衝撃圧縮に伴う温度変化の重要性と衝突現象

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[日本における超高速衝突
実験の現状と展望]
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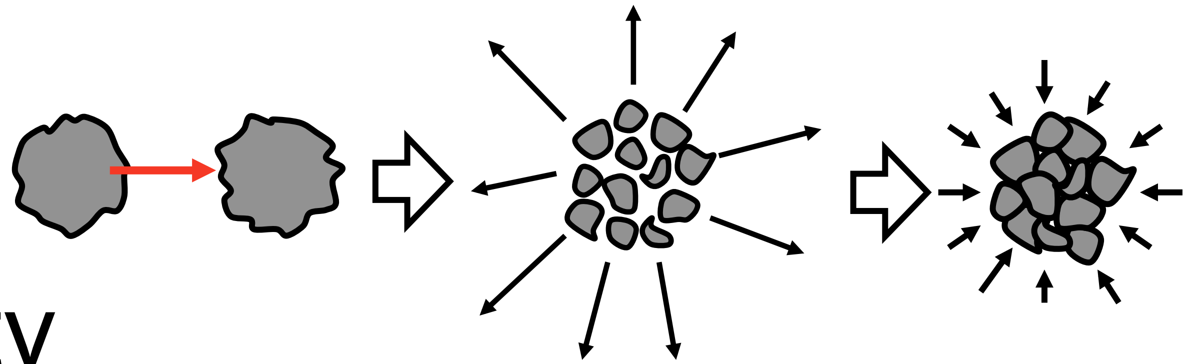
惑星科学研究センター

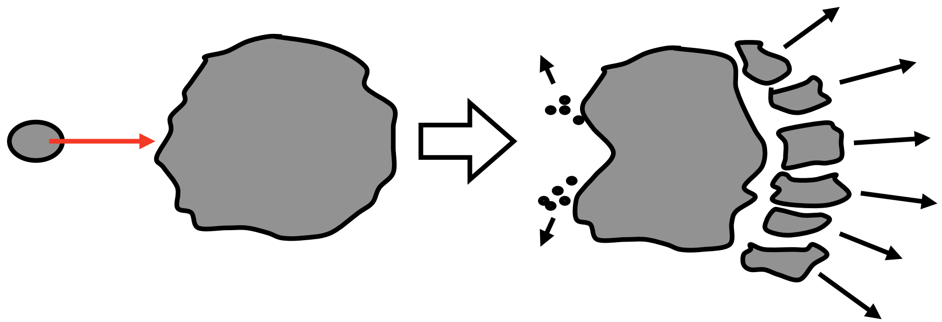
Objectives of this study

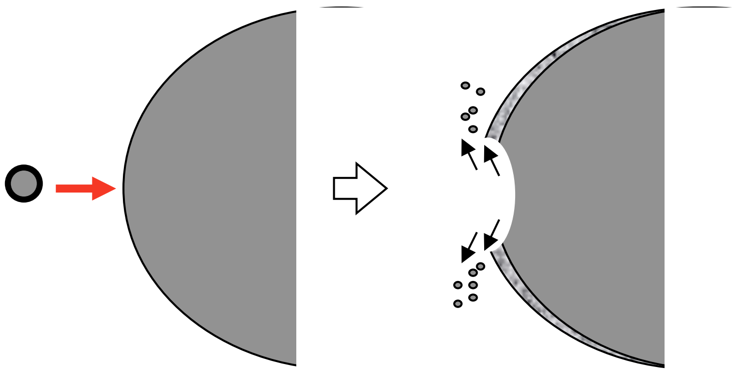
Impact phenomena; Planetary formation and evolution, origin of meteorites, and origin of life

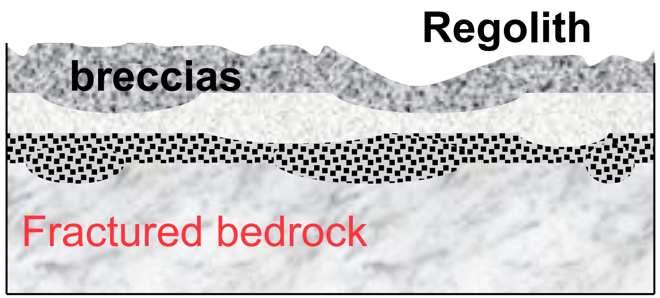
- How we reveal the shock strength in impacts from shocked meteorites and impactites
- Currently we have no full knowledge for that
- We need to understand impact phenomena comprehensively, but not individual changes in them
- It is important to understand totally physical changes during impact to improve the basic knowledge including temperature

High-velocity Impacts





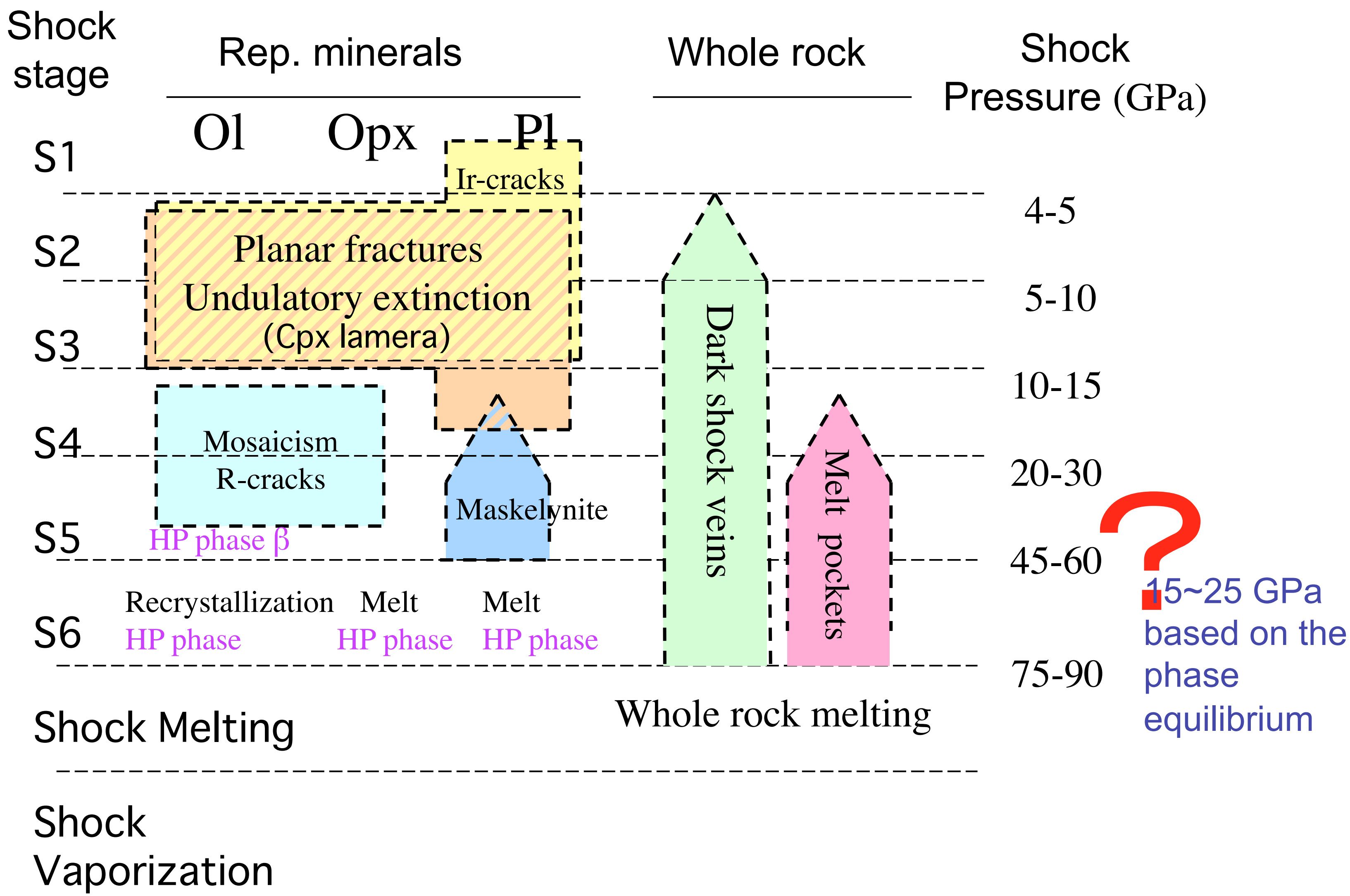




Difference between volcanic craters and impact craters

- Mechanism
  - Energy; external（shock waves=SW）or Internal （explosive eruptions=EE）
  - Strain rate; 10^4-10^6/s (SW) or 10^{-3}-10^{-6}/s(EE)
  - Stress level; ~5 GPa-100 GPa (SW) or < 2 GPa(EE)
  - Deformation; uniaxis or not
- Geophysical - Negative anomaly and
  - Positive anomaly
- Geological, Geochemical — Breccias and regolith on the surface, Pt group elements, and isotope ratios
- Petrological, Mineralogical — Shutter cones, Planar and planar deformation feature(PDF), HP minerals, and HP glasses
- No Morphological difference

Current status for shock metamorphism



Feldspar Hugoniots

Compiled by Sekine and Ahrens (1991)

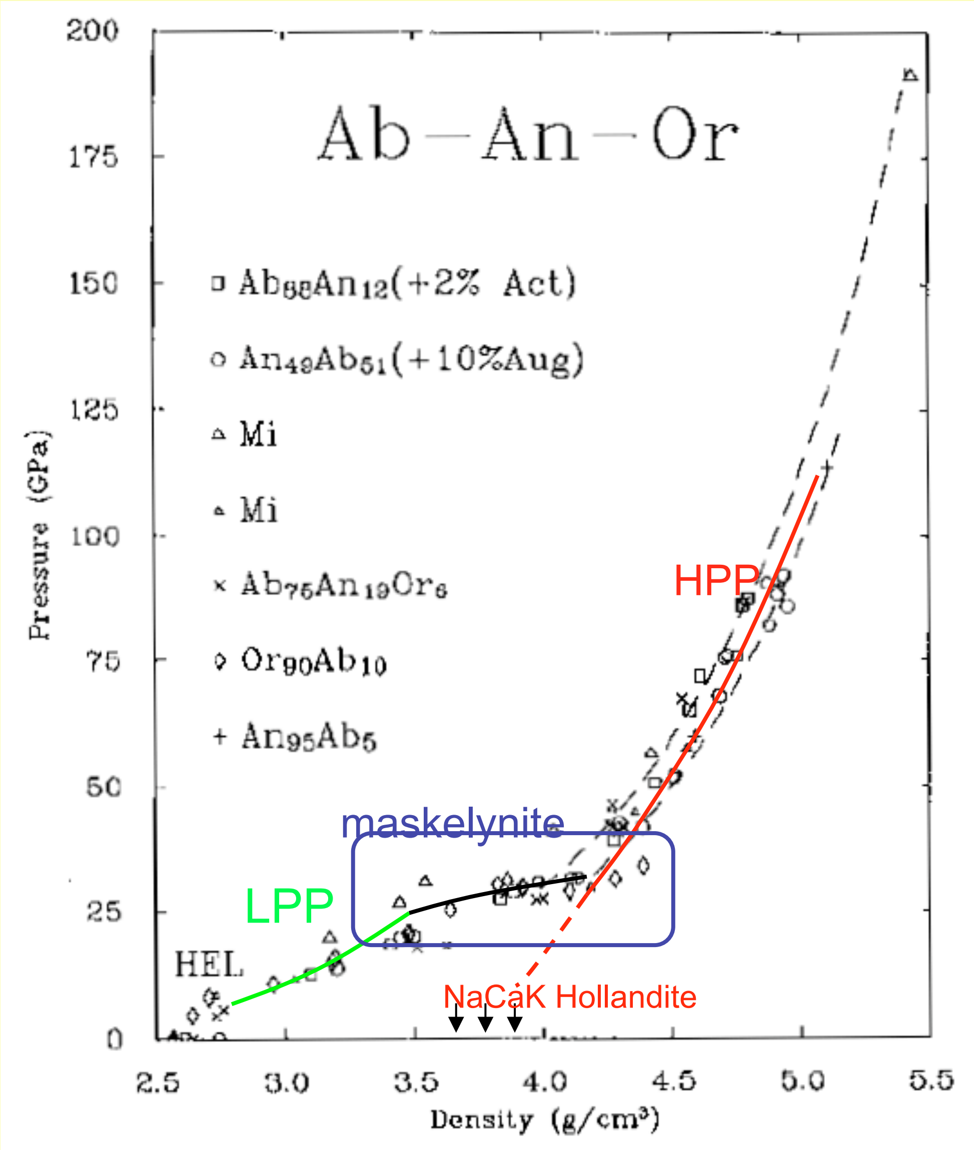
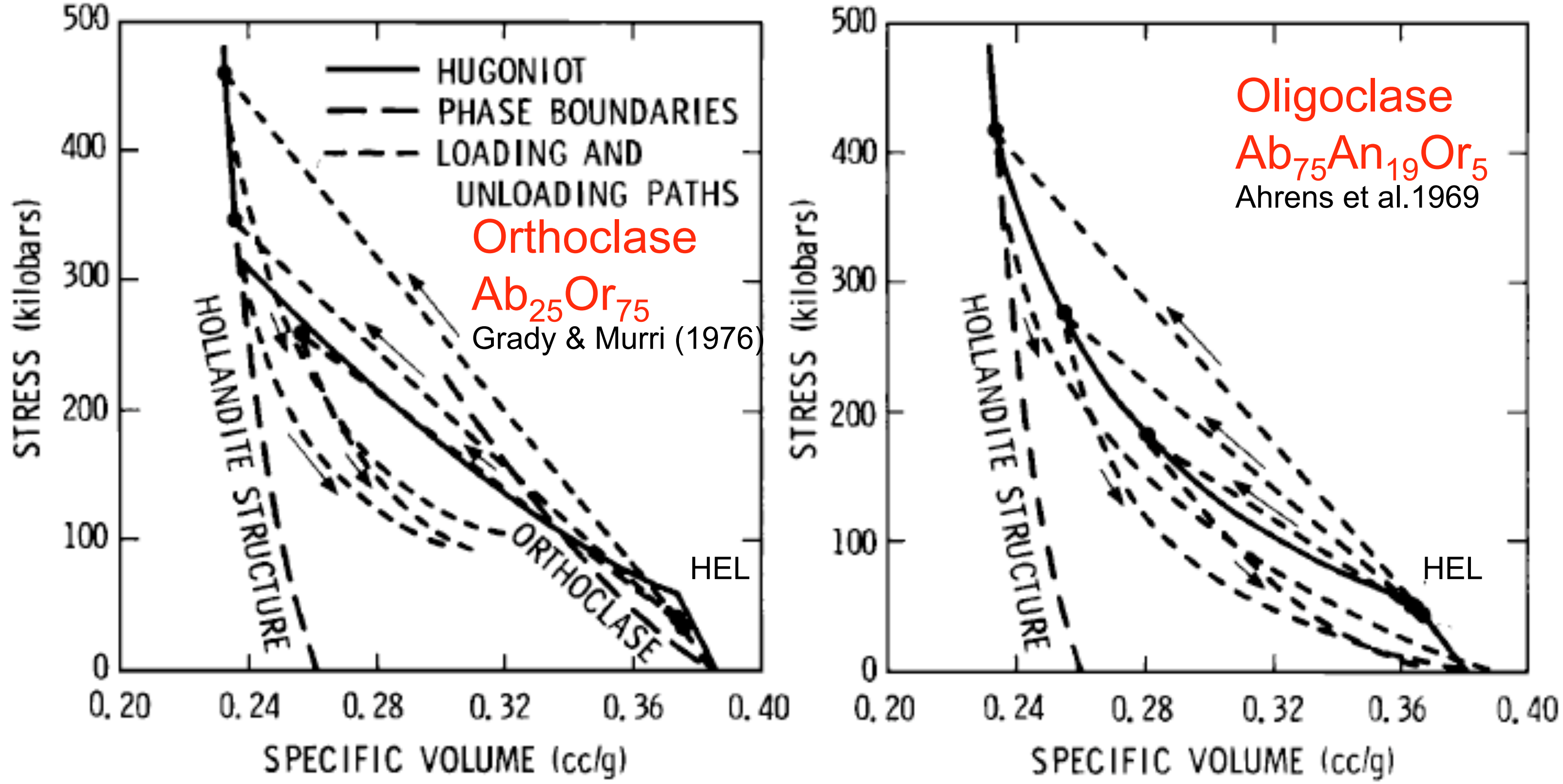


Fig. 2. Hugoniot density-pressure relations for plagioclase and alkali feldspars. Data from McQueen et al. (1967) (□, ○), Simakov et al. (1974) (△), Ahrens et al. (1969) (▵, ×), Ahrens and Liu (1973) (◇), and Jeanloz and Ahrens (1980) (+). *Upper* and *lower broken curves* are least-square fittings for high-pressure regimes for $NaAlSi_3O_8$- and $KAlSi_3O_8$-rich feldspars (□, ▵, ×, ◇) and $CaAl_2Si_2O_8$-rich plagioclase (○, +), respectively. Abbreviations; Ab = albite, An = anorthite, Mi = microcline, Or = orthoclase, Act = actinolite, Aug = Augite, and HEL = Hugoniot elastic limit

Release paths from Hugoniot states

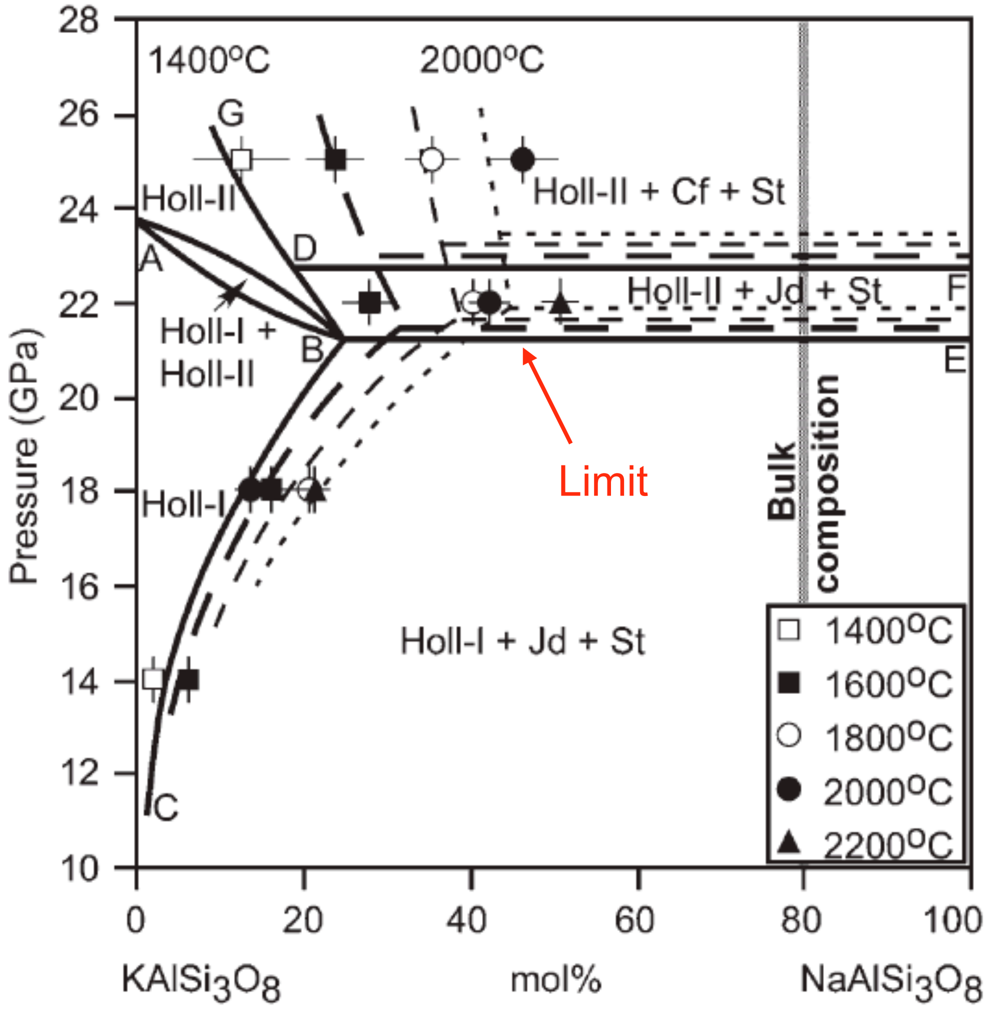


HP feldspar (hollandite) is unquenchable!
Why does Hol exist in some meteorites?

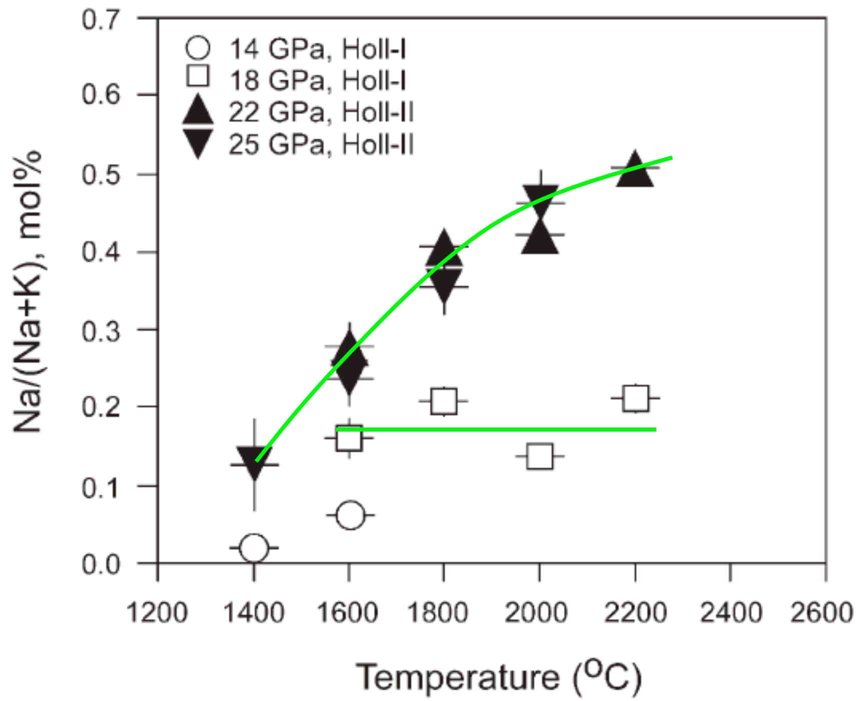
The system $KAlSi_3O_8$-$NaAlSi_3O_8$ at HPHT

Static pressure data by Liu (2006)

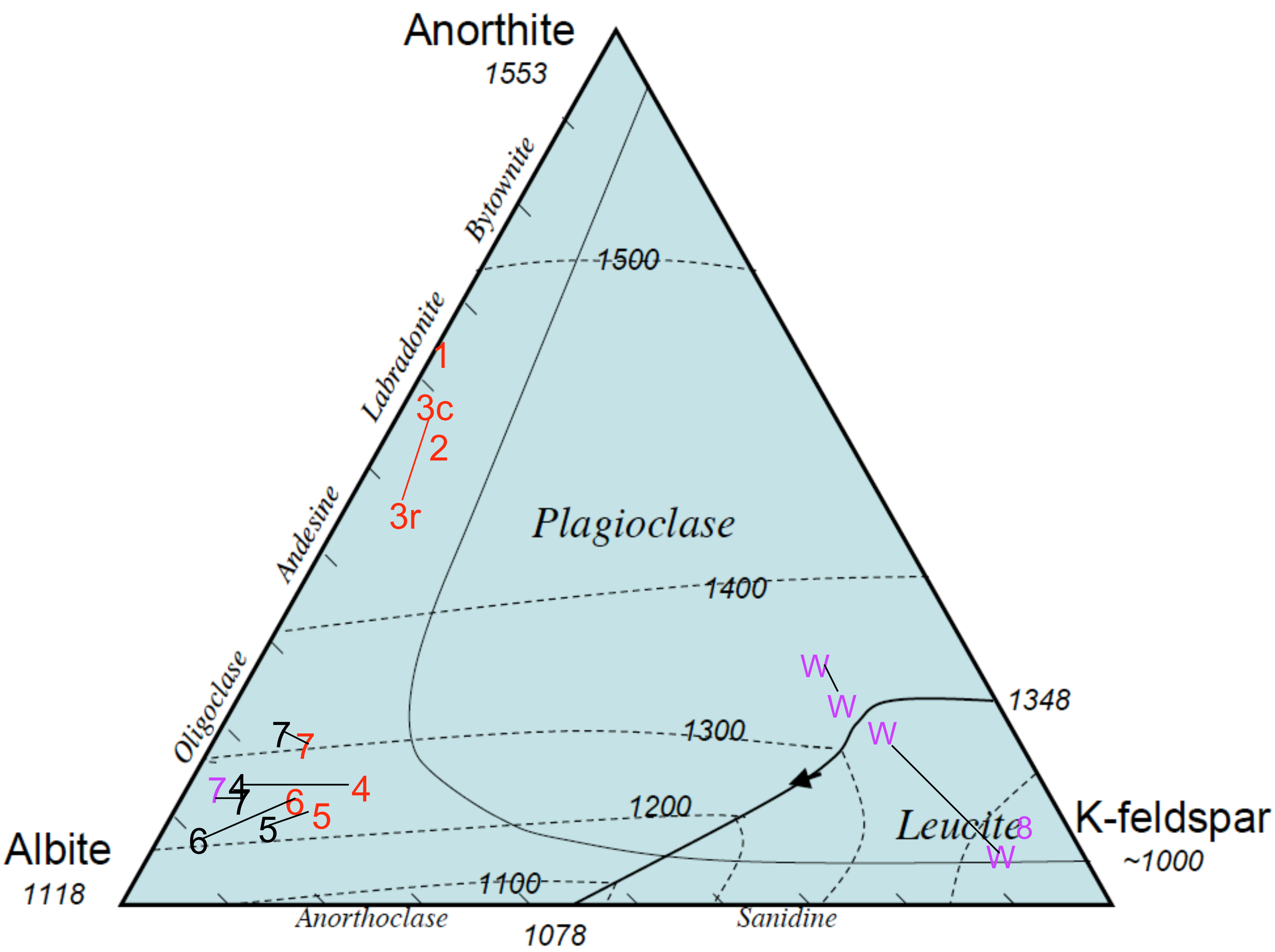
Cf. DAC Exp. Liu (1978) and Tutti (2007)



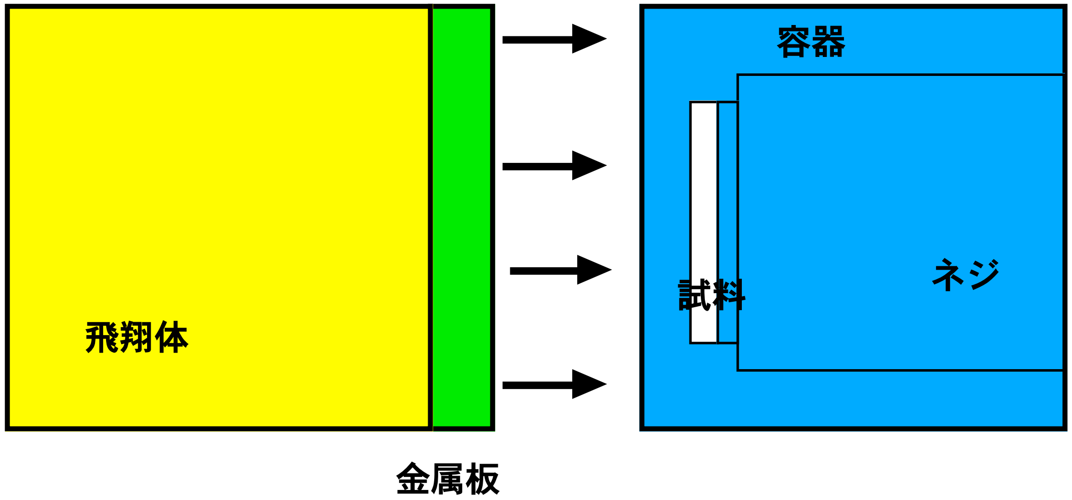
No Ab-rich Hollandite



Pl-Msk-Hol

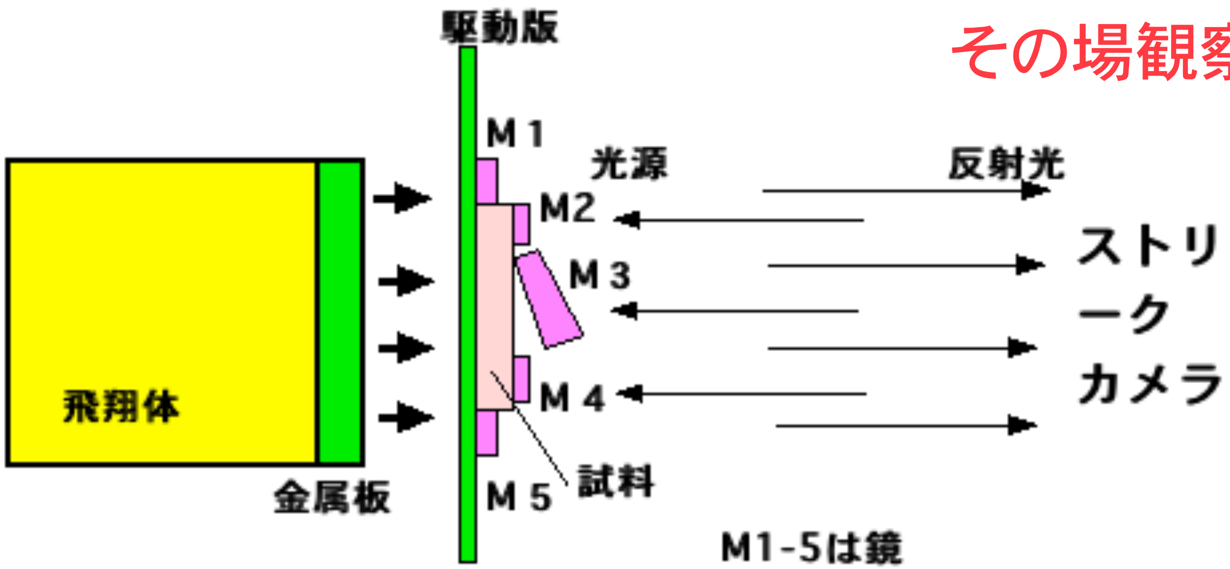


Anorthite
1553
Bytownite
Labradonite
Andesine
Oligoclase
1500
1400
1300
1200
1100
1348
Plagioclase
Leucite
Albite
1118
K-feldspar
~1000
Anorthoclase
1078
Sanidine
1
3c
2
3r
W
W
W
W
8
7
7
7
4
4
7
6
5
6
5



回収実験

その場観察実験

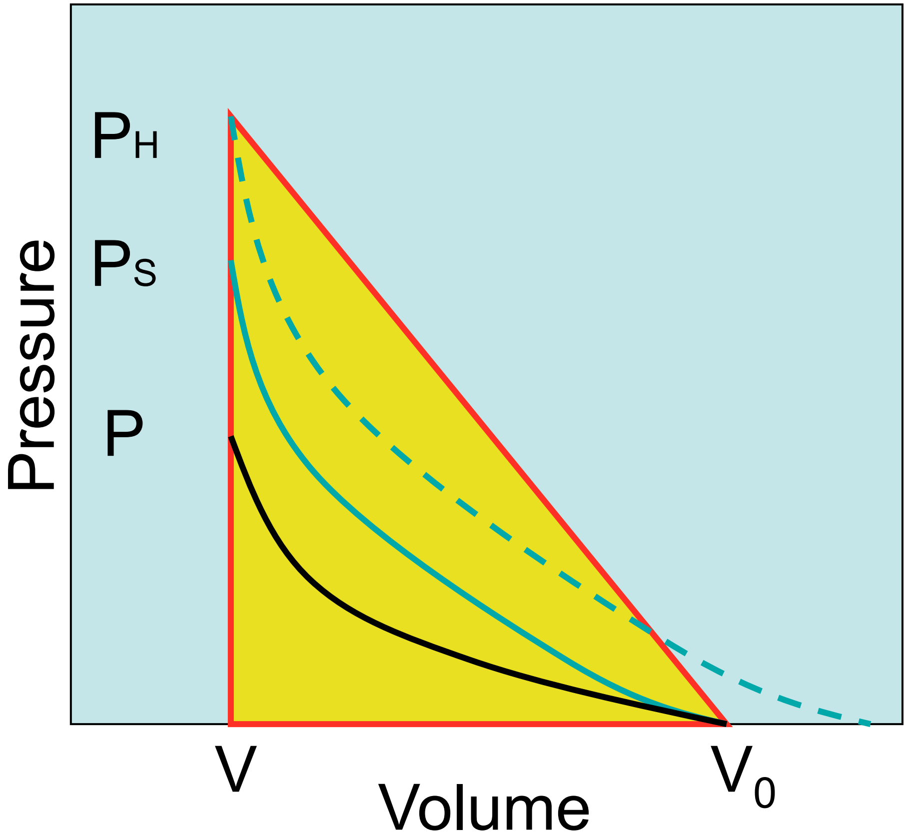


圧縮法の相違点

ー圧力発生原理と熱力学的相違ー

1. 衝撃圧縮
2. 静的圧縮
（準静的圧縮）
3. 等エントロピー圧縮

衝撃波の立たない動的圧縮



Shock temperature calculation

$$T_S = T_i \exp\left(\int_{V_a}^{V_b} \left(\frac{\gamma}{V}\right) dV \right)$$

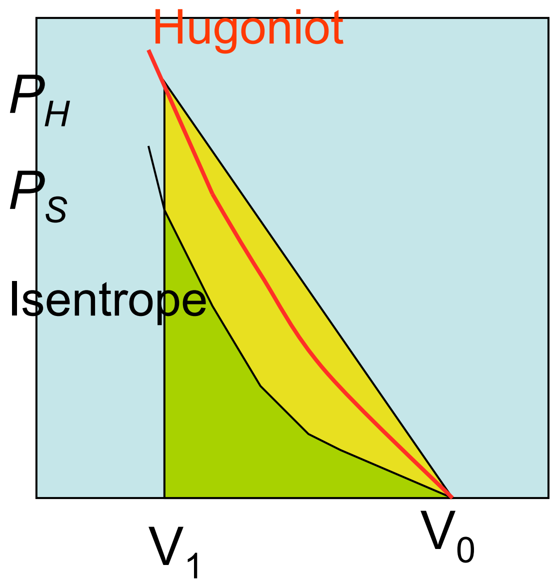
T_S : *temperature along the isentrope*

T_i : *initial temperature*

T_H : *shock temperature*

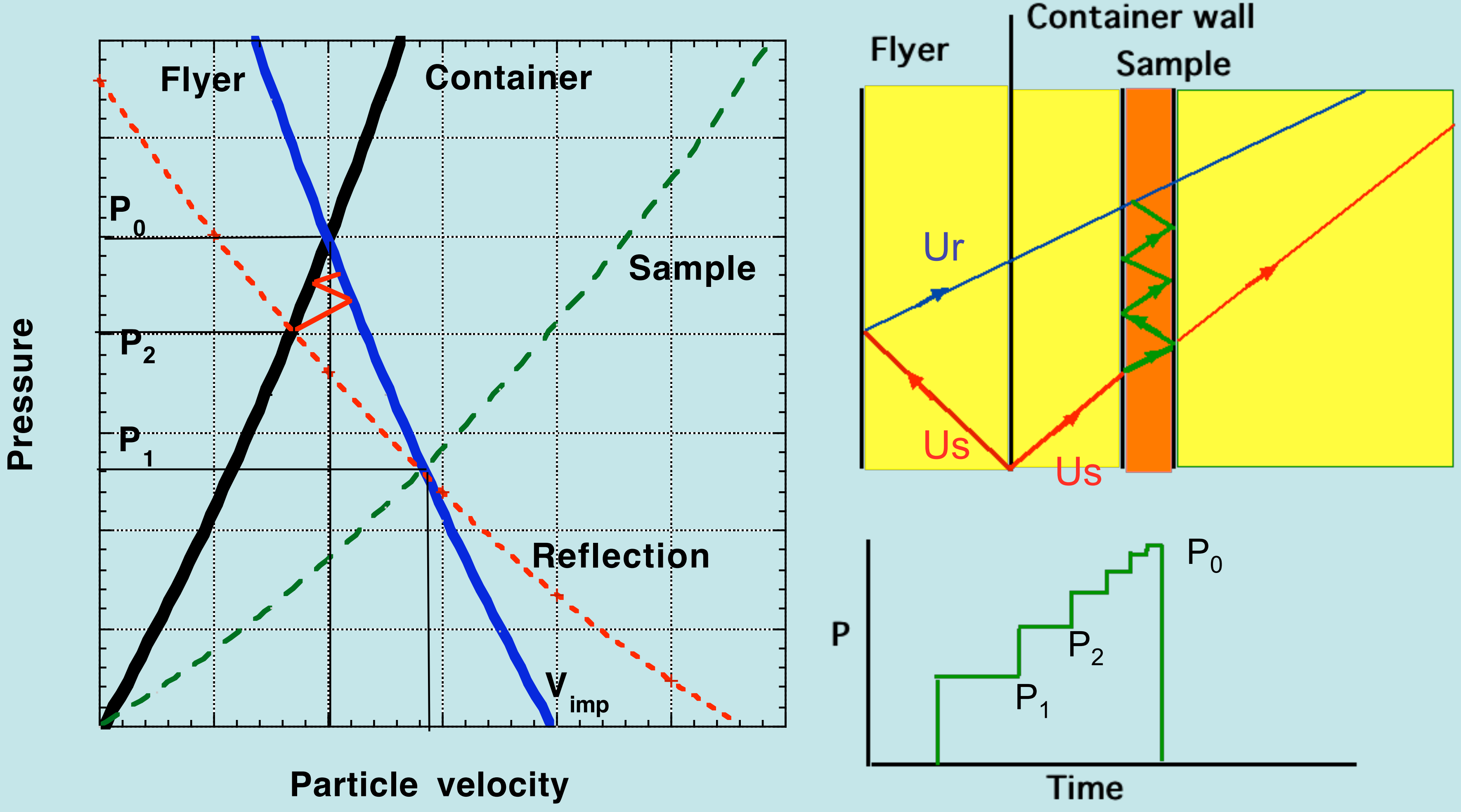
$$\frac{V}{\gamma}(P_H - P_S) = \int_{T_S}^{T_H} C_V \, dT$$

$$\frac{P_H}{2}(V_0 - V_1) = -\int_{V_0}^{V_1} P \, dV + \frac{V_1}{\gamma}(P_H - P_S) + E_{TR}$$



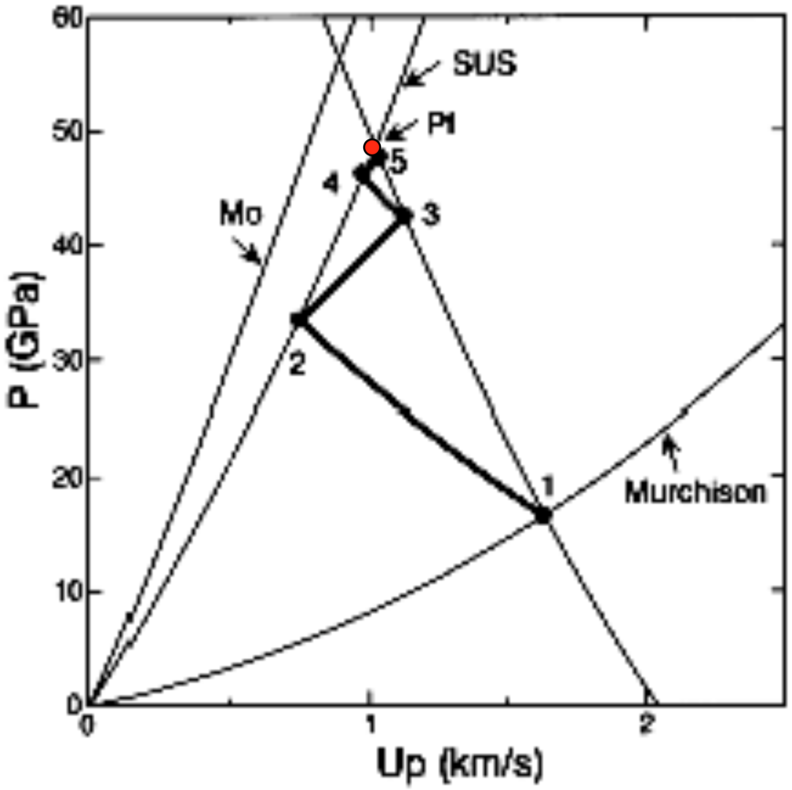
$$P = d_0 Up Us = d_0 Up(C_0 + SUp)$$

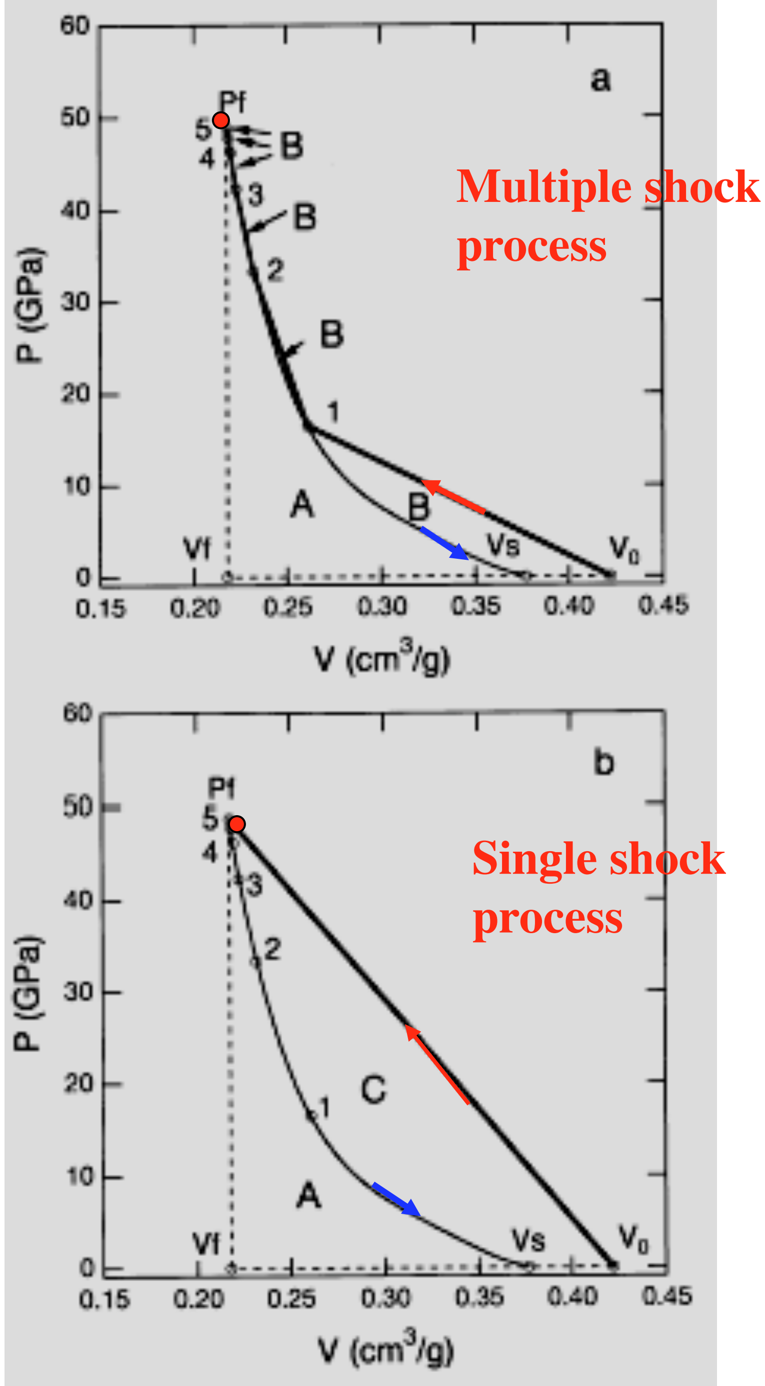
Impedance match diagram



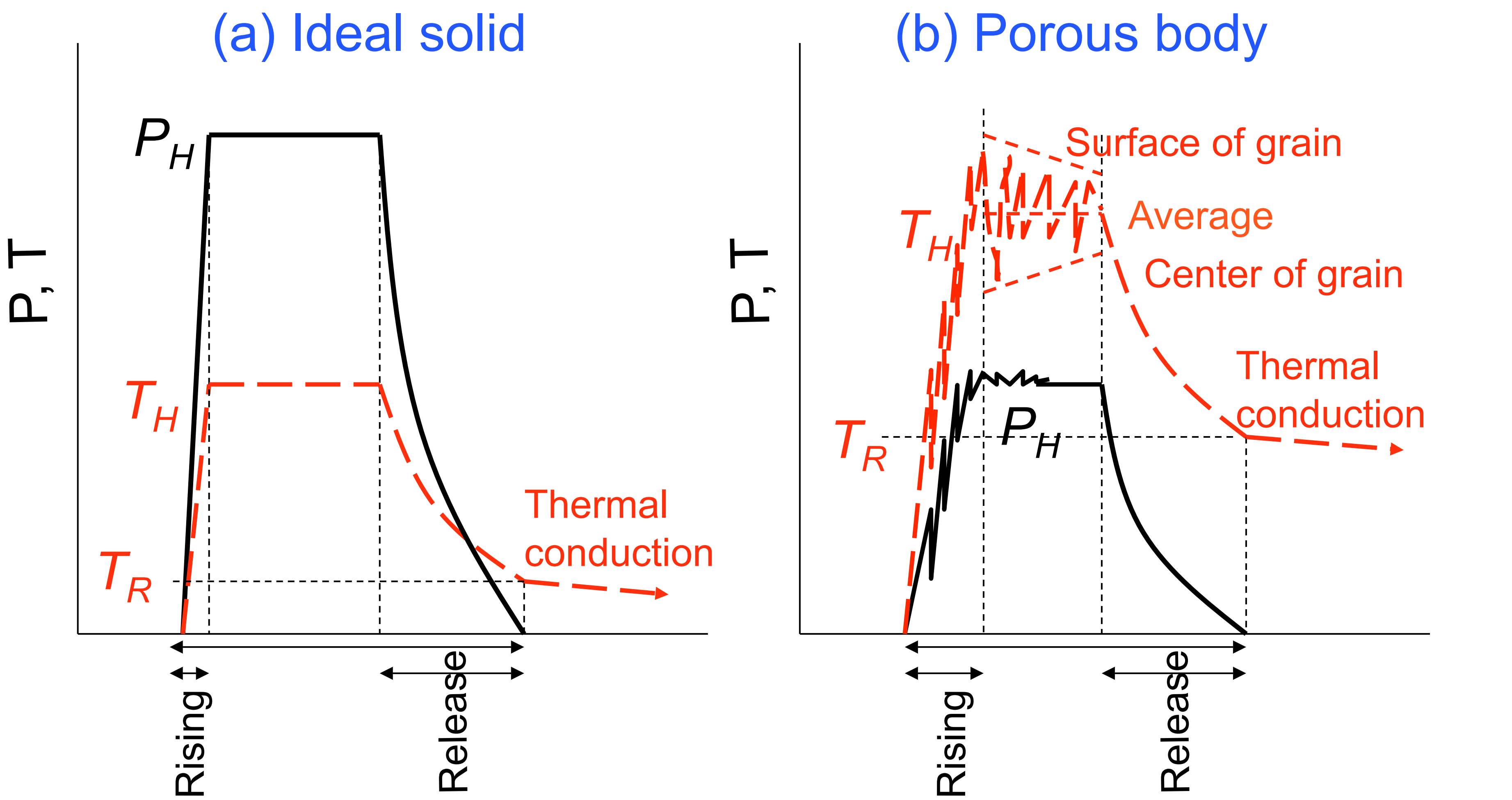
Shock pressure, internal energy, and residual temperature

(Porous samples)





PT profiles during impact process



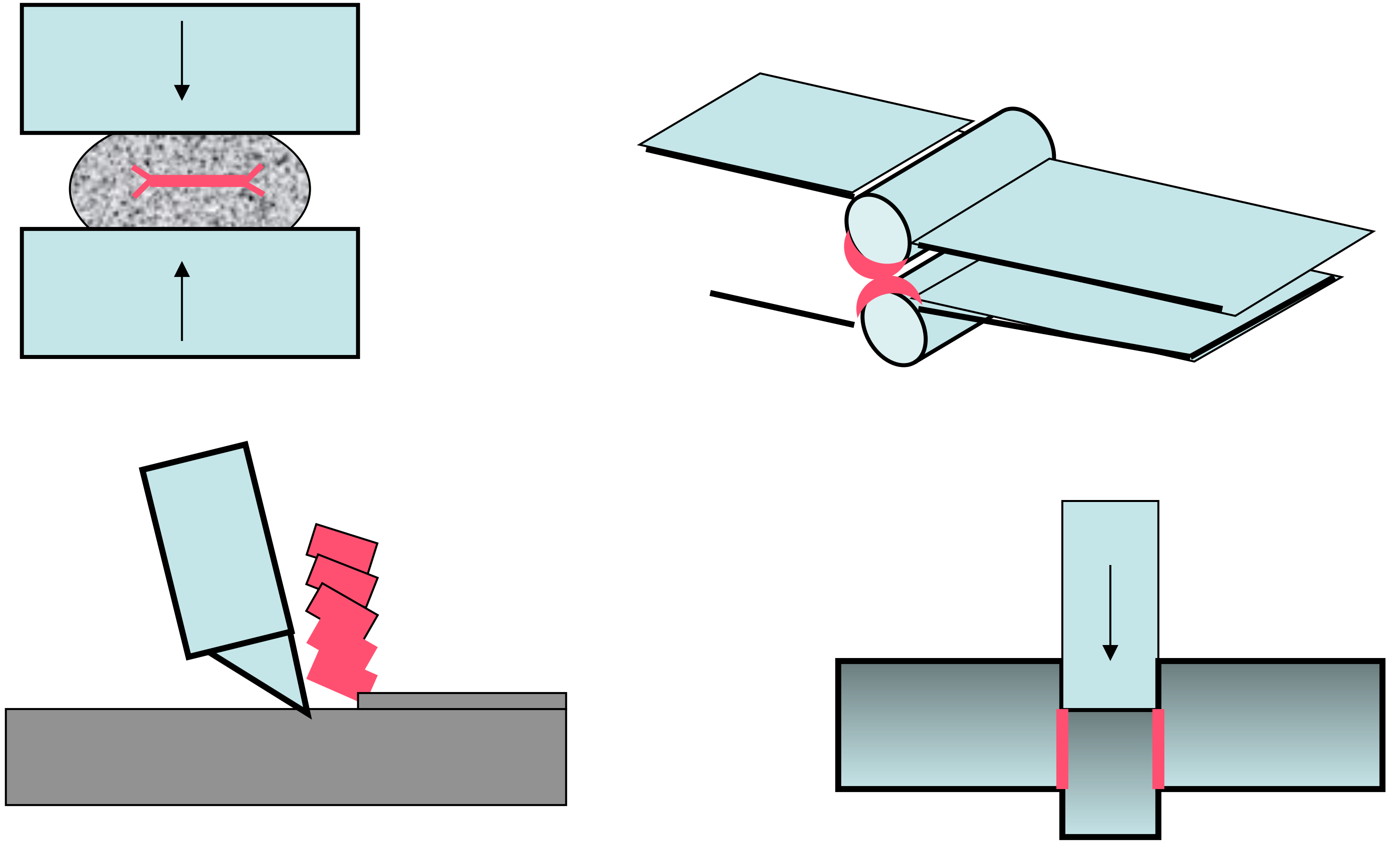
Shear Band

A region where plastic deformation in a material is highly concentrated

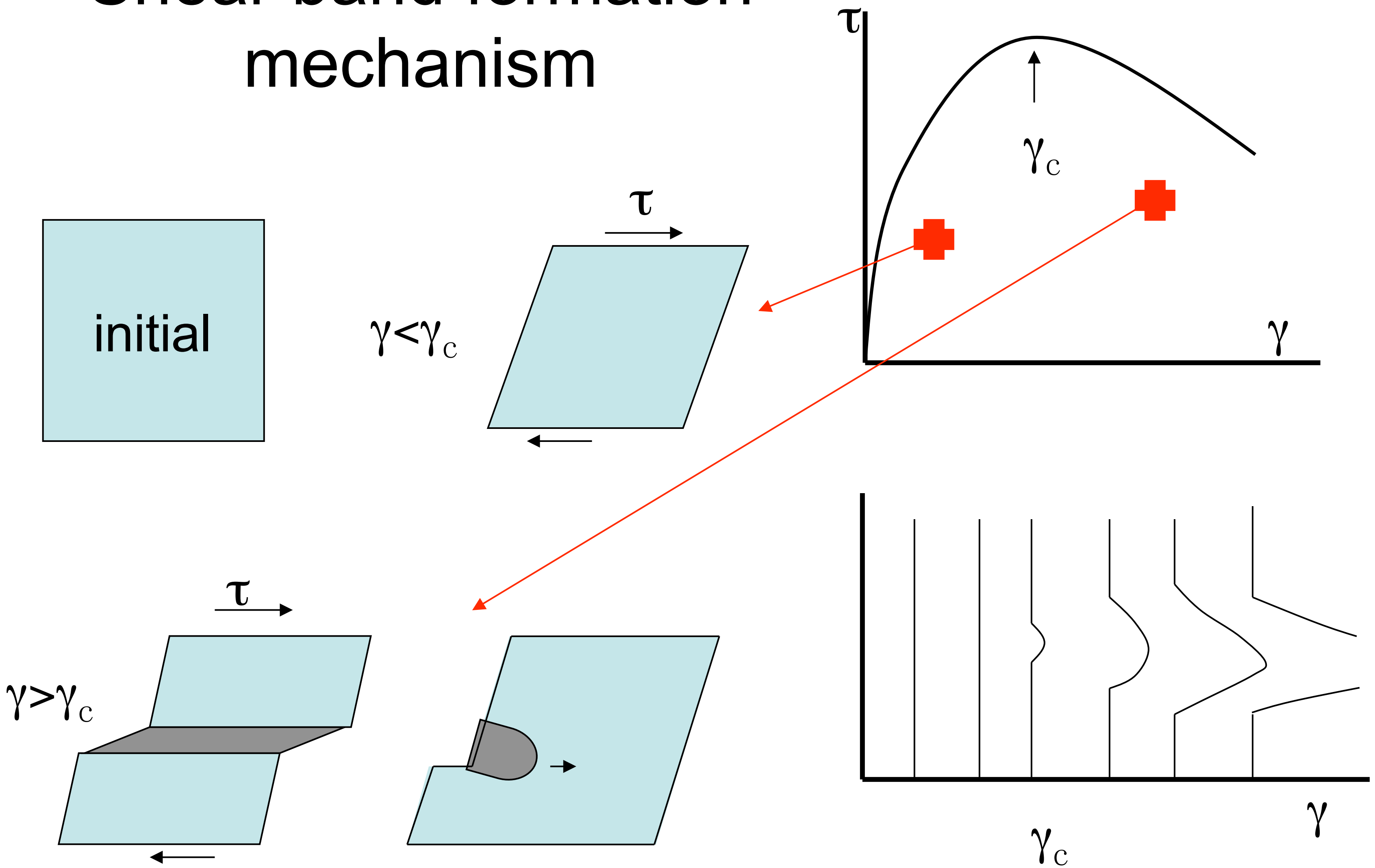
Fracture surface of a metallic glass along shear band (Chou & Spaepen, 1975)

- Ductile materials (metals, alloys, plastic, polymers, granular materials, and soils)
- Quasi-brittle materials (concrete, rock, ice, and some ceramics)
- not observed in brittle materials such as glass at room temperature

Shear bands



Shear band formation mechanism



Temperature increase by shear bands

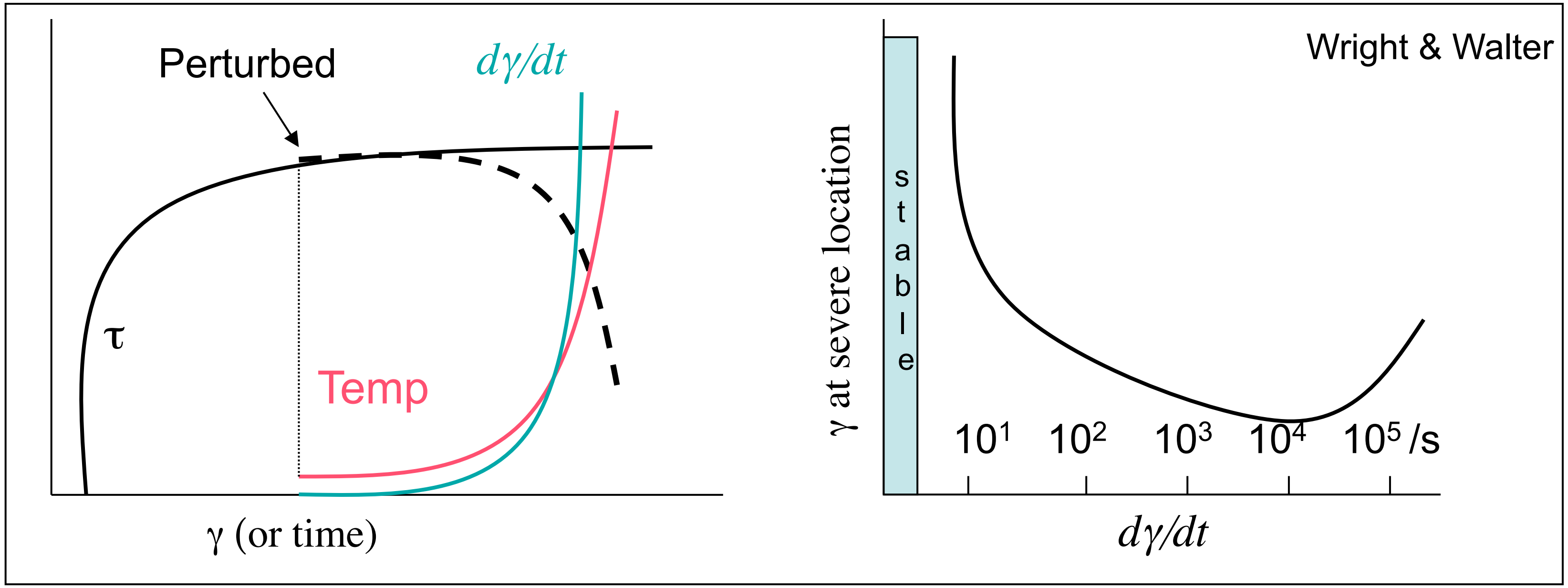
$$dW = \tau d\gamma$$

Stress τ, strain γ, work *W*

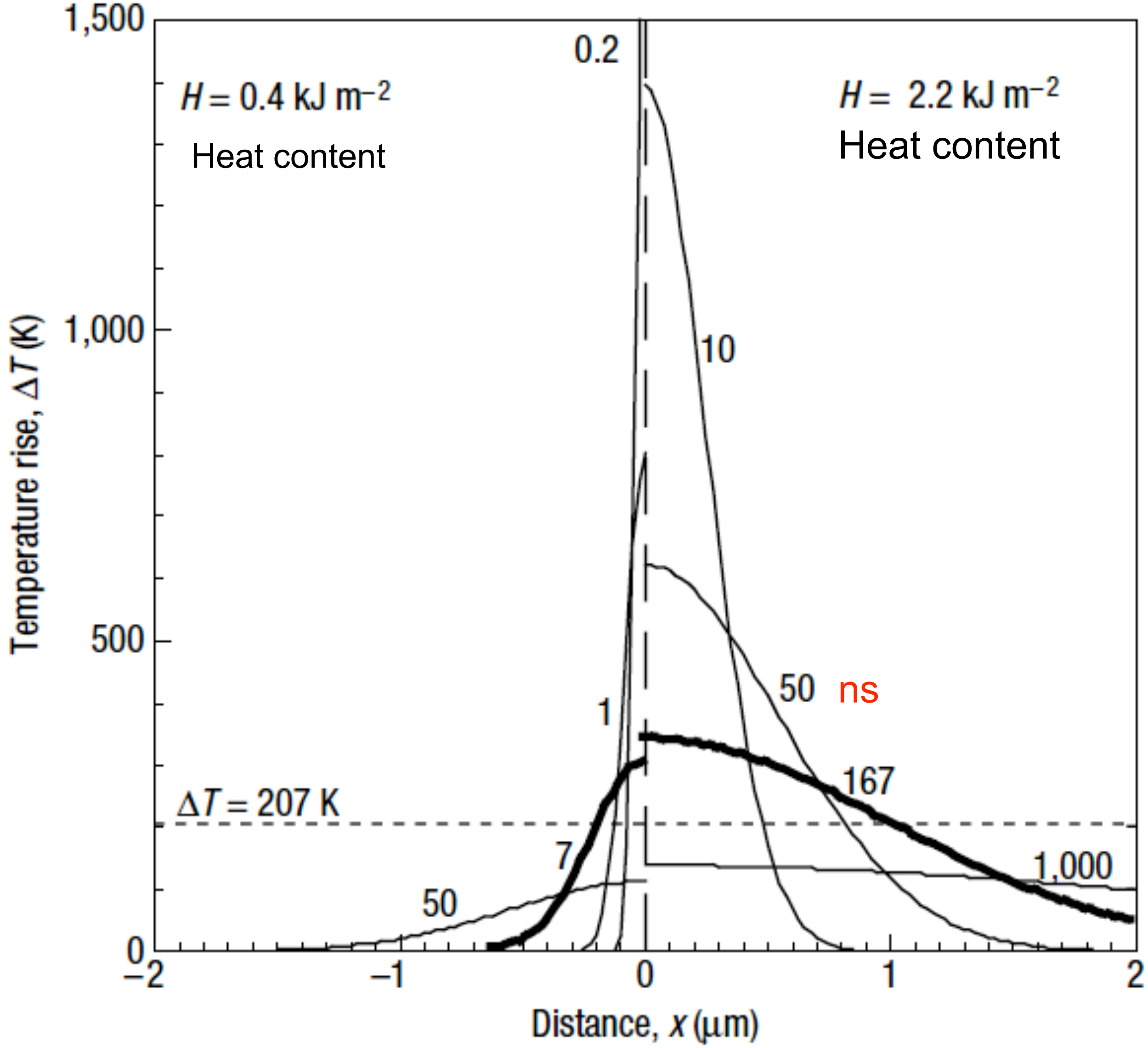
$$dT = \frac{\beta}{\rho C_v} dW = \frac{\beta}{\rho C_v} \tau d\gamma$$

Density ρ, heat capacity *Cv*
Efficiency of conversion of work β

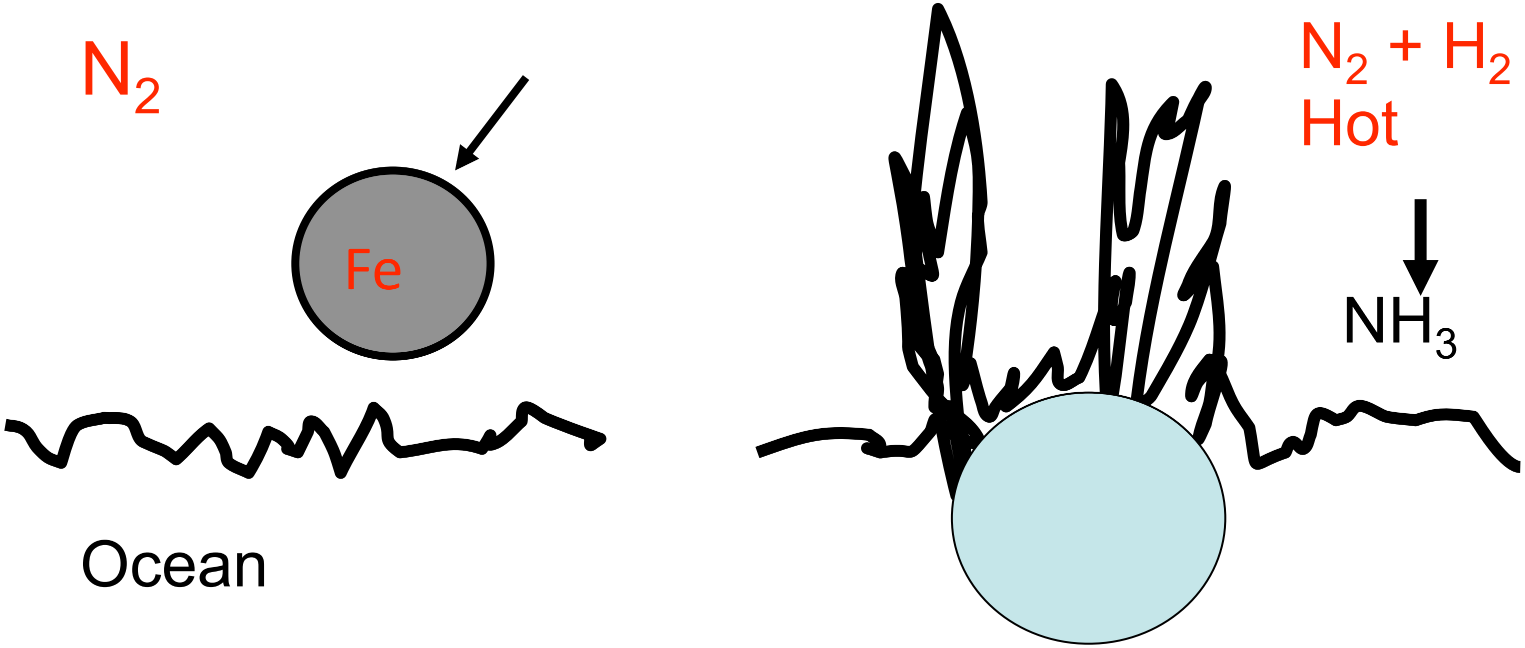
$$T = \frac{\beta}{\rho C_v} \int_0^\gamma \tau d\gamma$$



Local heating at a shear band, calculated by heat diffusion equation



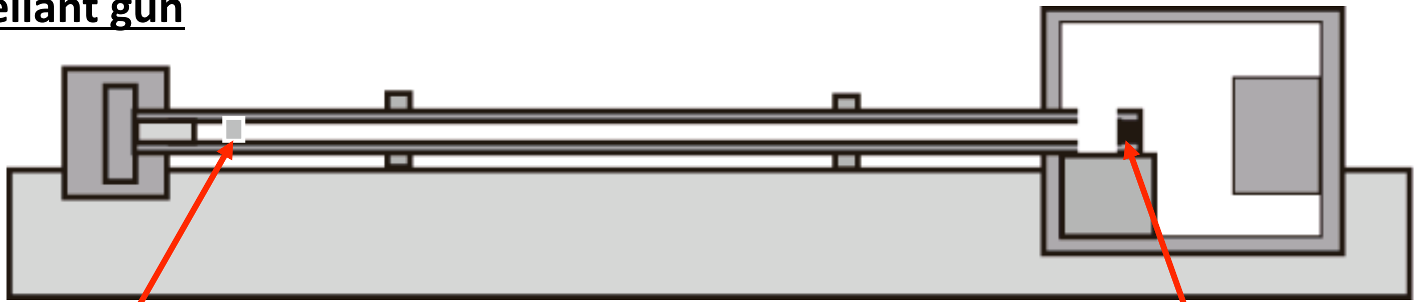
N_2 reduction to NH_3 by impacts



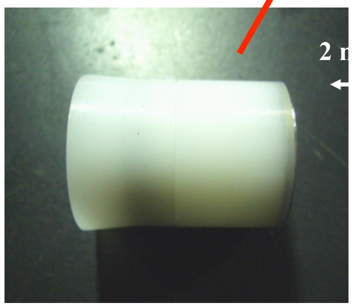
$Fe + H_2O = FeO + H_2$

Experimental method

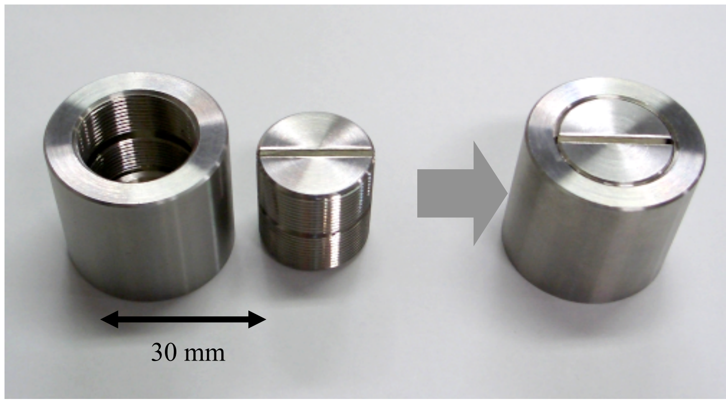
Propellant gun

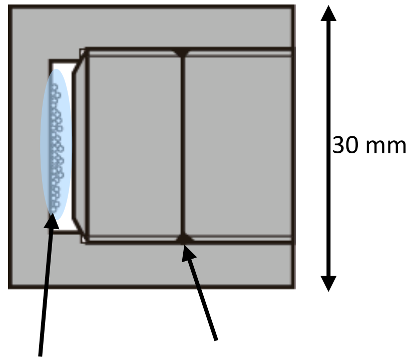


projectile



Container





Sample

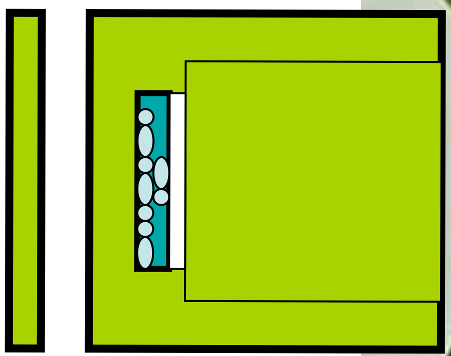
Pb gasket

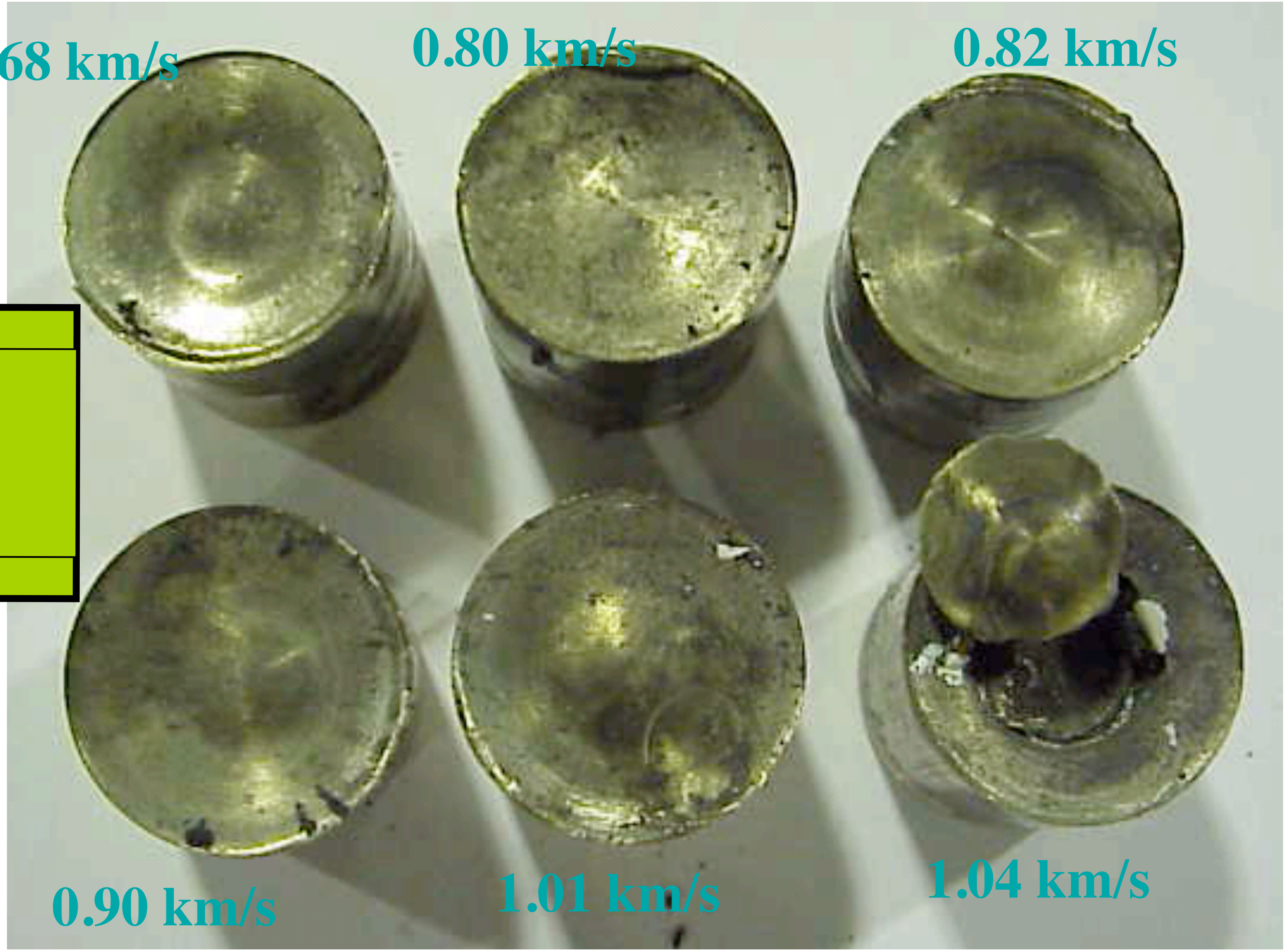
Sample

Fe, Ni, H_2O, N_2 (NH_3), ^{13}C (Solid)

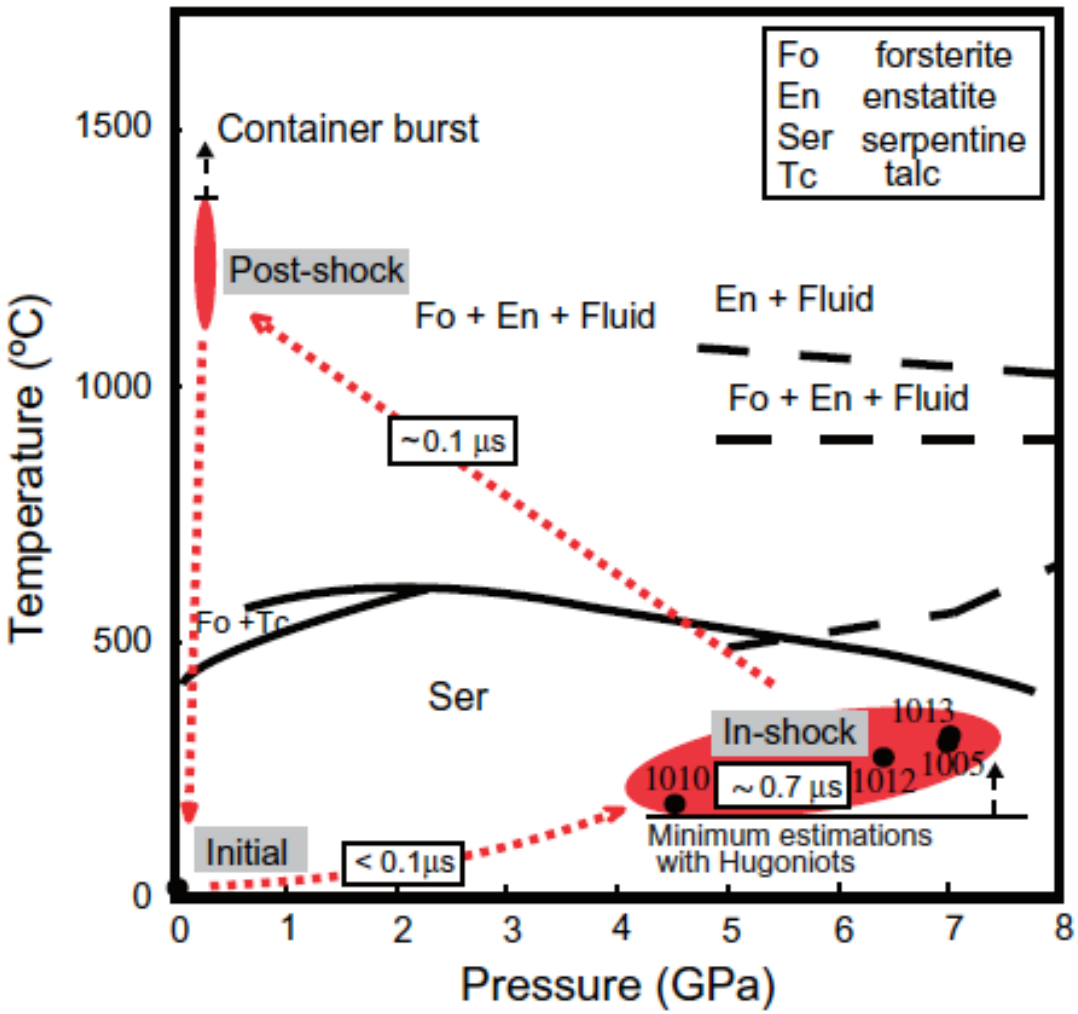
Shock P; 6 GPa, duration; 0.7 μs、T; 5,000～3,000 K

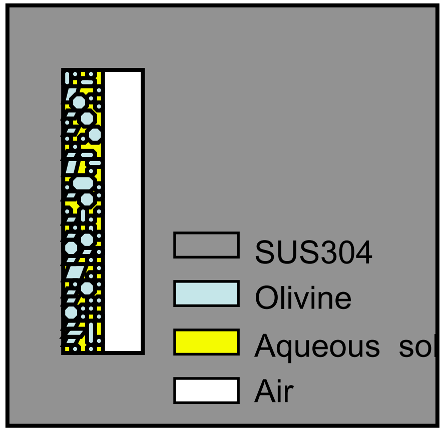
Containers to recover aqueous solutions

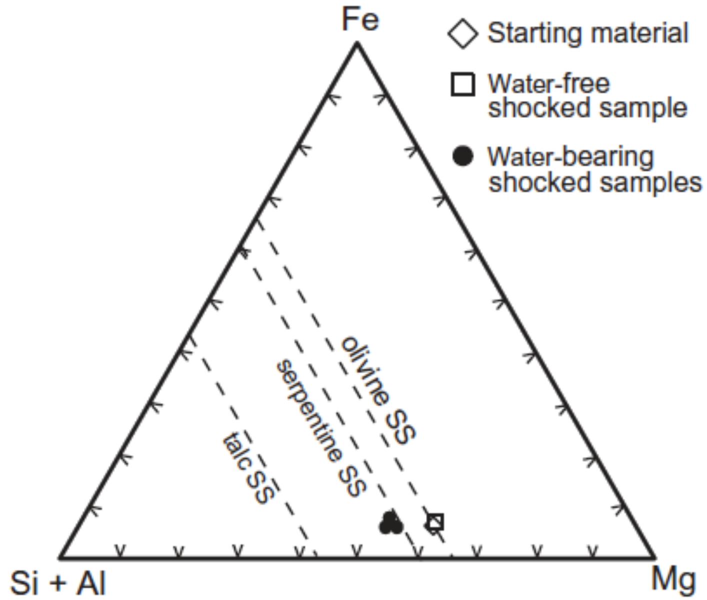




Shock process in Ol + H_2O







Summary

- HV impacts generate shock wave and rarefaction wave in materials at high strain rates
- They affect the state with a time lag, and interact each other to change local conditions of P and T
- The initial physical state of target is important, but in most case remains unknown
- Crystal sliding systems and pore distribution in the initial state generate higher T locally
- Adiabatic shear bands may play a key role to form shock veins where the T is locally higher than that of the host rock