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High temperature mechanical properties of zirconium diboride

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A deformation mechanism map for ZrB_2

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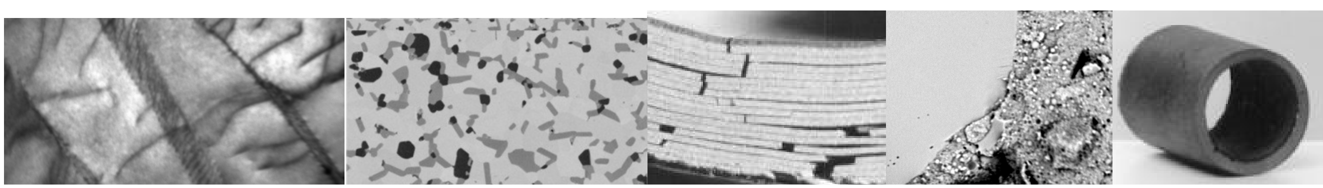
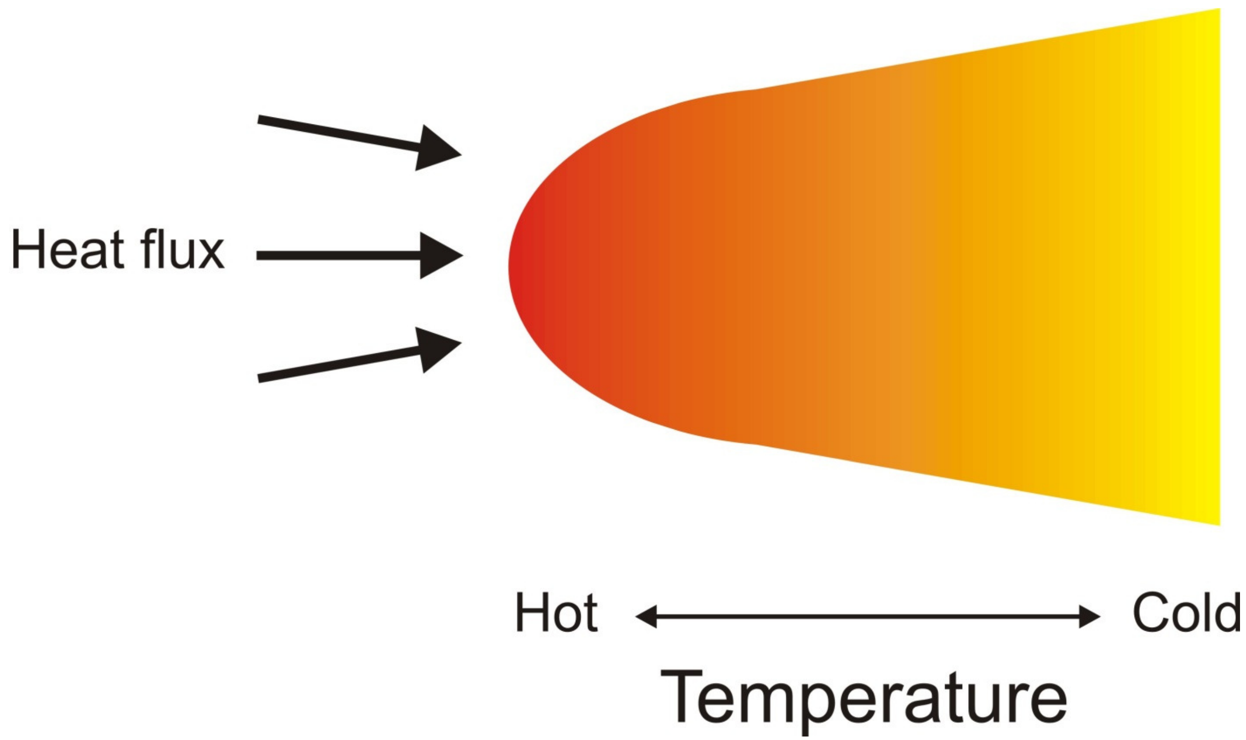
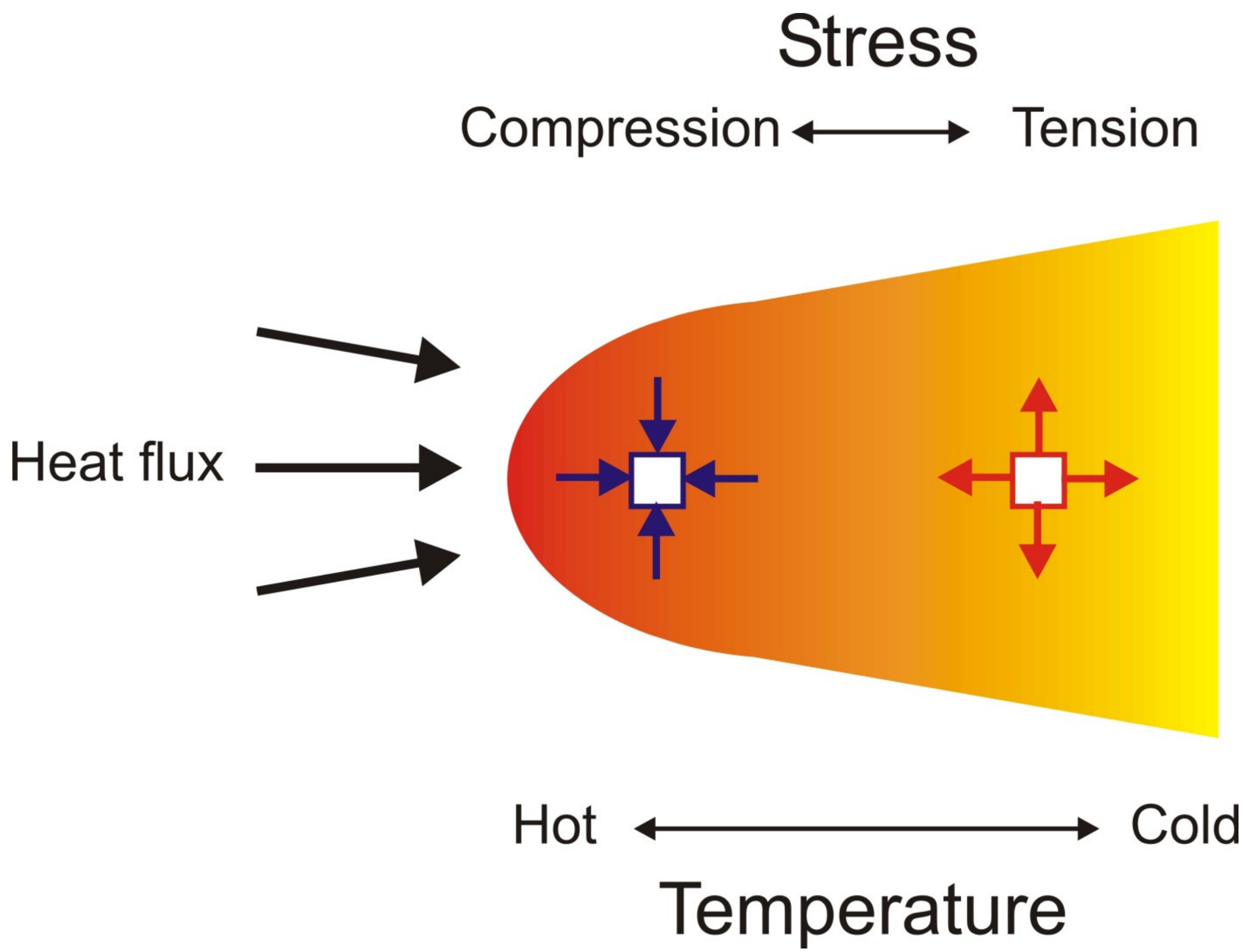


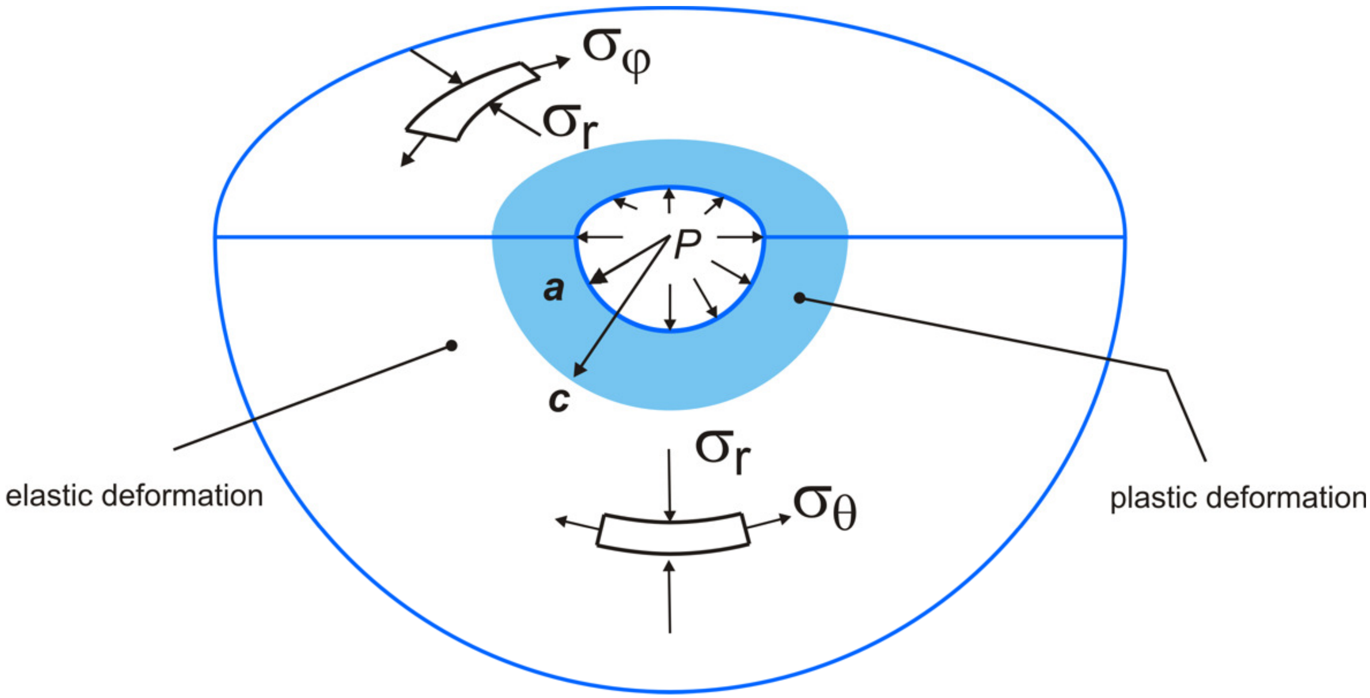
Introduction



Introduction



Hardness and yield strength

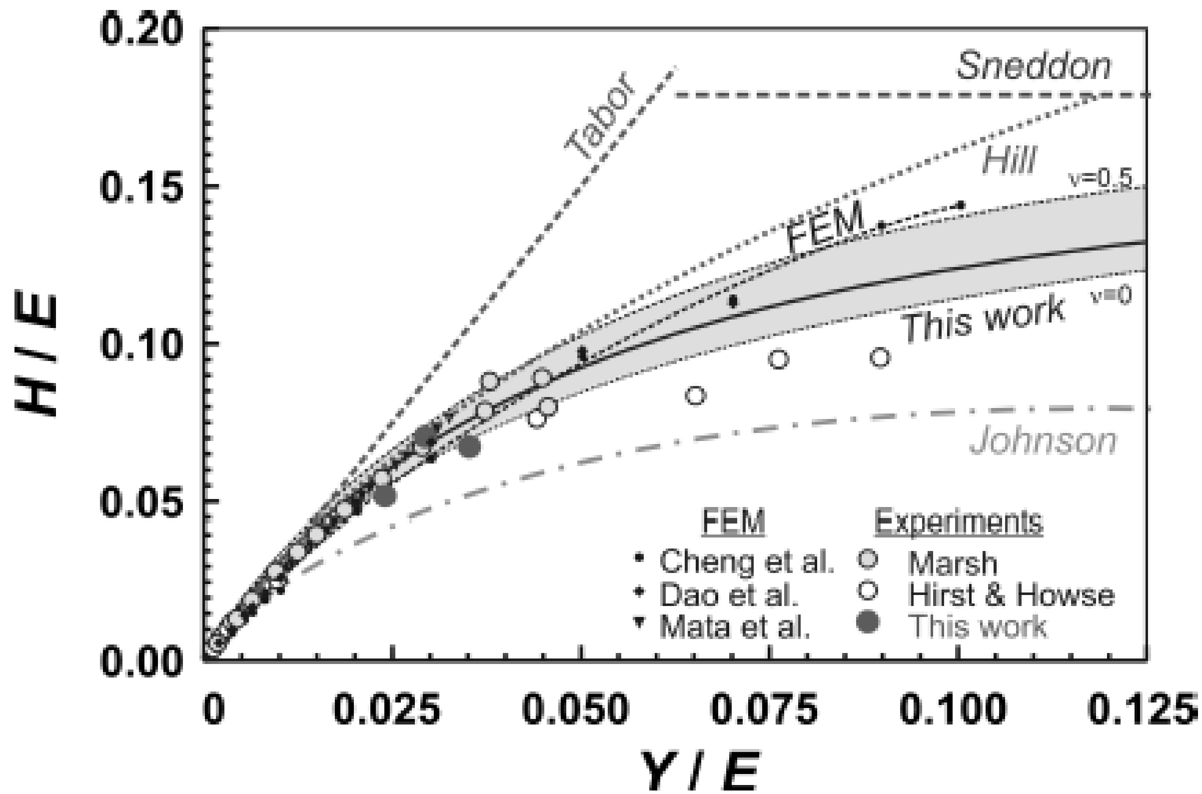


$$H \equiv P = \frac{2}{3}Y + 2Y\ln\left(\frac{c}{a}\right)$$

$$\frac{c}{a} \approx \sqrt[3]{\frac{E}{3Y(1-\nu)}}$$

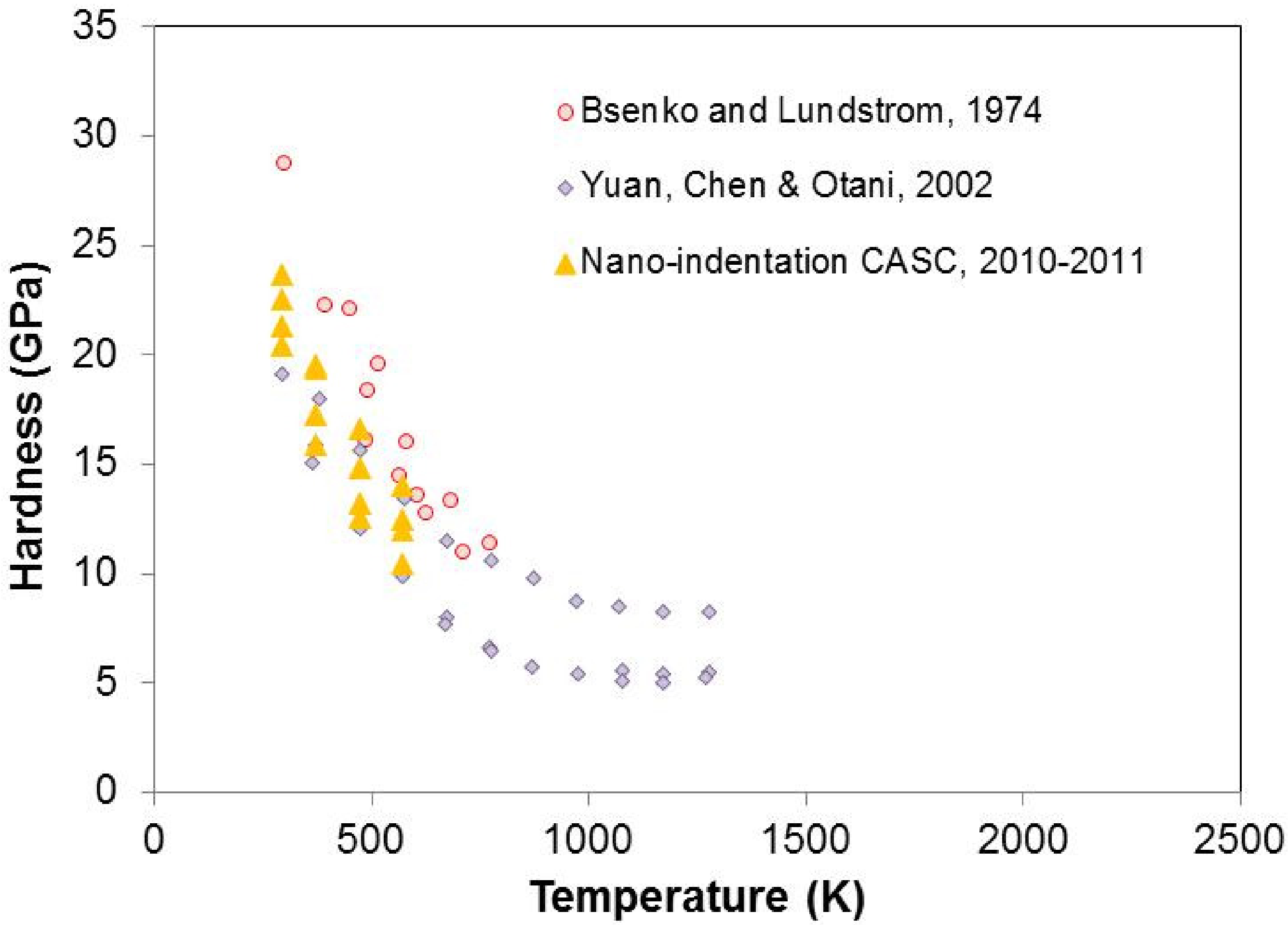
Hill, R. (1950). <u>The Mathematical Theory of Plasticity</u>, Oxford Clarendon Press.

Hardness versus yield strength

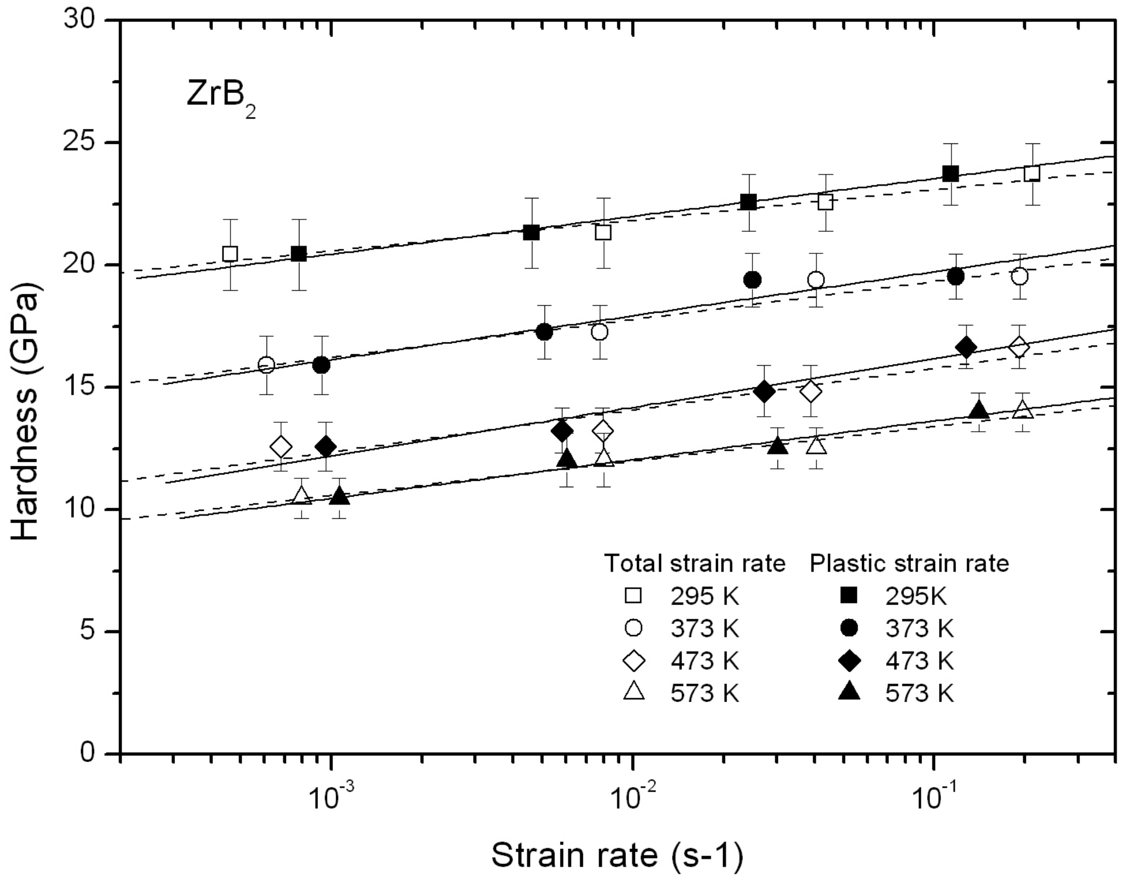


Vandeperre, L.J., F. Giuliani, and W.J. Clegg, Effect of elastic surface deformation on the relation between hardness and yield strength. Journal of Materials Research, 2004.

Hardness versus temperature



Hardness versus strain rate



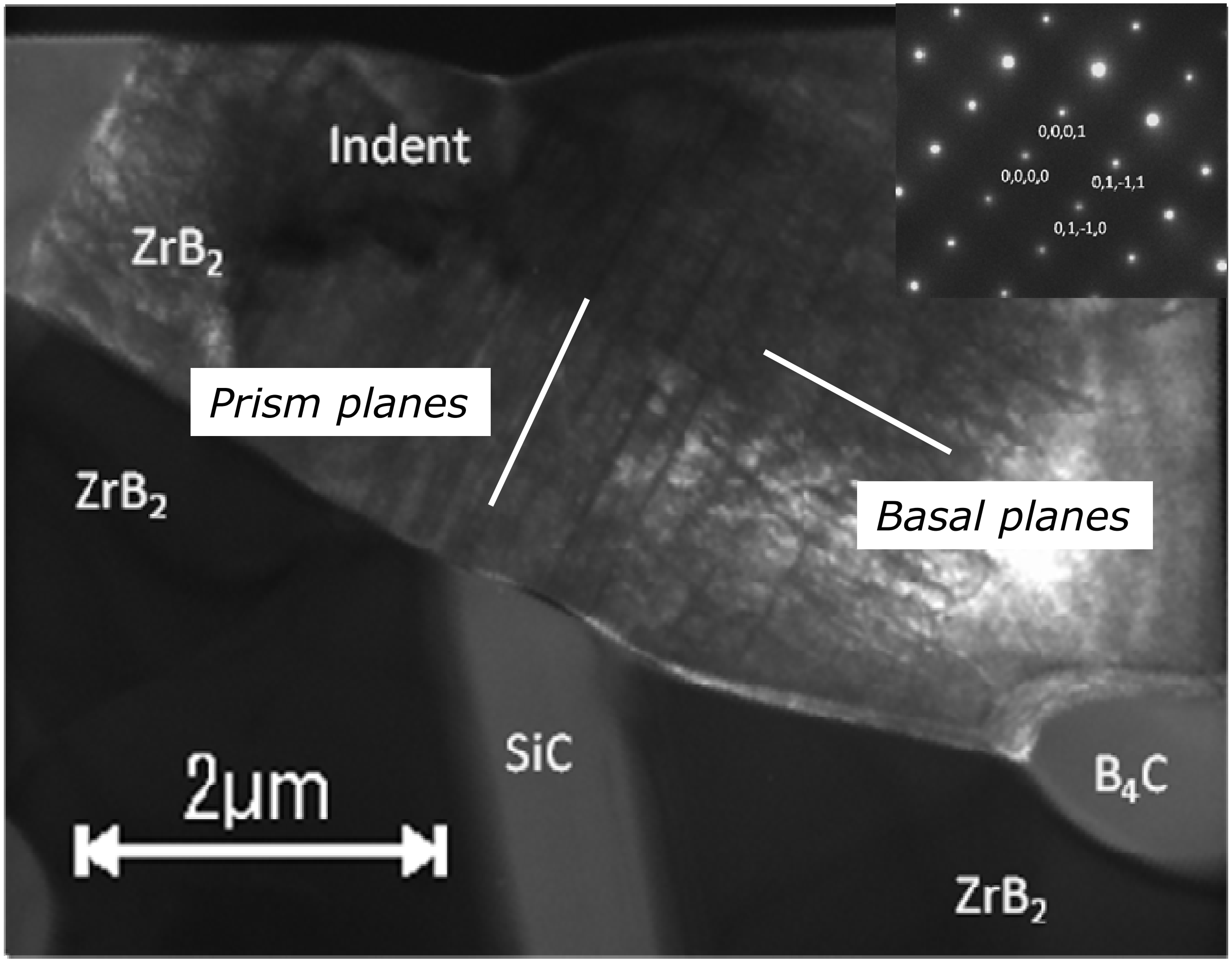
Peierls' stress
6.6 GPa

Activation energy
1.61 eV

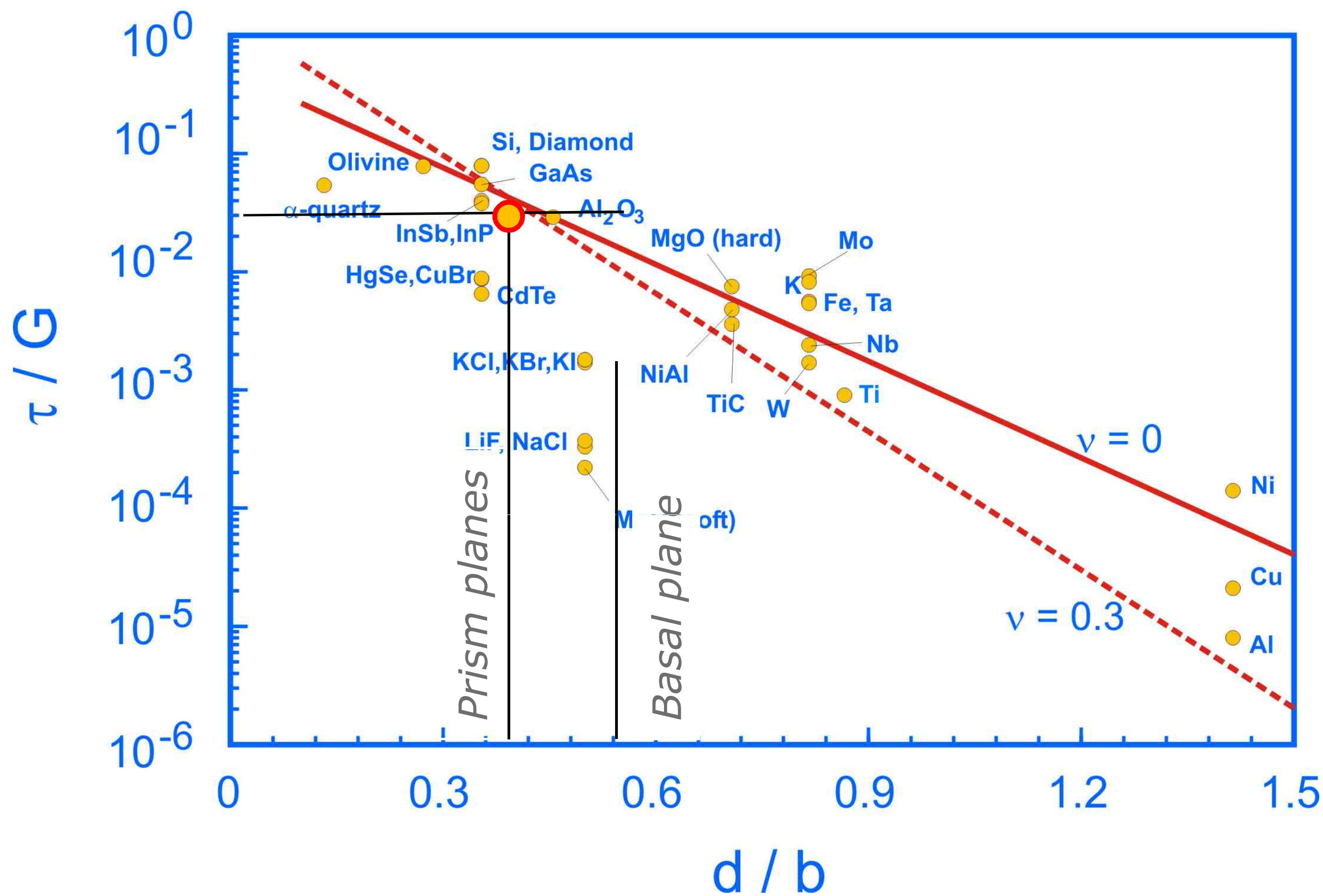
Activation volume
~ 1-2 b^3

V. Bhakhri, K. Ciurea, J. Wang, N. Ur-rehman, F. Giuliani, L.J. Vandeperre, Instrumented Nanoindentation Investigation into the Mechanical Behaviour of Ceramics at Moderately Elevated Temperatures, J. Mat. Res., 2011

TEM observations near indentations 298 K



Comparing with Peierls' prediction lattice resistance



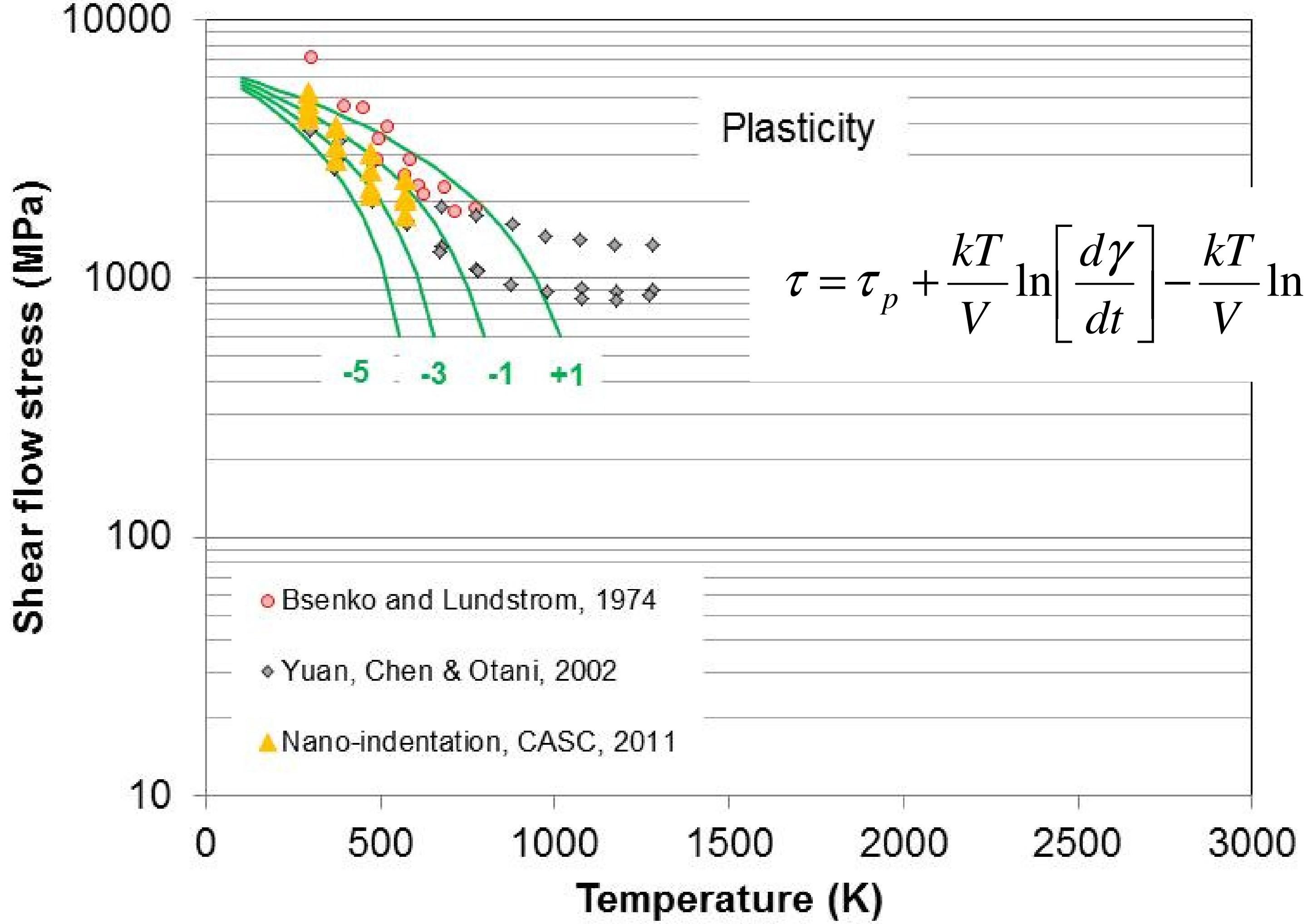
Peierls, E., Proc. Phys. Soc., ***52****: 34-37 (1940)*
Clegg, W.J., unpublished

Deformation mechanisms ?

LOW TEMPERATURE

- Glide
  - Controlled by lattice resistance
    - » Decays rapidly due to low activation energy

Deformation mechanism map



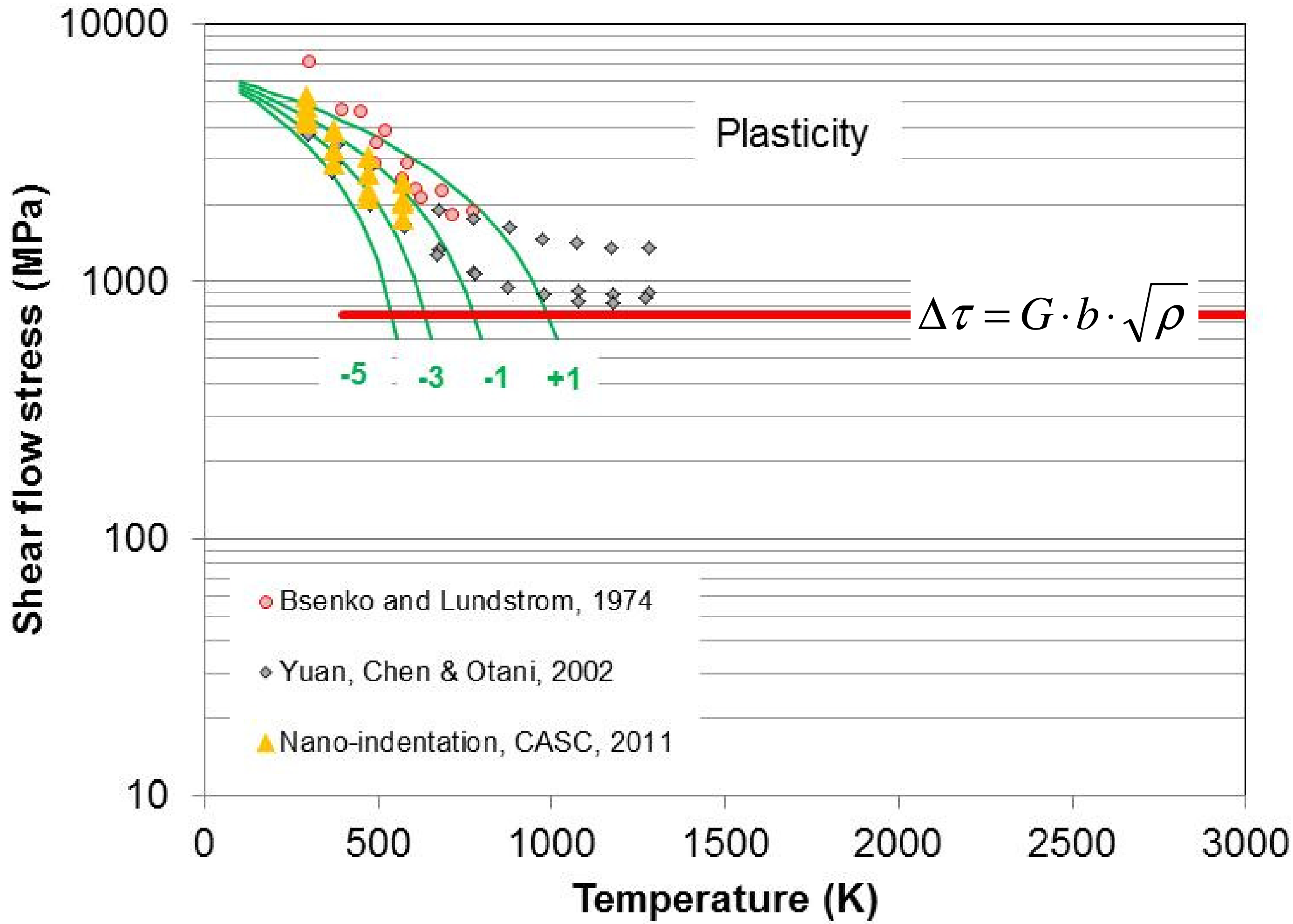
$$\tau = \tau_p + \frac{kT}{V}\ln\left[\frac{d\gamma}{dt}\right] - \frac{kT}{V}\ln\left[\rho_m \cdot b^2 \cdot \upsilon\right]$$

Deformation mechanisms ?

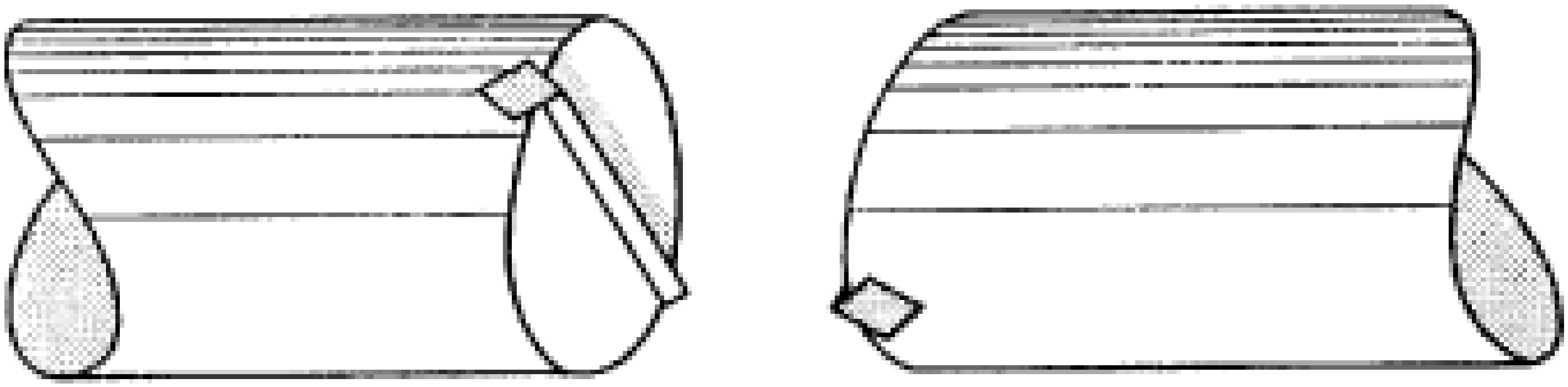
LOW TEMPERATURE

- Glide
  - Controlled by lattice resistance
    - » Decays rapidly due to low activation energy
  - Controlled by microstructure
    - » strain hardening (other dislocations)
    - » solid solutions
    - » grain size (Hall-Petch)
    - » second phase particles

Deformation mechanism map

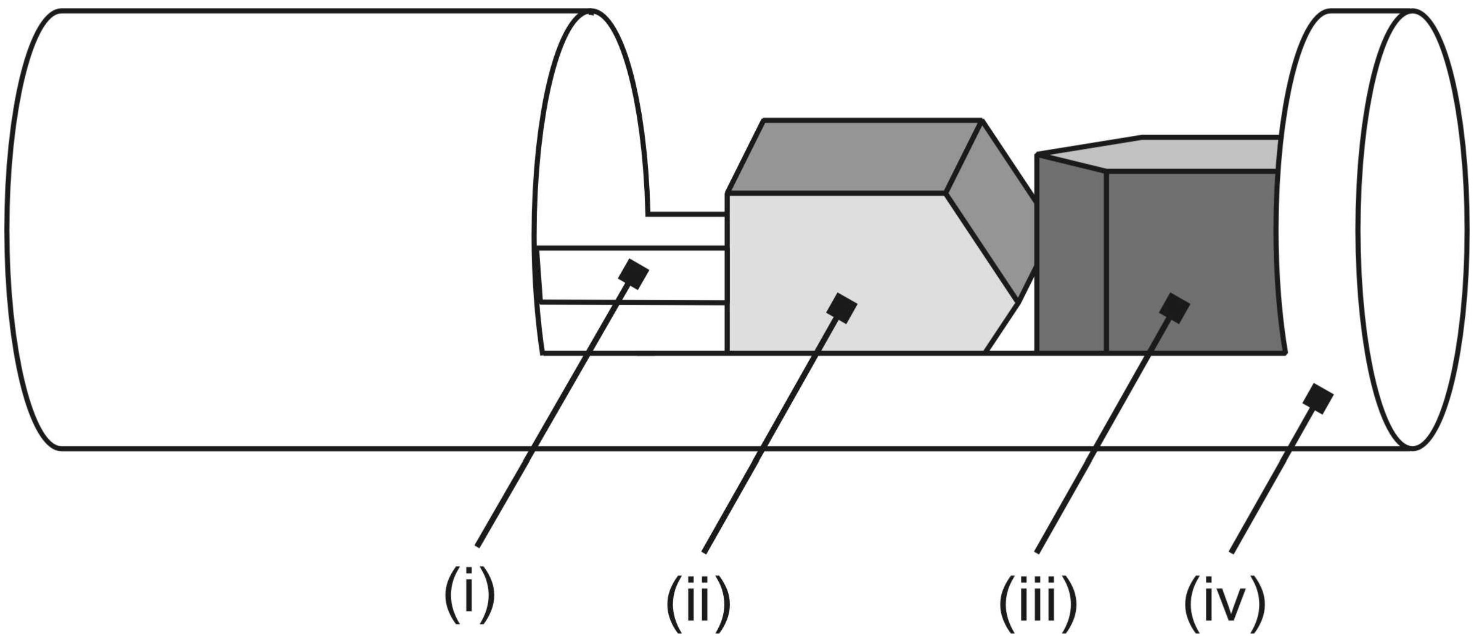


Self-indentation via cross-bar arrangement



Atkins, A. G. and D. Tabor (1966). Proc. R. Soc. ***A292****: 441-459*

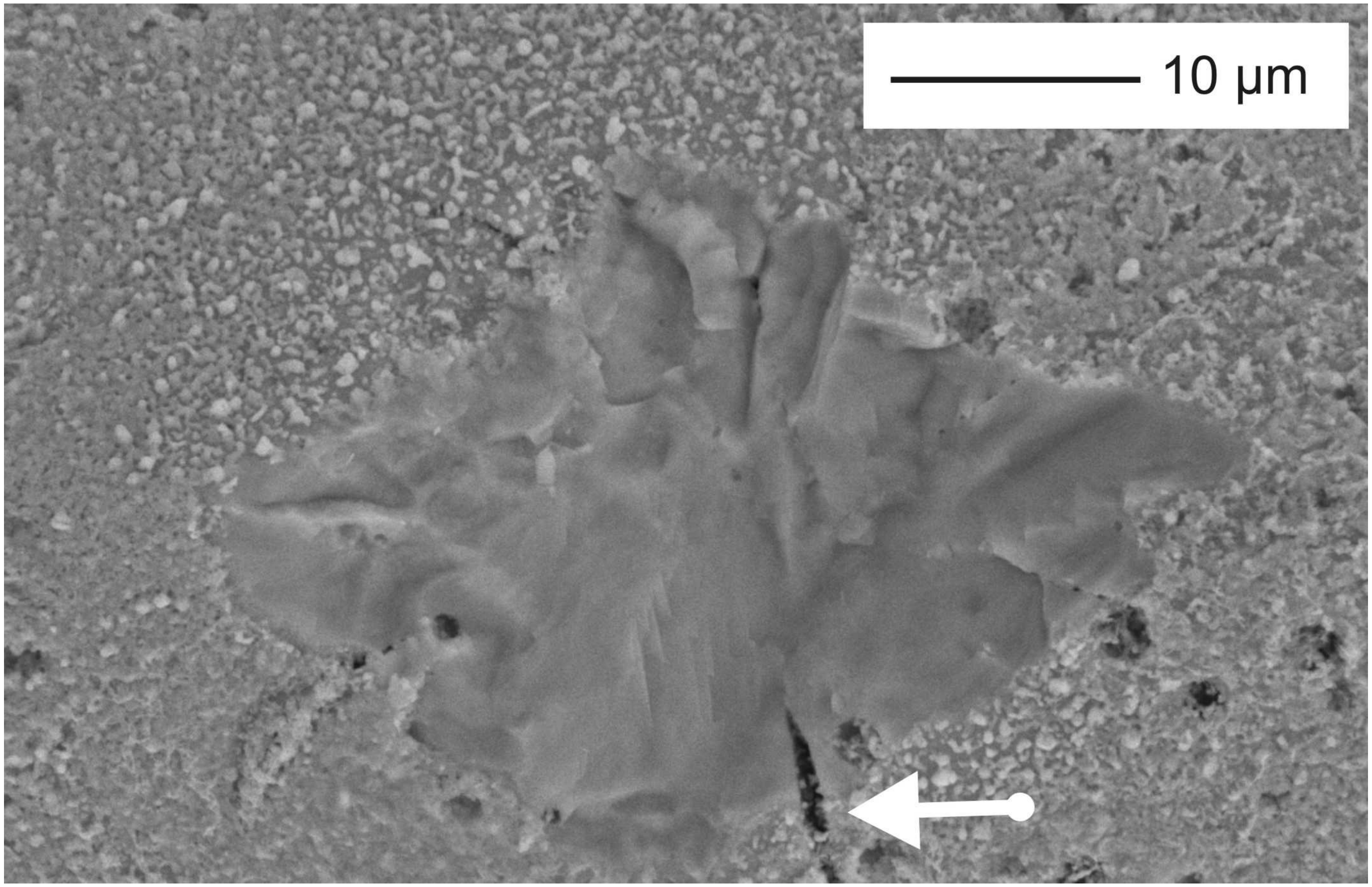
Experimental



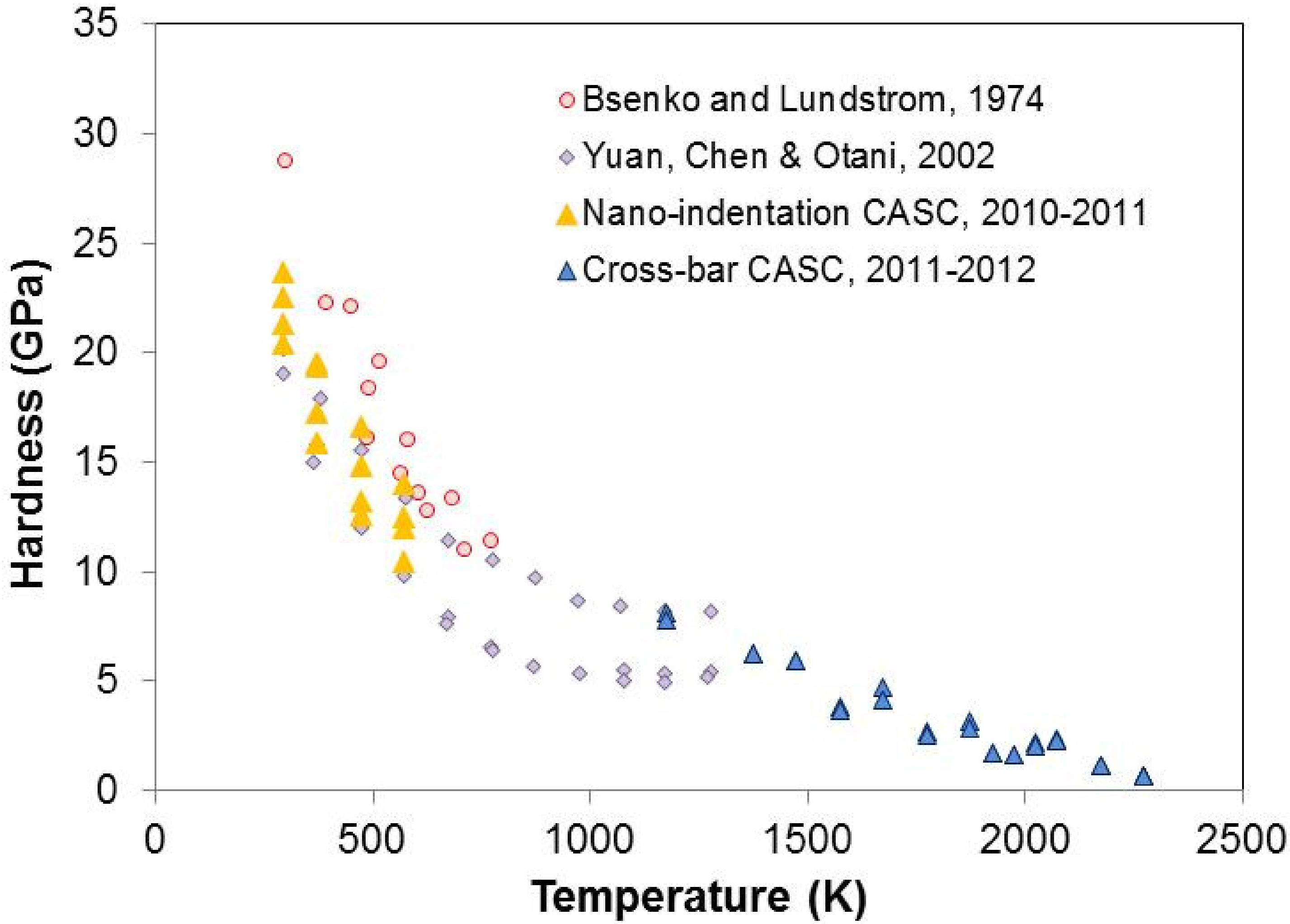
(i) Dilatometer push-rod, (ii),(iii) samples, (iv) dilatometer tube

Experiments on ZrB_2

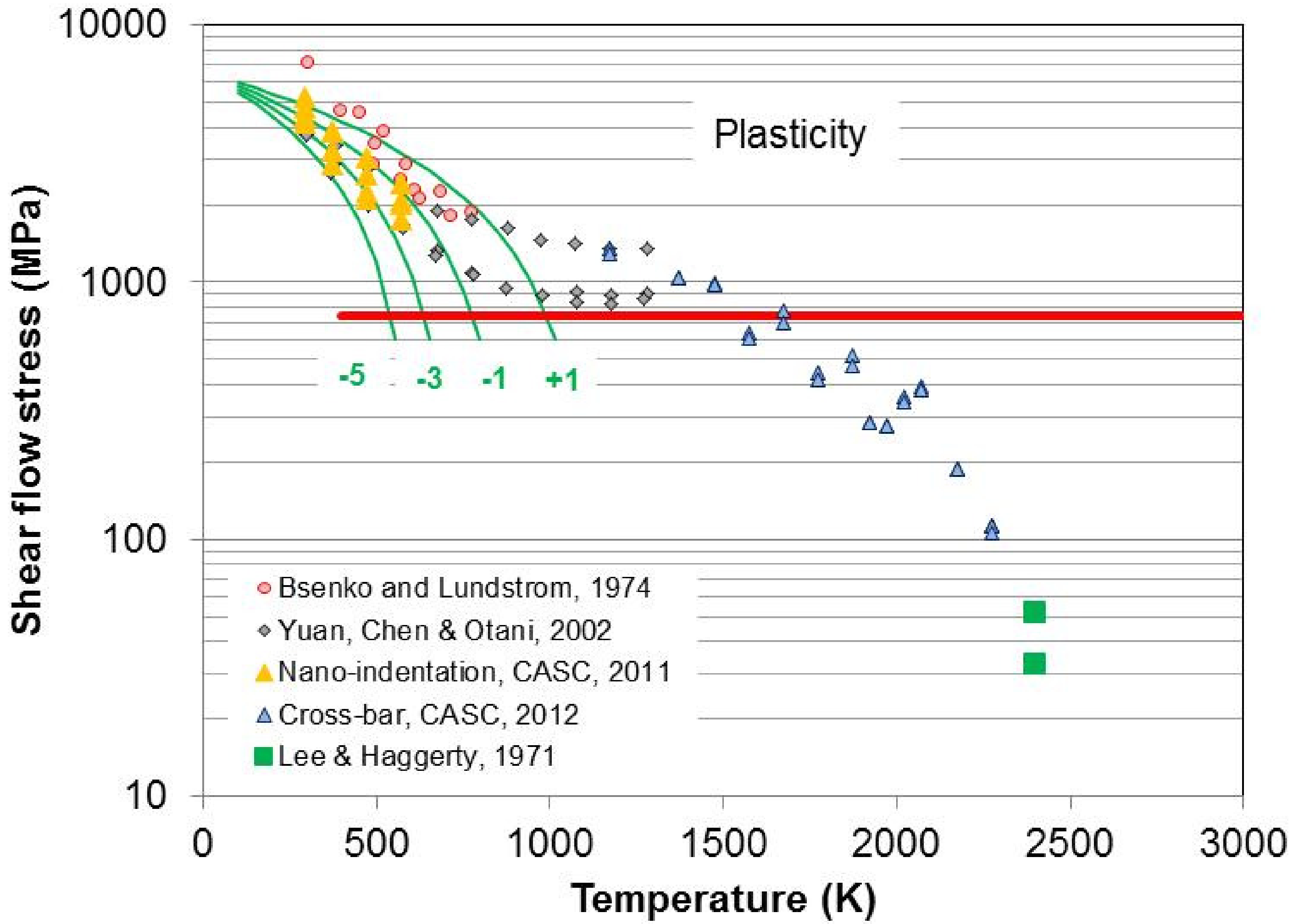
1873 K



Hardness versus temperature



Shear flow stress versus temperature



Deformation mechanisms ?

HIGH TEMPERATURE

- Creep
  - Transport of matter by dislocations
    - » Power-law creep
      - ▪ Climb controlled glide

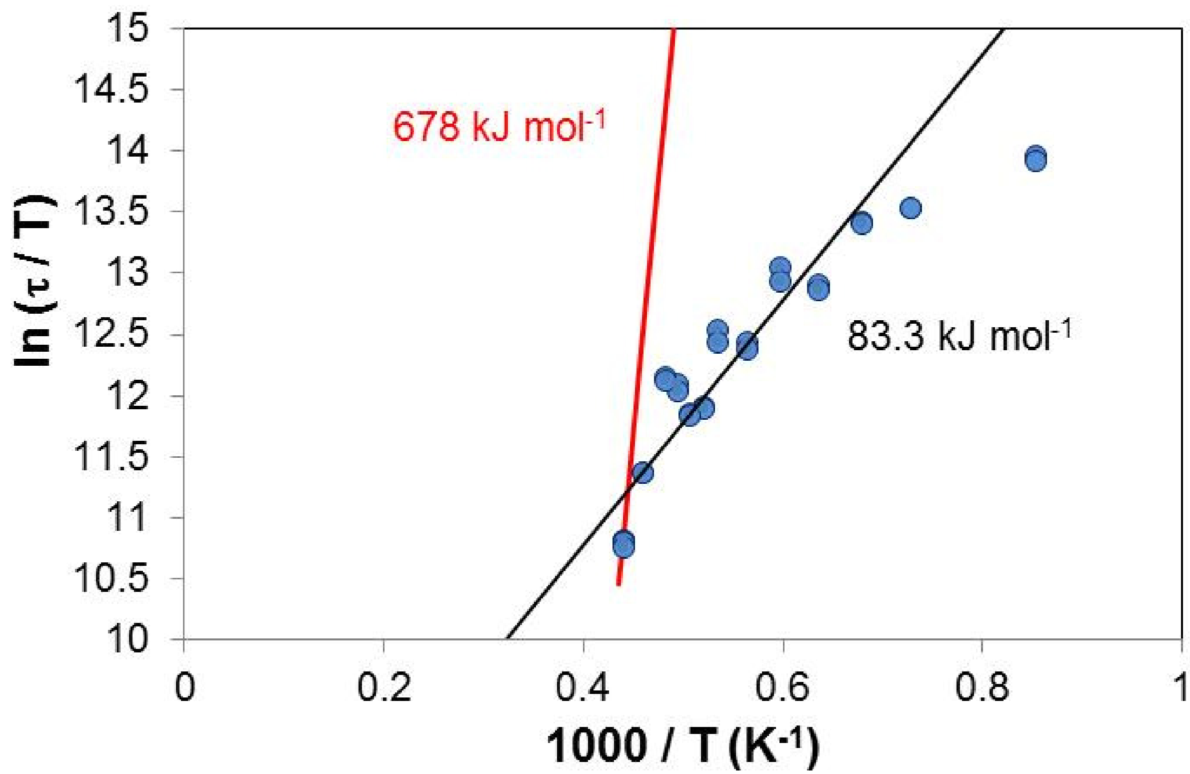
$$\tau = G \cdot \left(\frac{\gamma^{\bullet} \cdot k \cdot T}{A_2 \cdot D_v \cdot G \cdot b} \right)^{1/n}$$

  - Transport of matter by diffusion
    - » Nabarro-Herring creep
      - ▪ Bulk diffusion
    - » Cobble creep
      - ▪ Grain boundary diffusion

$$\tau = \frac{\gamma^{\bullet} \cdot k \cdot T \cdot d^2}{42 \cdot \Omega \cdot D_{eff}}$$

Activation energy from variation with temperature

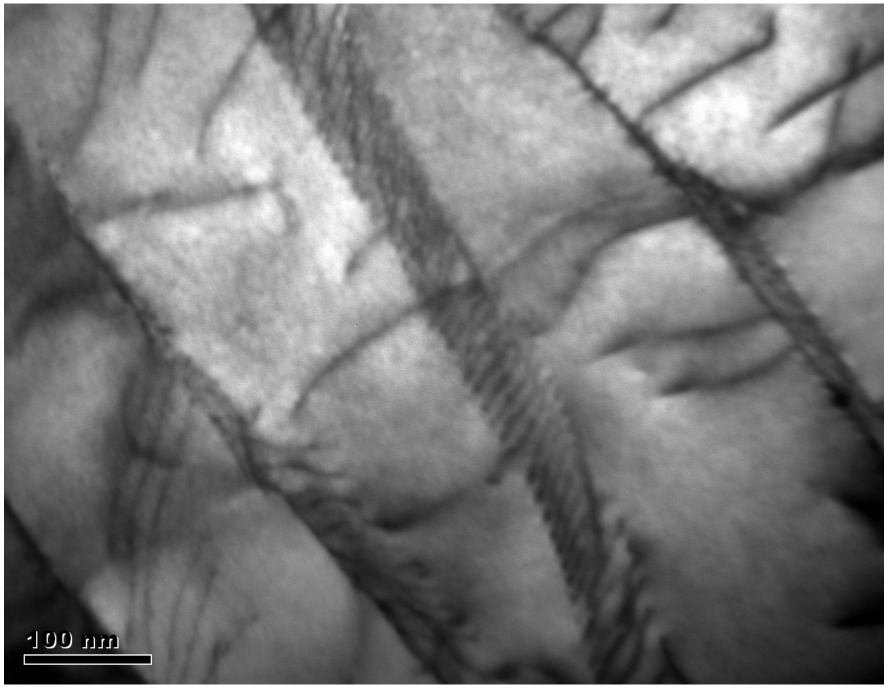
Nabarro – Herring creep : $\ln\left(\frac{\tau}{T}\right) = \ln\left[\frac{\gamma^{\bullet} \cdot k \cdot d^2}{42 \cdot \Omega \cdot D_{b0}}\right] + \left(\frac{Q_{bd}}{k}\right) \cdot \frac{1}{T}$



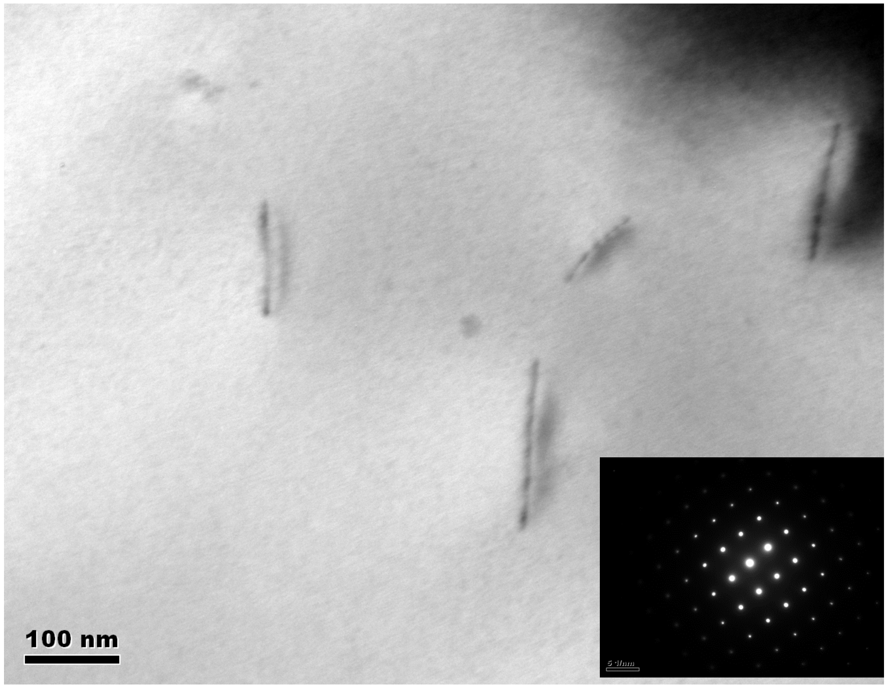
Activation energy for bulk diffusion 678 kJ mol^{-1}
Kislyi, P.S. and M.A. Kuzenkova, Poroshkovaya Metallurgiya, 1966

TEM observation of deformation

1773 K

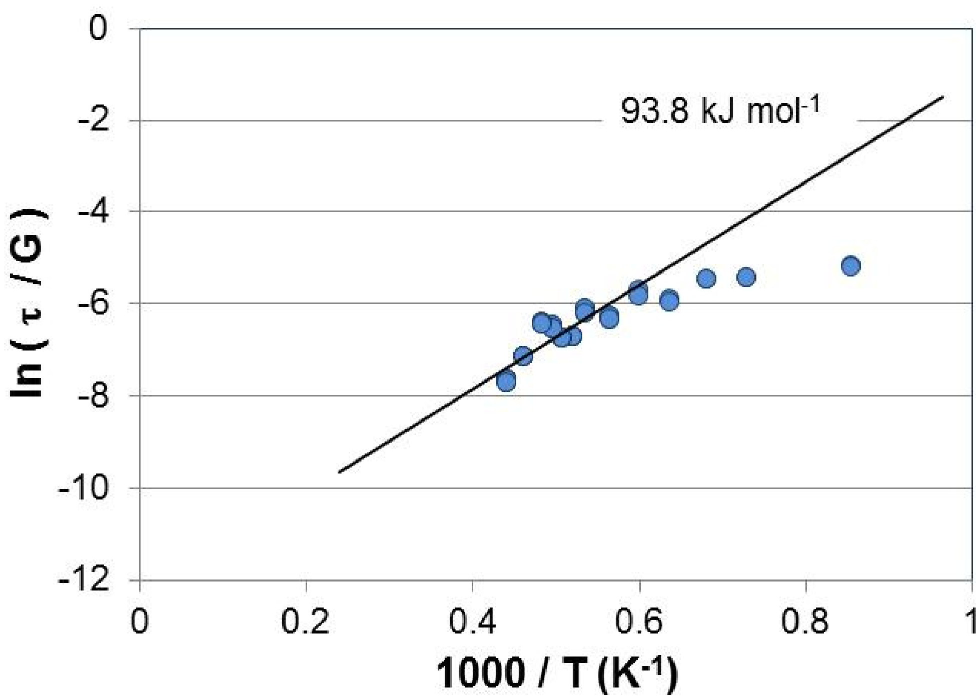


2273 K



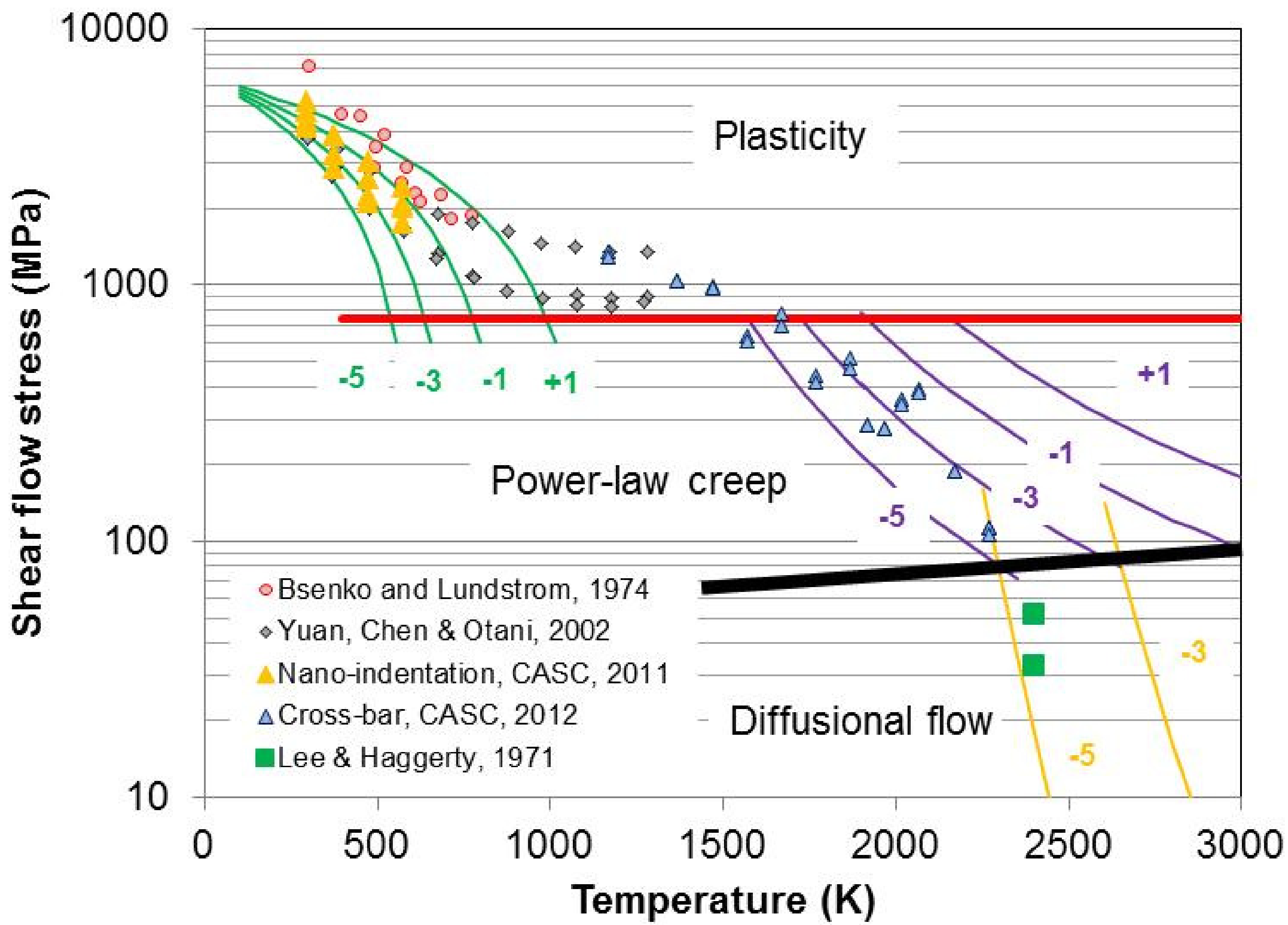
Activation energy from variation with temperature

Power law creep : $$\ln\left(\frac{\tau}{G}\right) = \frac{1}{n}\ln\left[\frac{\dot{\gamma}\cdot k\cdot T}{A_2\cdot D_{vo}\cdot G\cdot b}\right] + \frac{Q}{nk}\cdot\frac{1}{T}$$



$$n = \frac{678}{93.8} = 7.2$$

Deformation mechanism map



Conclusions

- Hardness data was used to propose a deformation mechanism map for ZrB_2

- Low temperature regime
  - Lattice resistance T < 500 K
  - Microstructure 500 K < T < 1500 K
- High temperature deformation mechanisms
  - Power law creep (n = 7.2) 1500 K < T < 2300 K
  - Diffusional flow T > 2300 K

Questions ?

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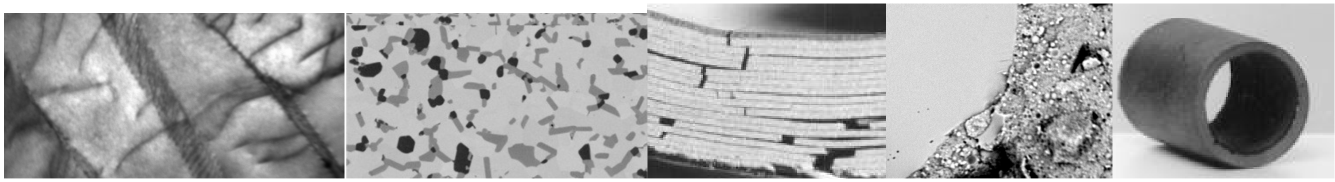
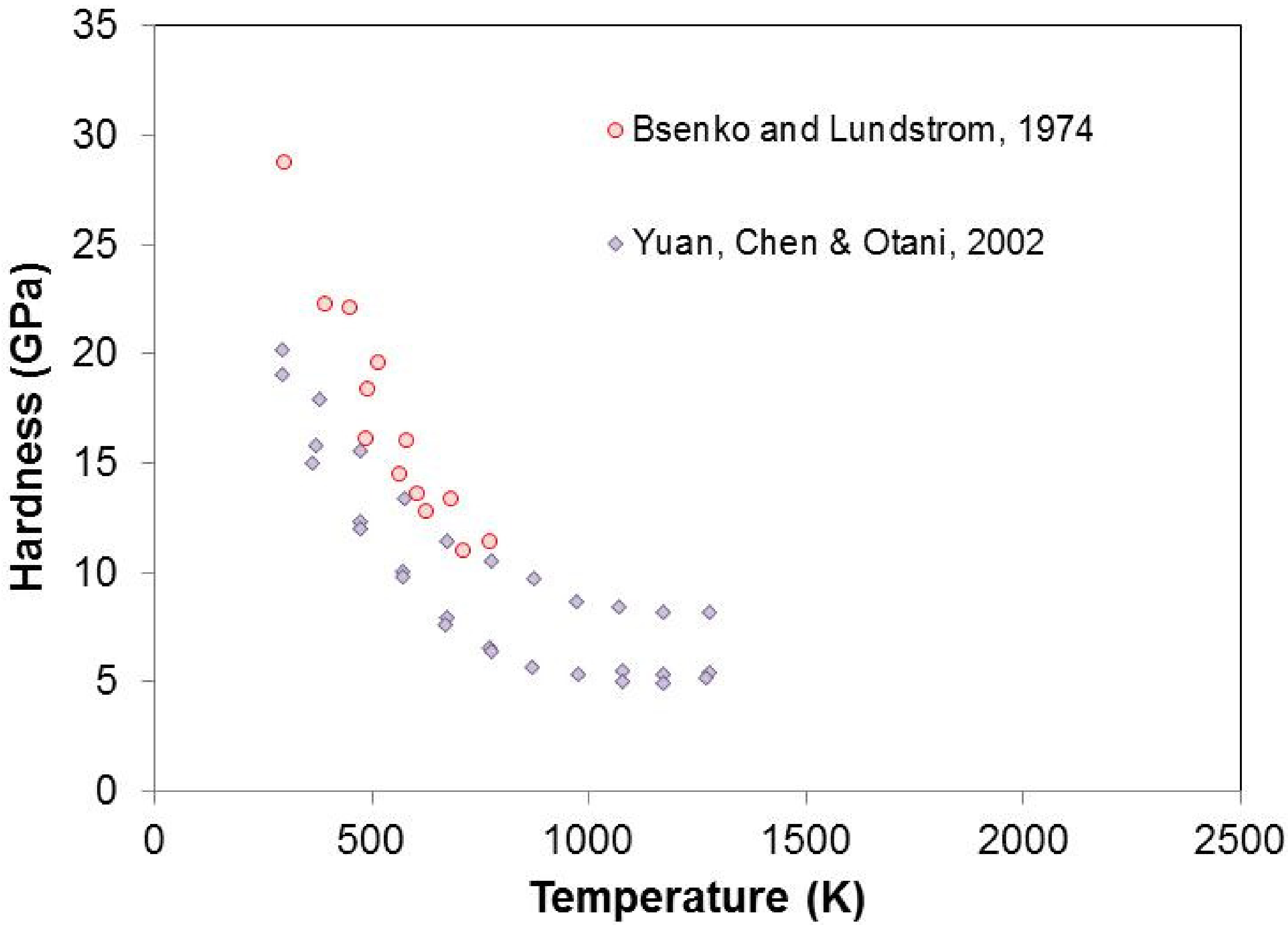
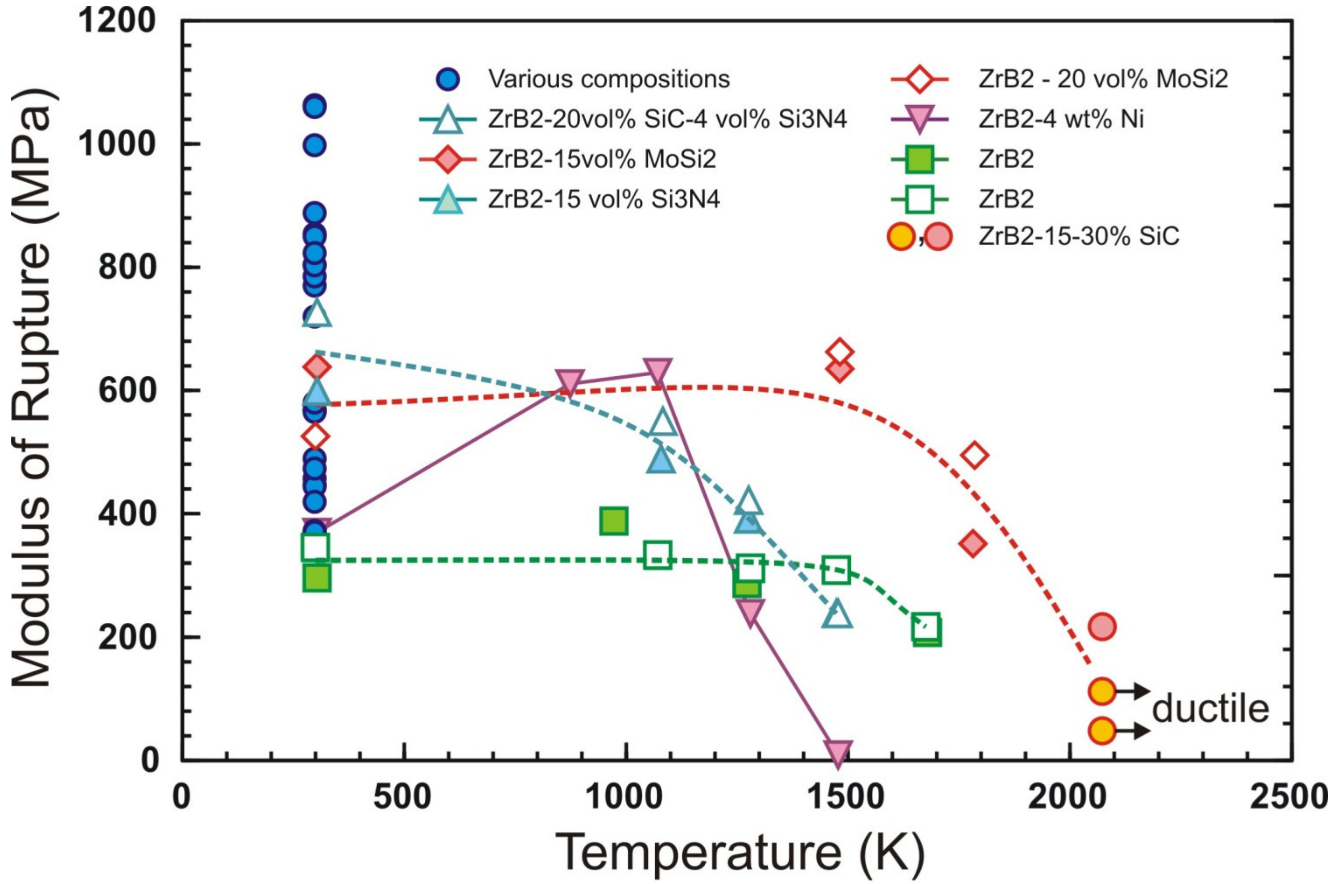


Studying plasticity in ceramics : hardness

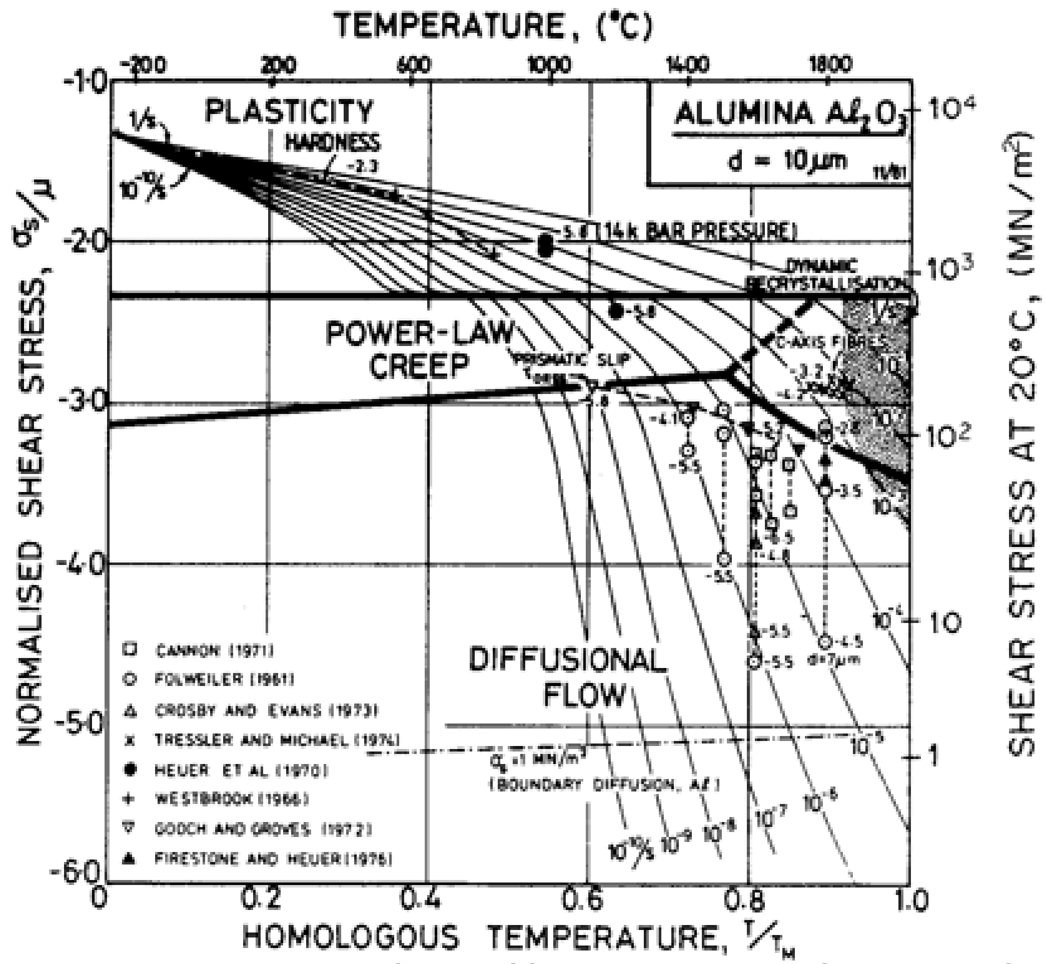


Tensile properties



(Sciti, Brach et al. 2005; Rezaie, Fahrenholtz et al. 2007; Li, Zhang et al. 2008; Zimmermann, Hilmas et al. 2008; Guo 2009; Zhao, Wang et al. 2009; Hu and Wang 2010)

Deformation mechanism map Al_2O_3



http://engineering.dartmouth.edu/defmech/