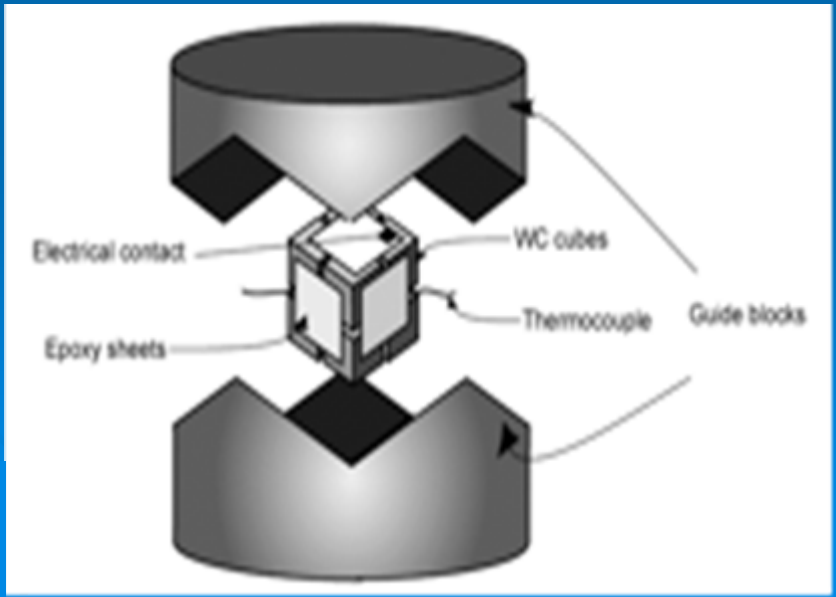
Experimental data: Acoustic wave velocities

Experimental Method:

- Ultrasonic Interferometry technique
- Simultaneous pressure and Temperature
- Synchrotron X-radiation

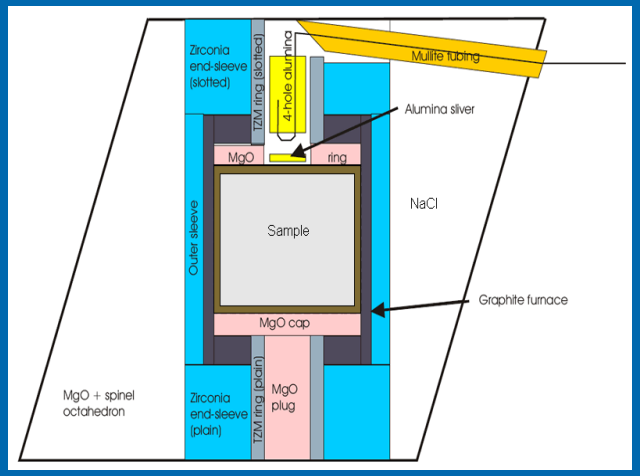
The 2000-ton uni-axial split-sphere multi-anvil press (USSA-2000)





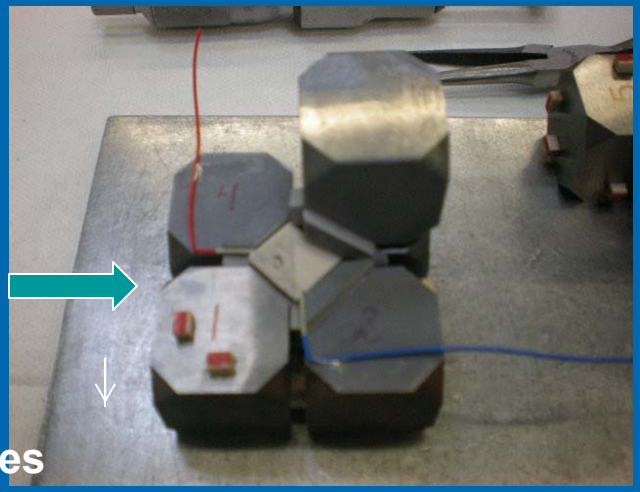
P = 30 GPa (300,000 atms)
T = 2500°C (4532 F)

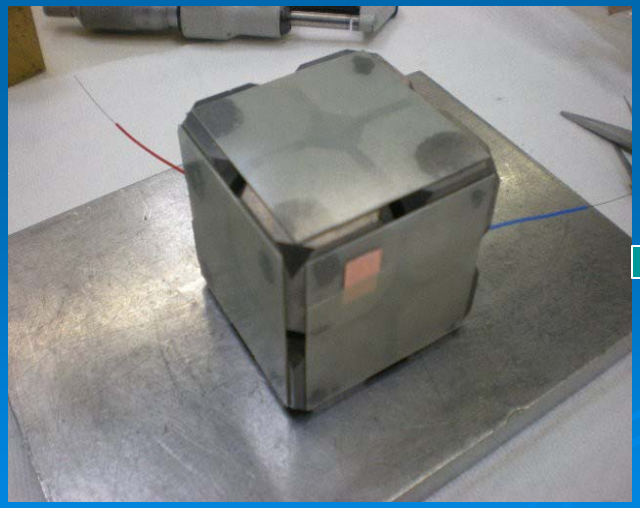
Sample Synthesis Procedure



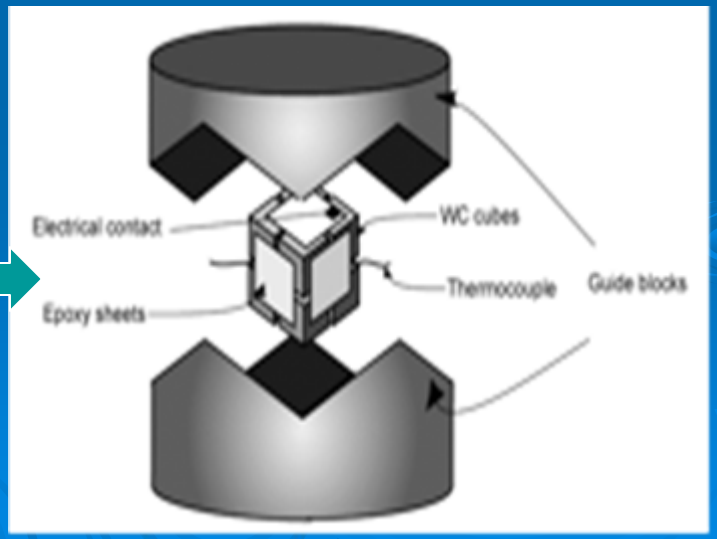
Cell assembly

Tungsten Carbide (WC) cubes





Assembled cubes



Upper and lower press guide blocks

Common Earth Minerals

Olivine (α) Phase $(Mg,Fe)_2SiO_4$

14 GPa
1600K

410 km

Wadsleyite (β) phase

20 GPa
1800K

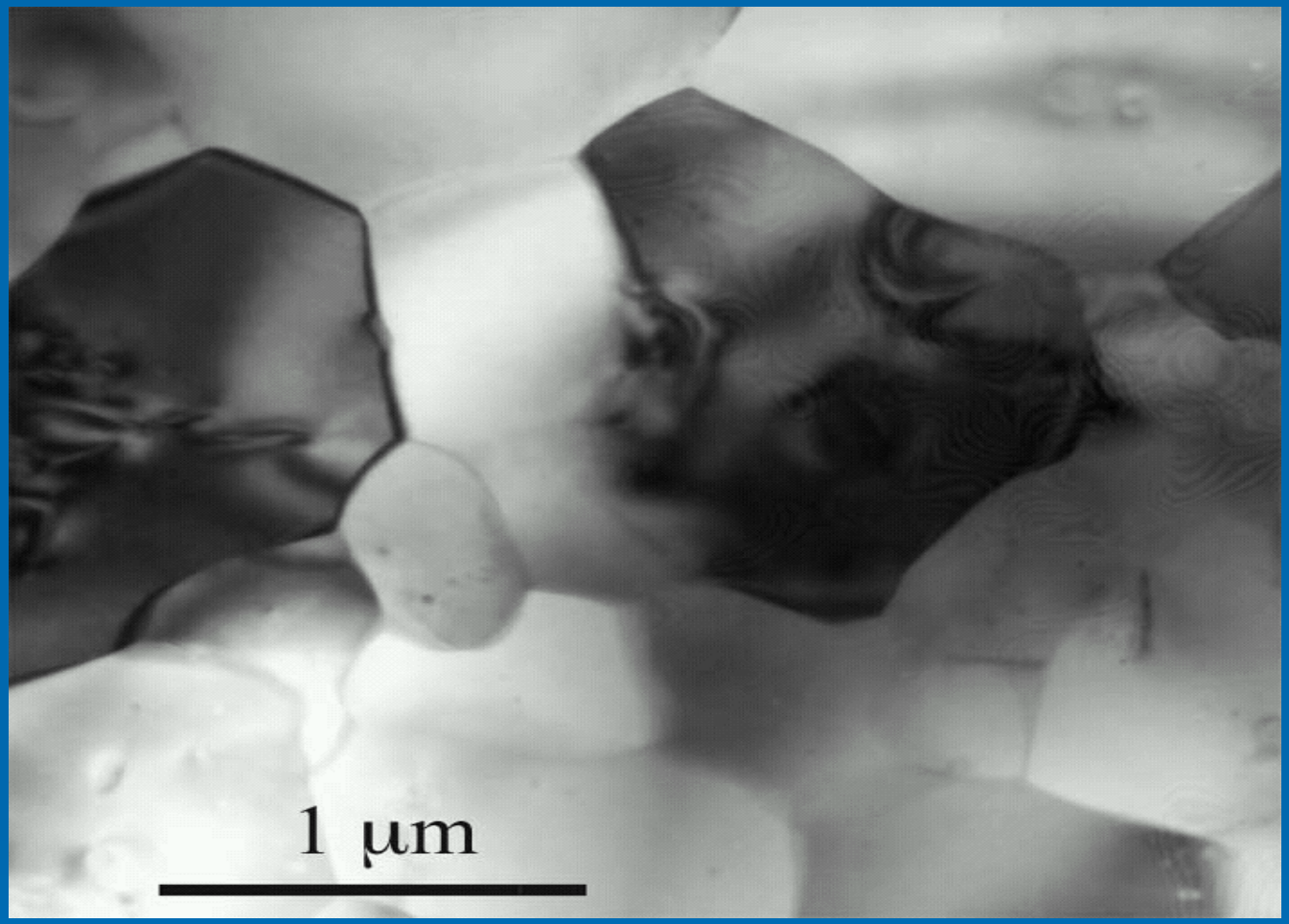
660 km

Ringwoodite (γ) phase

Pyroxene $(Mg,Fe)SiO_3$

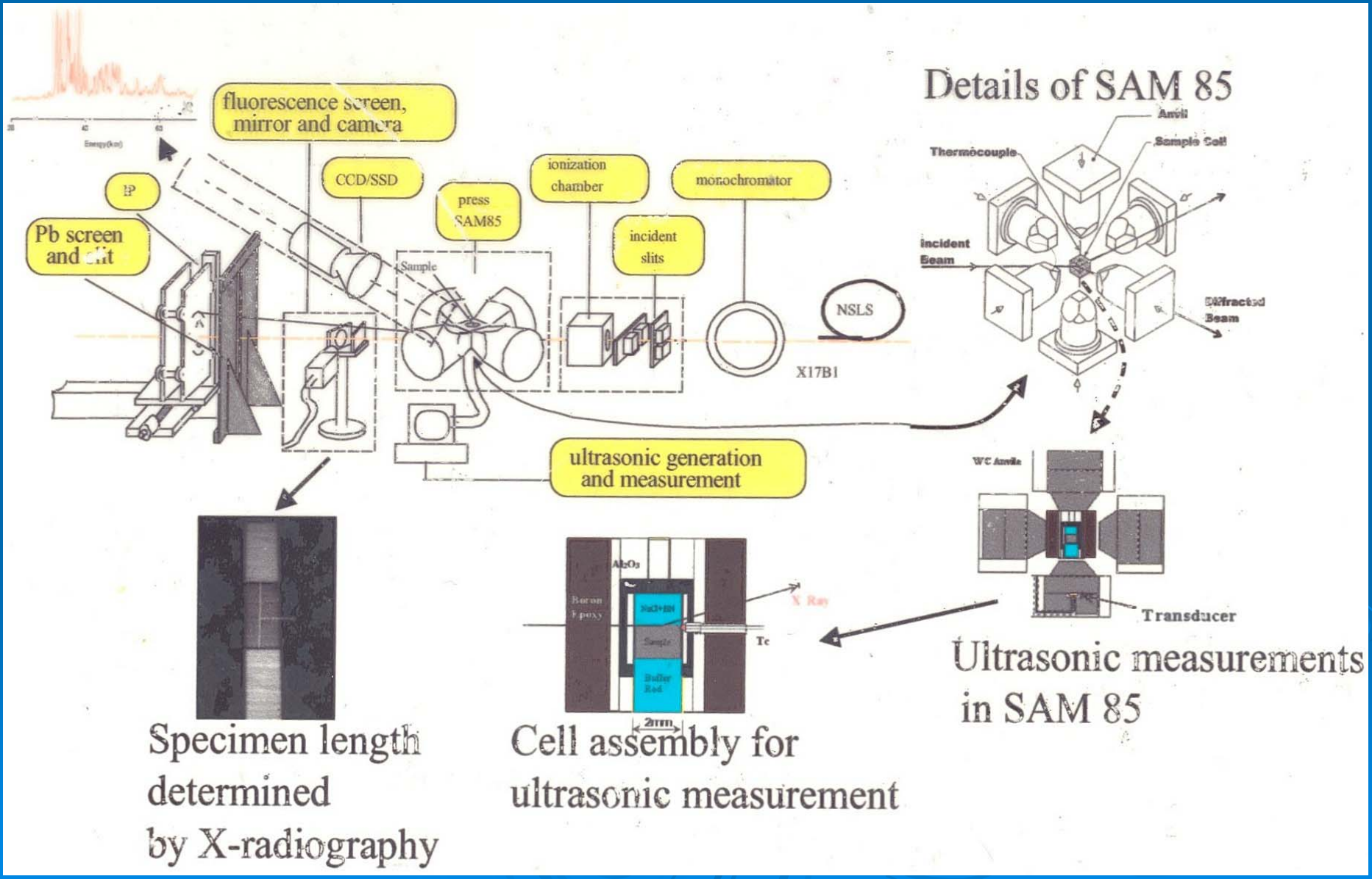
410-660 km

Garnet

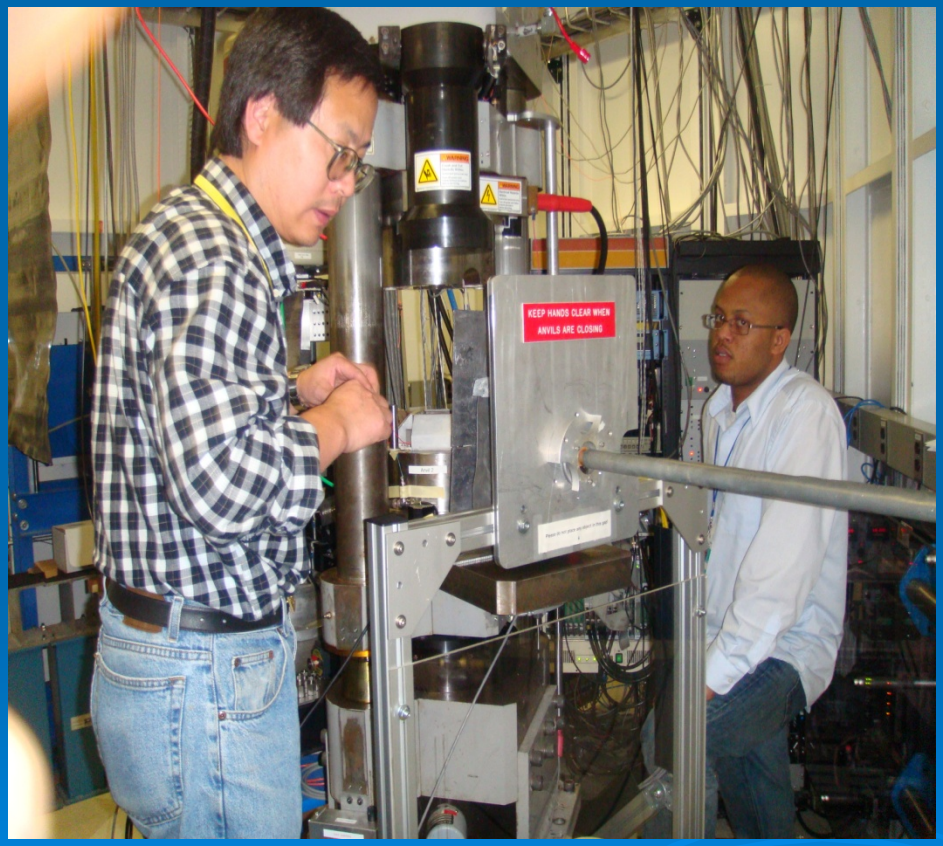


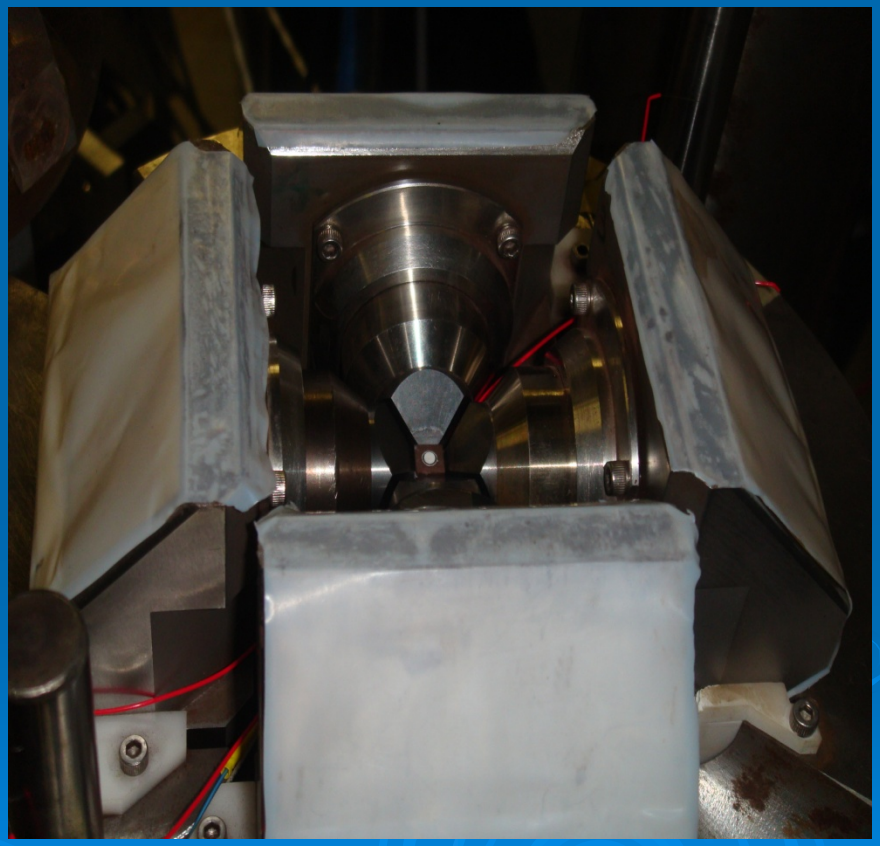
Fine-grained
Pore-free
Homogeneous
No preferred grain orientation

Elasticity Measurements at High P and T in Conjunction with Synchrotron X-radiation at X17B2

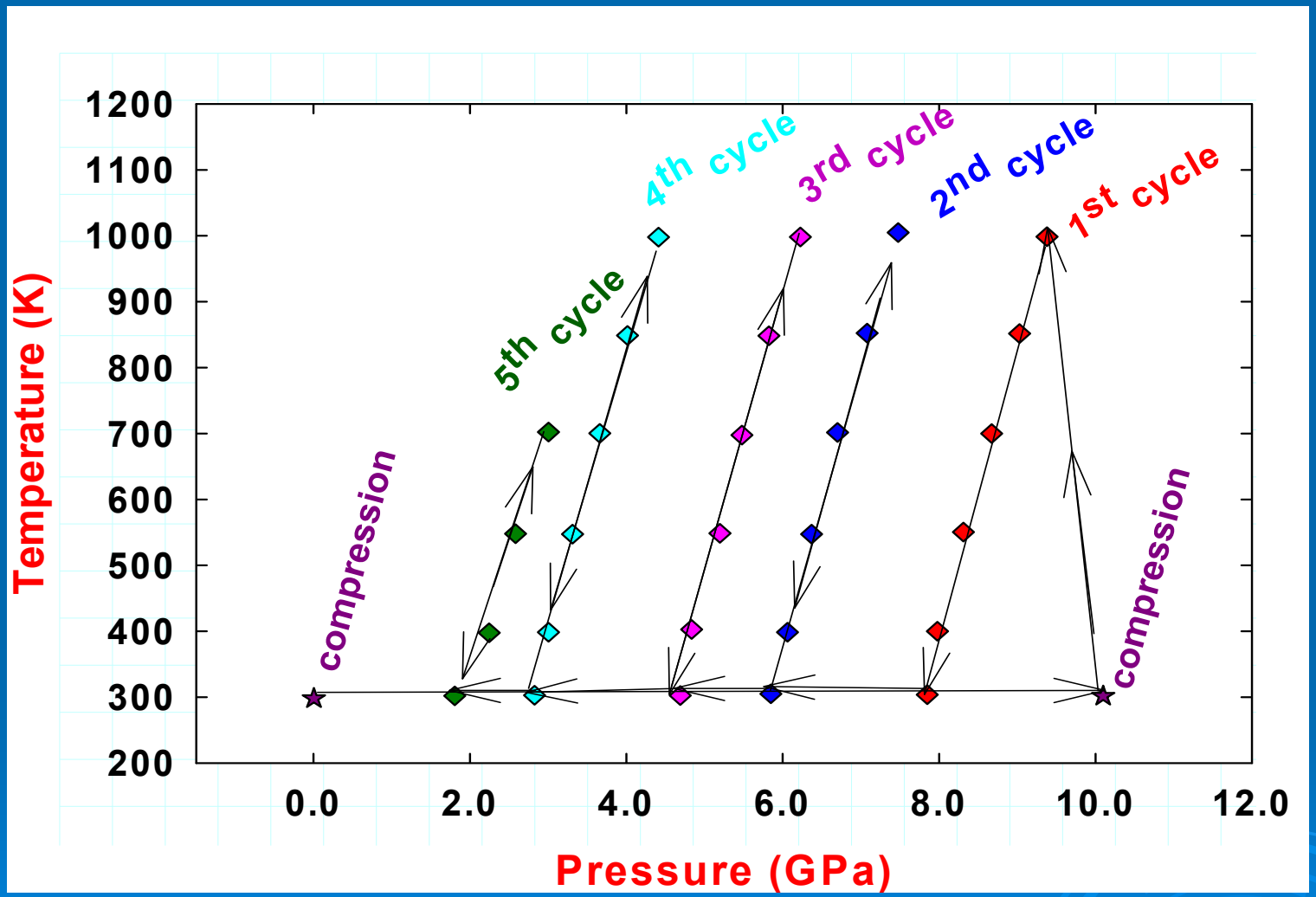


Cubic Multi-Anvil Press on X-17B2 Beam line





Experimental Path for Garnet Experiment



- *Sample is compressed cold, then heated to 1000K*
- *Data collected at each point- x-ray, temperature, travel times of P and S waves*

Data from Experiment

Data	Source
sample length (l)	X-ray/Image of sample
sample density (ρ)	X-ray of sample
Sample pressure (P)	X-ray of NaCl
Acoustic wave travel times (t_p, t_s)	ultrasonic

Product of Data Analysis

V_P = P-wave velocity

$$v_p = \frac{2\ell}{t_p}$$

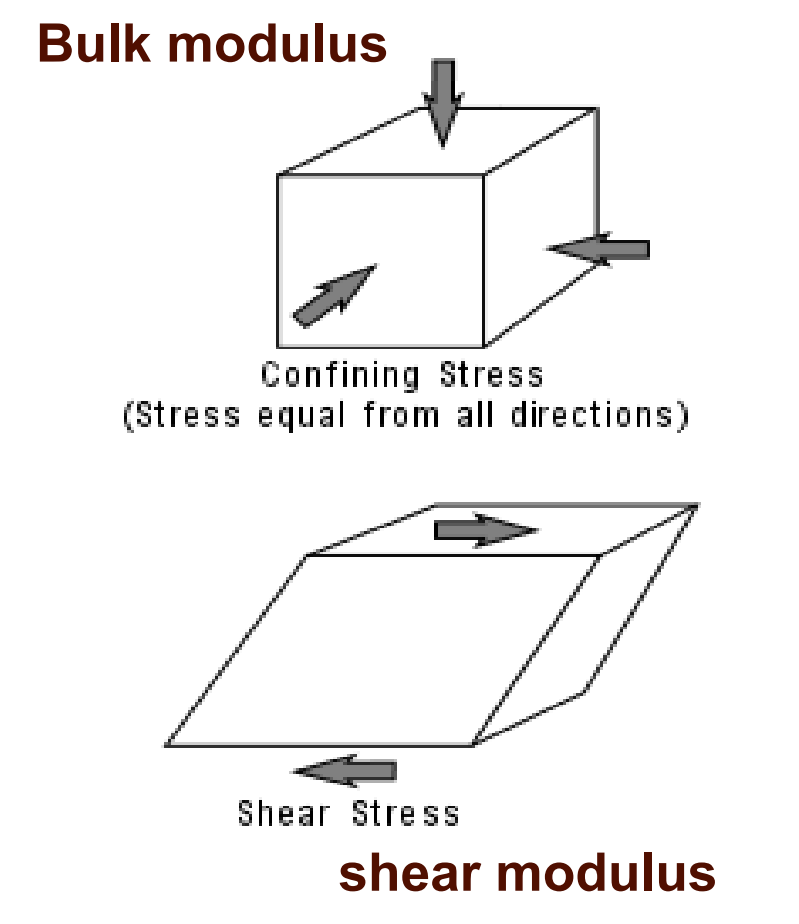
V_S = S-wave velocity

$$v_s = \frac{2\ell}{t_s}$$

Elastic Properties

$$G = v_s^2 \rho$$

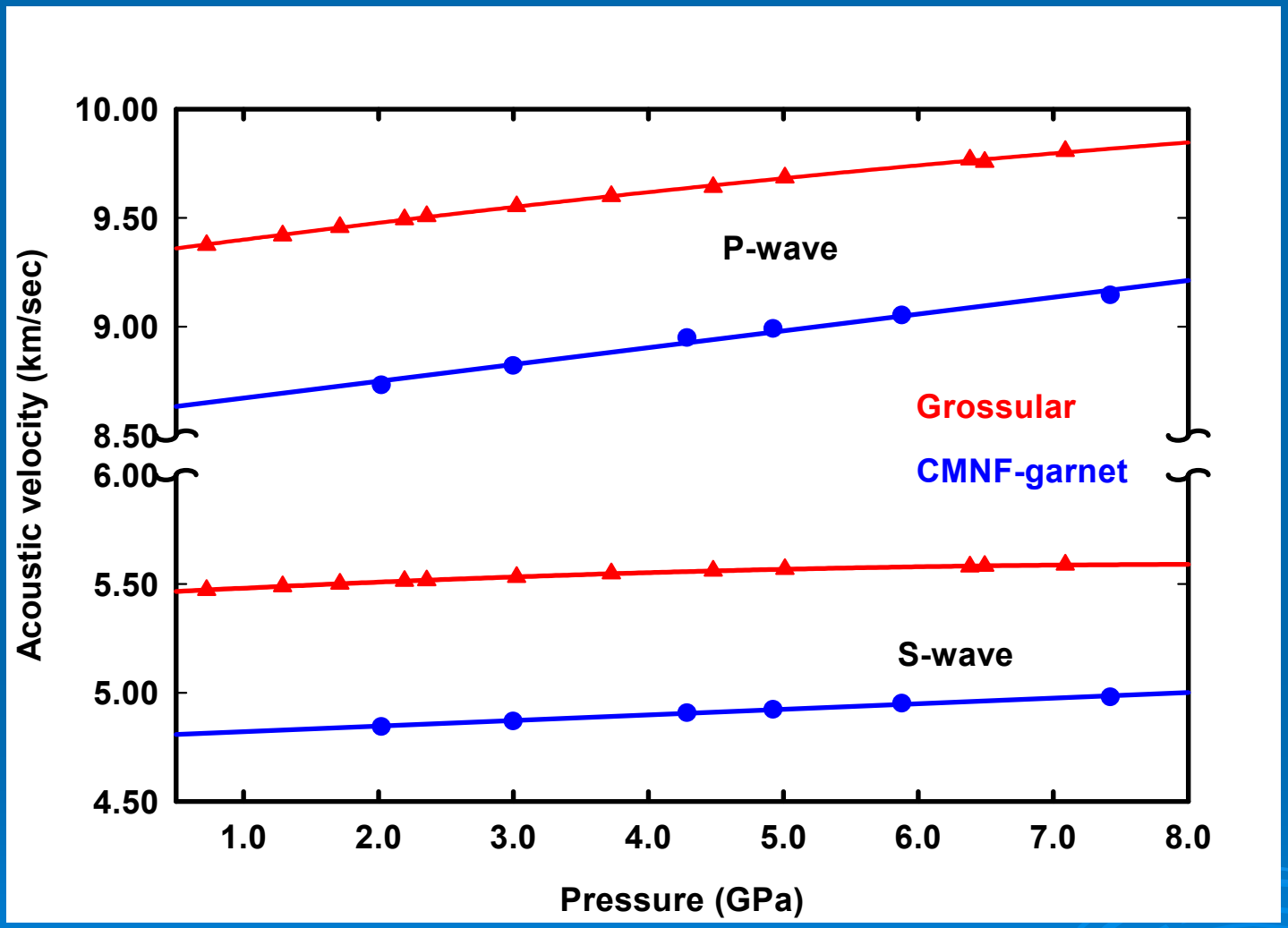
$$K_s = (v_p^2 \rho) - (4/3 G)$$



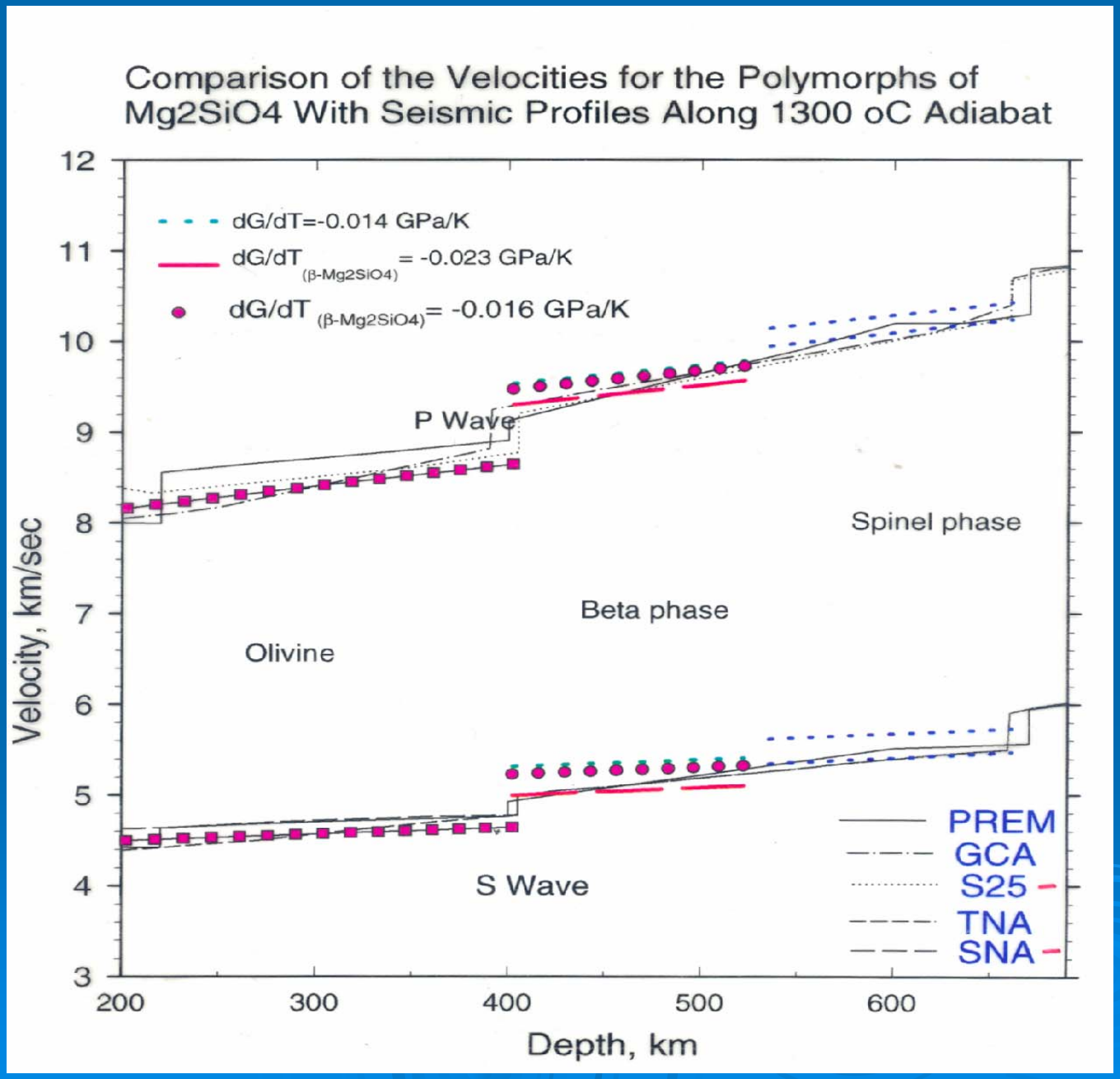
- **Compressibility = 1/K (*related for inter-atomic forces*)**
  Material with high K have strong bonds

- **K is also empirically correlated with the interstitial electron density, cohesive energy, and mechanical hardness.**

Velocity data for two garnets



Grossular = $Ca_3Al_2Si_3O_{12}$
CMNF = 0.2 $NaAlSi_{12}O_6$ + 0.3 $Mg_2Si_{12}O_6$ + 0.4 $CaMgSi_{12}O_6$+ 0.1 $Fe_2Si_{12}O_6$


Comparison of the Velocities for the Polymorphs of Mg2SiO4 With Seismic Profiles Along 1300 oC Adiabat
dG/dT=-0.014 GPa/K
dG/dT (β-Mg2SiO4) = -0.023 GPa/K
dG/dT (β-Mg2SiO4) = -0.016 GPa/K
P Wave
S Wave
Olivine
Beta phase
Spinel phase
PREM
GCA
S25
TNA
SNA
Velocity, km/sec
Depth, km
12
11
10
9
8
7
6
5
4
3
200
300
400
500
600

Education Opportunities and Training

Delaware State undergraduate students

NSF - Funding

SUNY High Pressure lab and Geophysical Laboratory.

COMPRES – Consortium for Materials Properties Research in Earth Sciences

NSLS and OEP at BNL

INCREASE - Interdisciplinary Consortium for Research and Educational Access in Science and Engineering .

DSU Undergraduate students

Interdisciplinary Consortium for Research And Educational Access in Science and Engineering (INCREASE)

- Partnership with the National Synchrotron Light Source
- Enable and facilitate access to NSLS research facilities by MSI faculty and students
- BNL researchers Assist Faculties in developing competitive beam line proposals.
- Developing a new user community for DOE facilities
- Program extended to CFN
- Expanding initiative to other BNL facilities

Workshop 2007

Workshop 2008

INCREASE and Career Training Opportunities

- Promote research in science and engineering involving design and utilization of advanced instrumentations for materials fabrications and characterization.
- Establish research and education partnerships among member institutions; explore common research themes to take advantage of major research and education funding.
- Develop an *Introductory Synchrotron* course for integration into undergraduate science curricula.

Stony Brook Master of Science in Instrumentation (MSI) Programs

- Physics
- Geosciences (new) – A Career Path for African-American Students from HBCU's to National Laboratories (Liebermann, Lars, Gwanmesia)