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Carbon segregation and partitioning between martensite and retained austenite in steels

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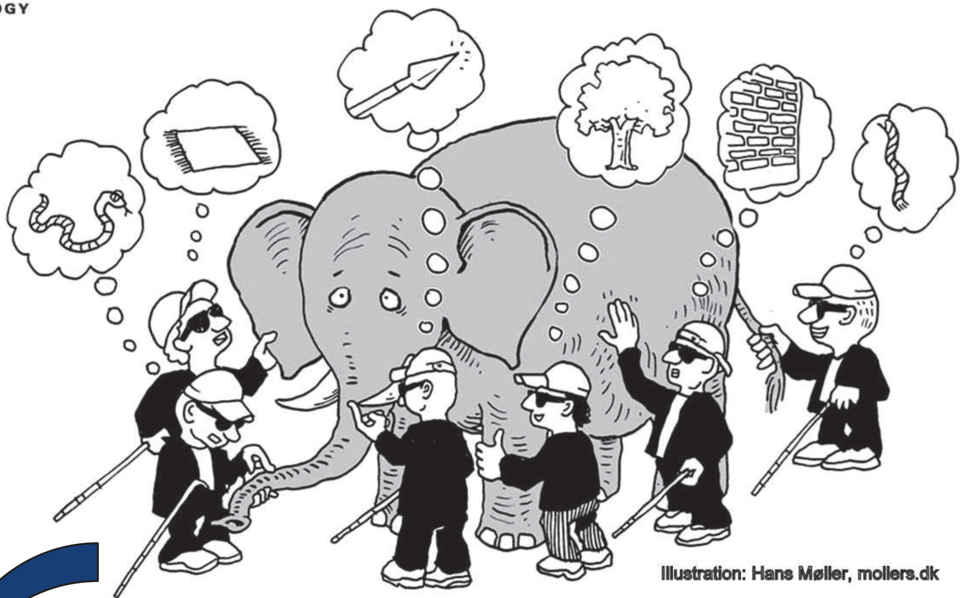
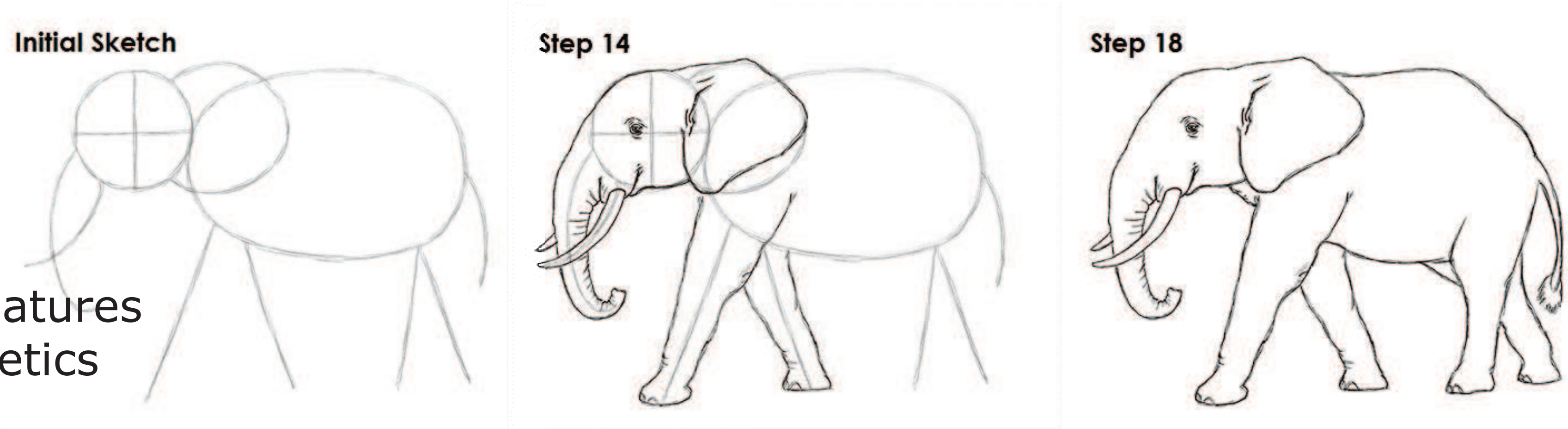
hero-m

Outline



Part I
C segreg.



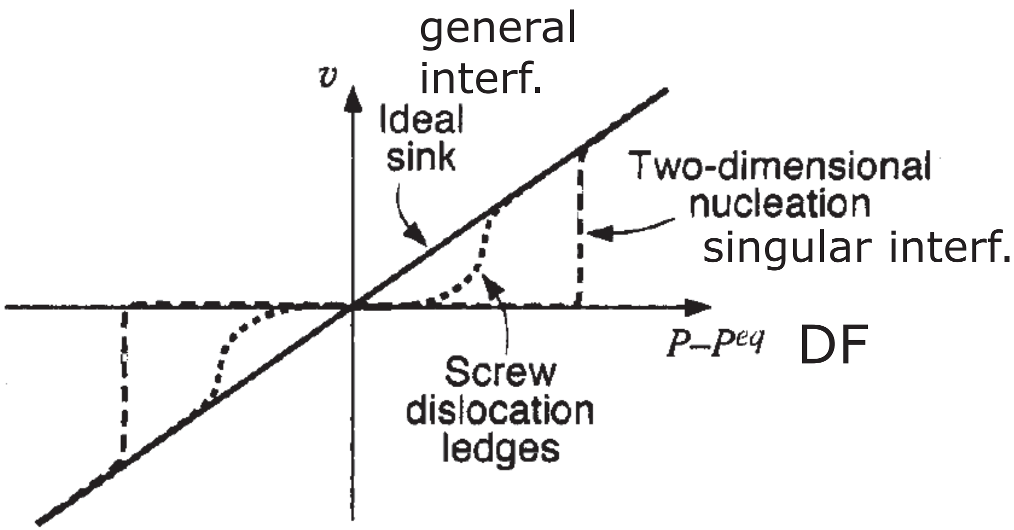
Part II
Some general features of interfacial kinetics
(Very much of brainstorming!)

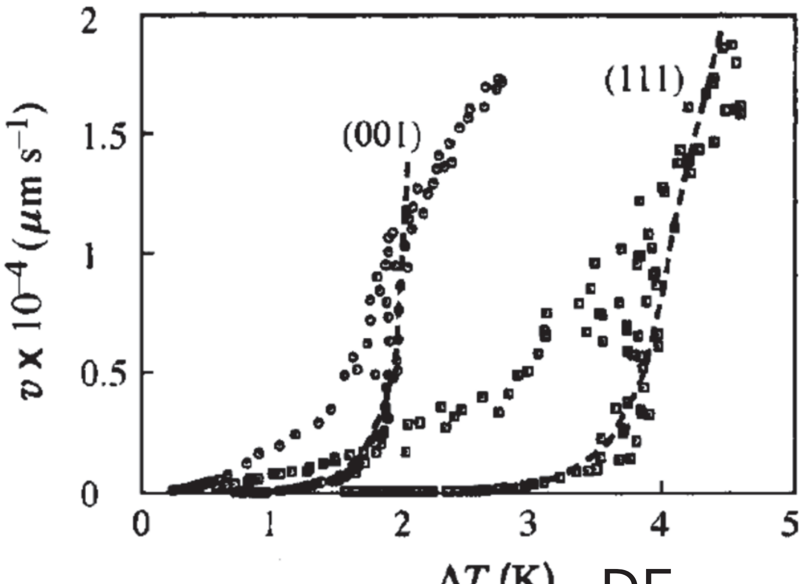
Part II. Interfacial kinetics: some general features

- Phenomenological description
- Unary system:
  - Velocity—temperature—driving force v=v(T, DF)
- Alloy system:
  - v(T,DF) and solute partitioning

Unary system: v(DF)

- Crystal-vapor interface
- Crystal-liquid interface





J. Howe, Interfaces in Materials (1997)

- Solid-solid phase transformation is restrictive because of v(T, DF(T))
- Insight from grain boundary and dislocation b/c DF can be independent of T

Dislocation: v(DF)

- Dislocation in crystal

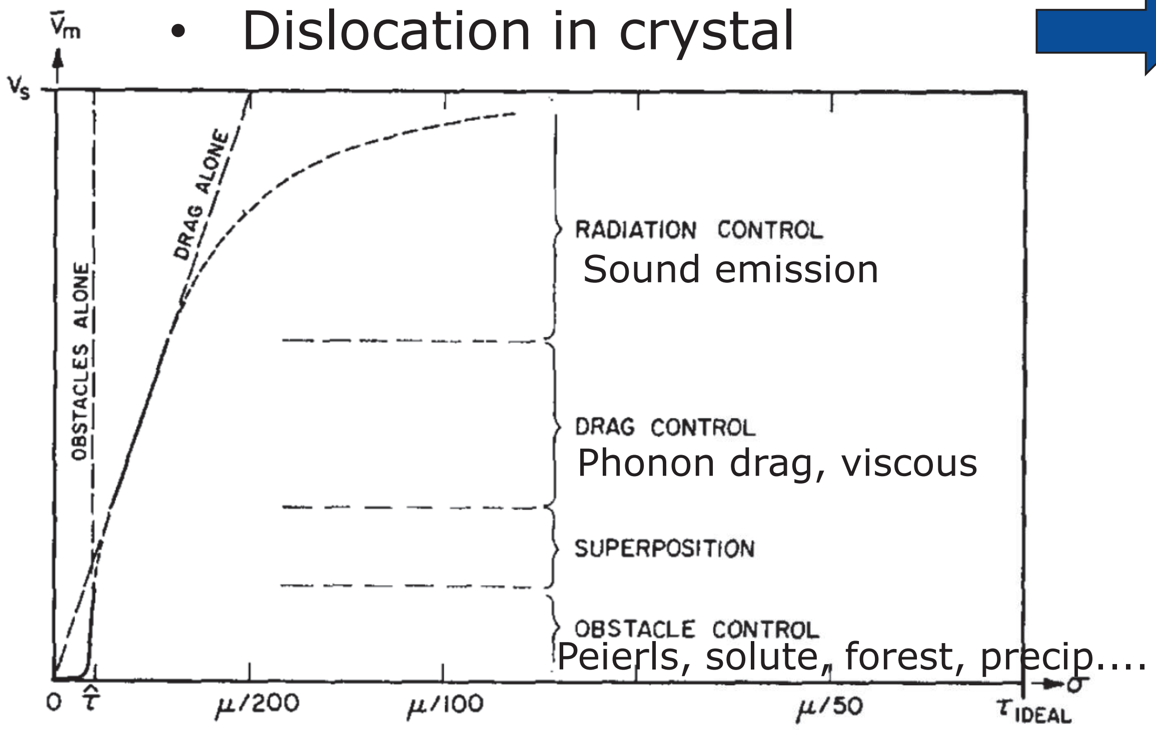
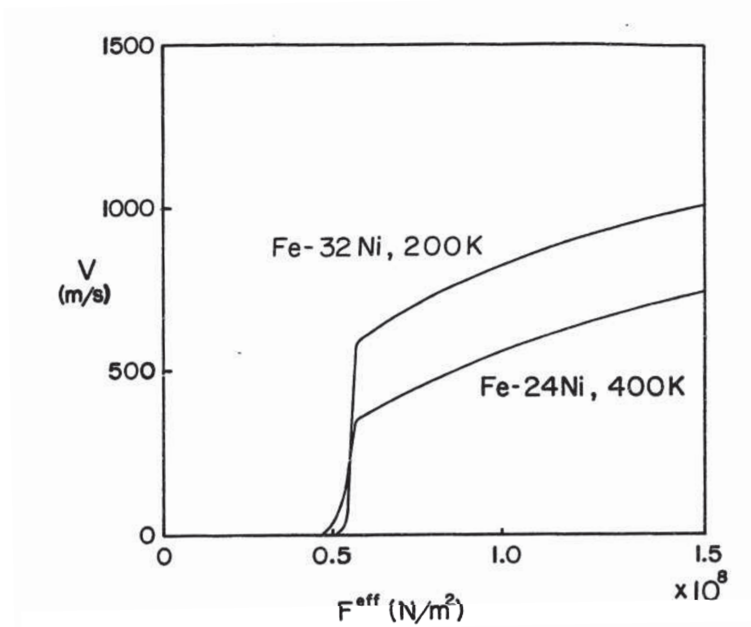


FIG. 34-1. Schematic velocity-stress diagram up to the respective natural limits.

Kocks, Argon, Ashby, Prog. Mater. Sci. 19(1975)1

- Martensite/austenite interface (model)



Predicted dependence of interfacial velocity on the effective interfacial force. The low-velocity regime is modeled after thermally activated dislocation slip, whereas phonon-drag mechanisms control the high-velocity growth rate.

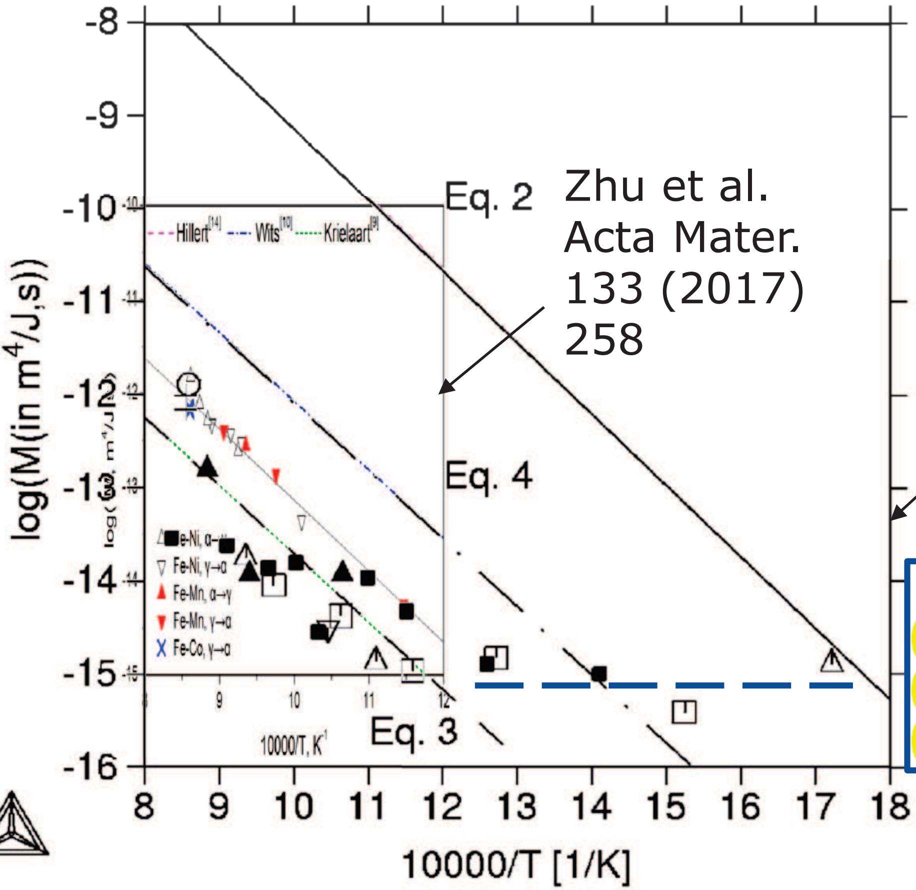
D. Haezebrouck, PhD thesis, MIT (1987)

- Similar v(DF) relationship to interface, although physical mechanism quite different

V(T): thermal—athermal transition?

$$v = M \cdot DF$$
$$M = M_0 \exp(-Q/RT)$$

$$Q = Q(DF)?$$

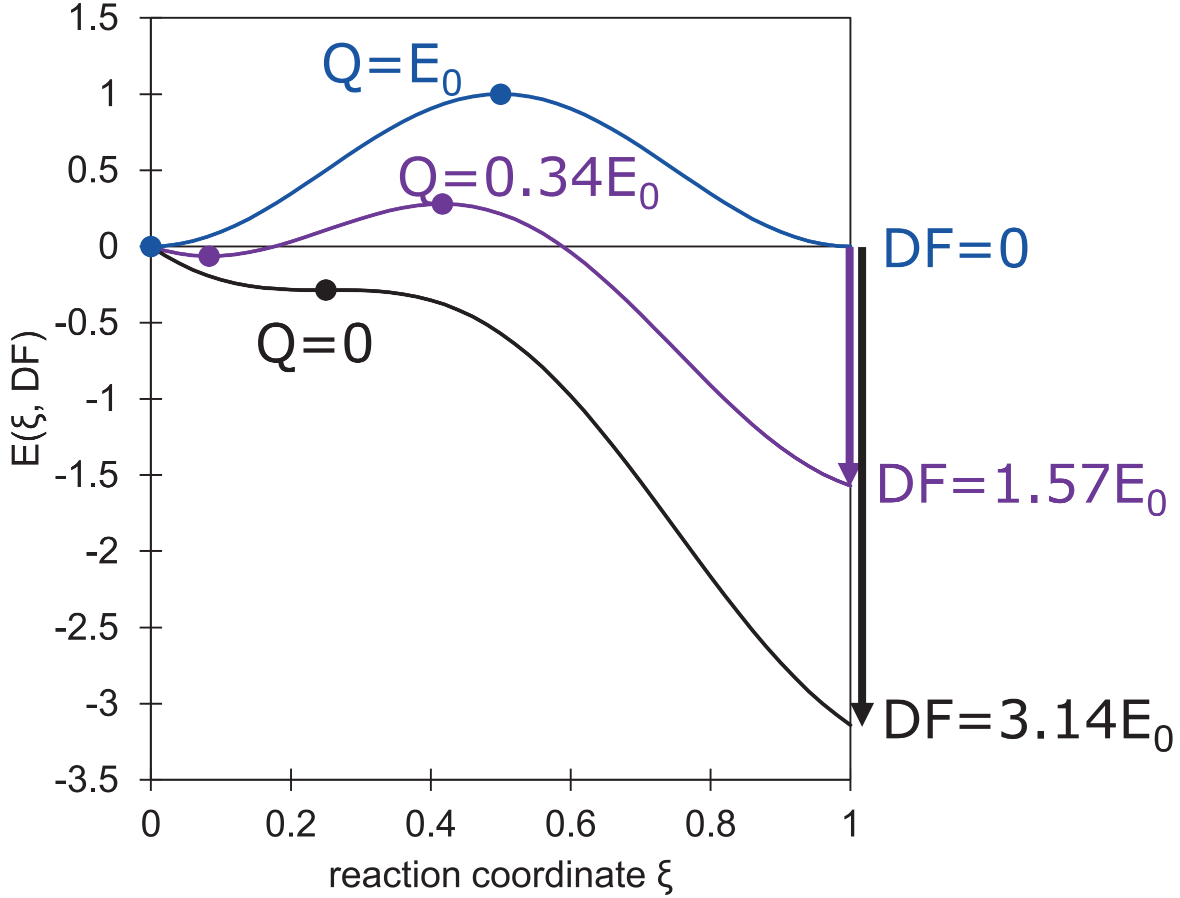


transformation at 504 °C. It seems that the results from Fe–Ni and Fe–Mn alloys, indicating that the mobility approaches a constant value at the lower temperatures, may not be characteristic of the massive transformation.

Fig. 3. New information on the mobility of α/γ interfaces obtained from the massive transformation. (+): γ → α in Fe, Liu et al. [9], (○): γ → α in Fe–Co and (▽): γ → α in Fe–Mn, Liu et al. [7], (■): α → γ in Fe–Ni, (□): γ → α in Fe–Ni, (▲): α → γ in Fe–Mn and (△): γ → α in Fe–Mn [15].

Q=Q(DF): a toy model (phenom.)

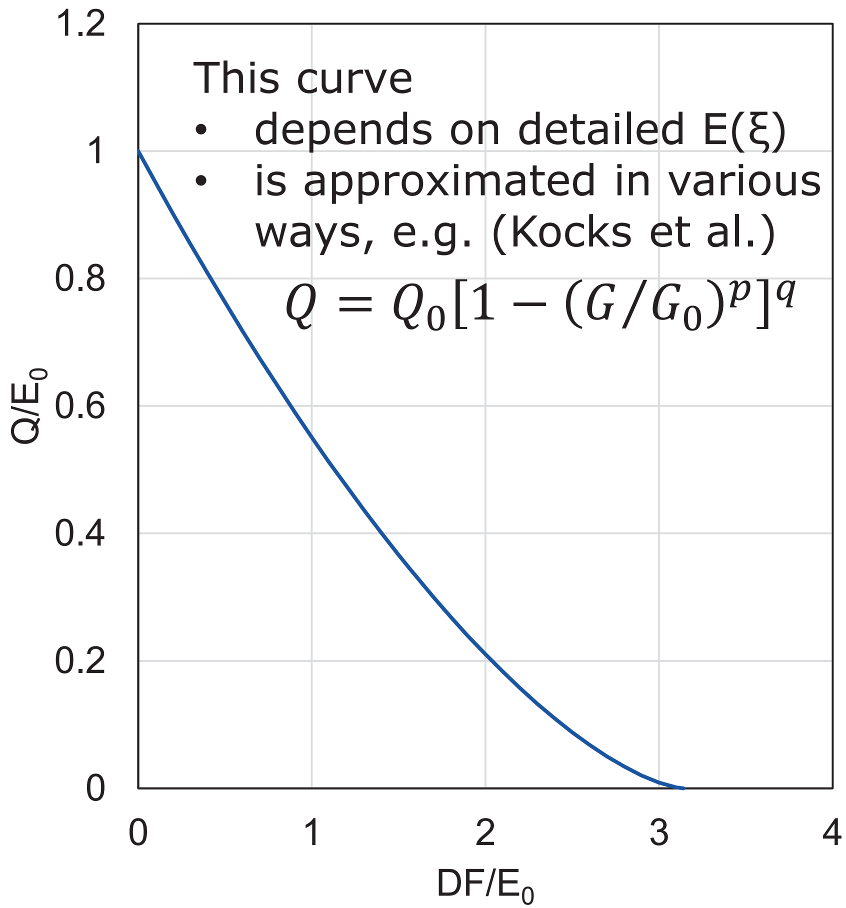
$$E(\xi, DF) = \frac{E_0}{2}(1 - \cos 2\pi\xi) - (DF)\xi$$



This curve

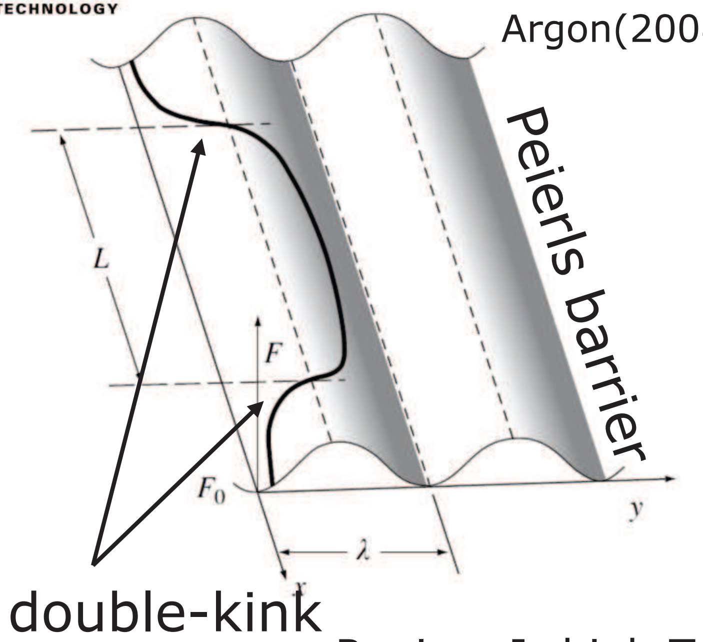
- depends on detailed E(ξ)
- is approximated in various ways, e.g. (Kocks et al.)

$$Q = Q_0[1 - (G/G_0)^p]^q$$



Athermal process may require other DF

Q=Q(DF) in reality for dislocation



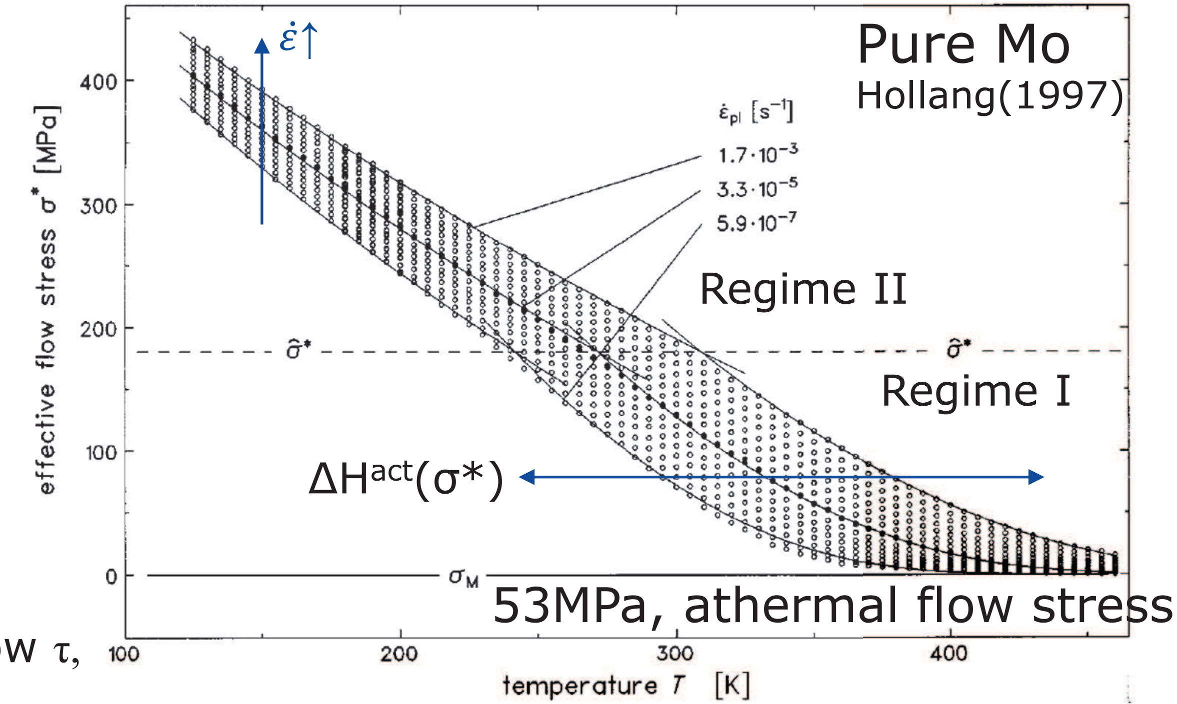
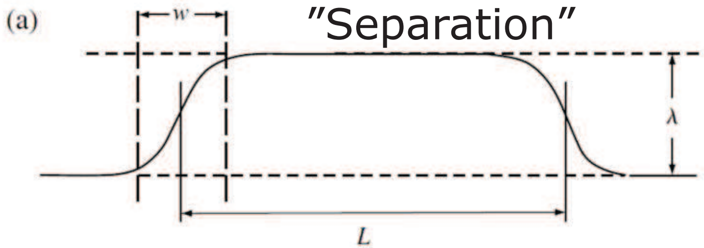


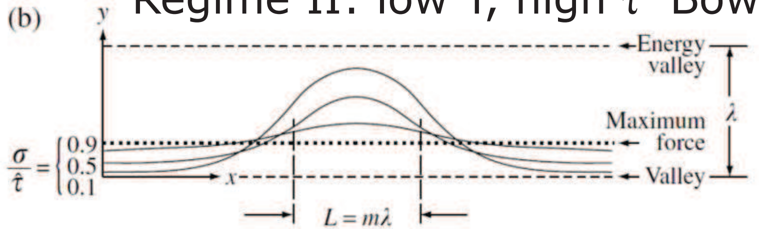
Fig. 11. Temperature dependence of the effective flow stress of specimen 1 assuming $(\bar{1}01)$ glide. The solid lines represent the calculated curves for $|\dot{\varepsilon}_{pl}| = 5.9 \times 10^{-7}$, 3.3×10^{-5} and $1.7 \times 10^{-3}\,s^{-1}$. The athermal component of the flow stress σ_M corresponding to $\sigma^* = 0$ (cf. Eq. (8) and Fig. 6), and the upper-bend stress $\hat{\sigma}^*_{\{110\}} = 180$ MPa are marked by the solid and dashed horizontal lines, respectively

Regime I: high T, low τ, "Separation"



Regime athermal: high kT/(Peierls), straight dislocation

Regime II: low T, high τ "Bow-out"



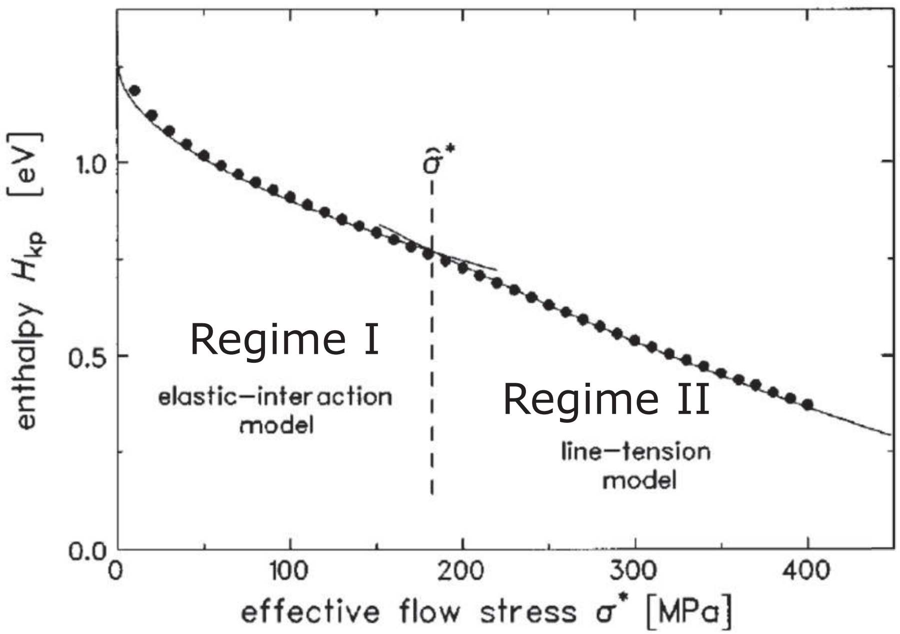
Q=Q(DF) in reality for dislocation

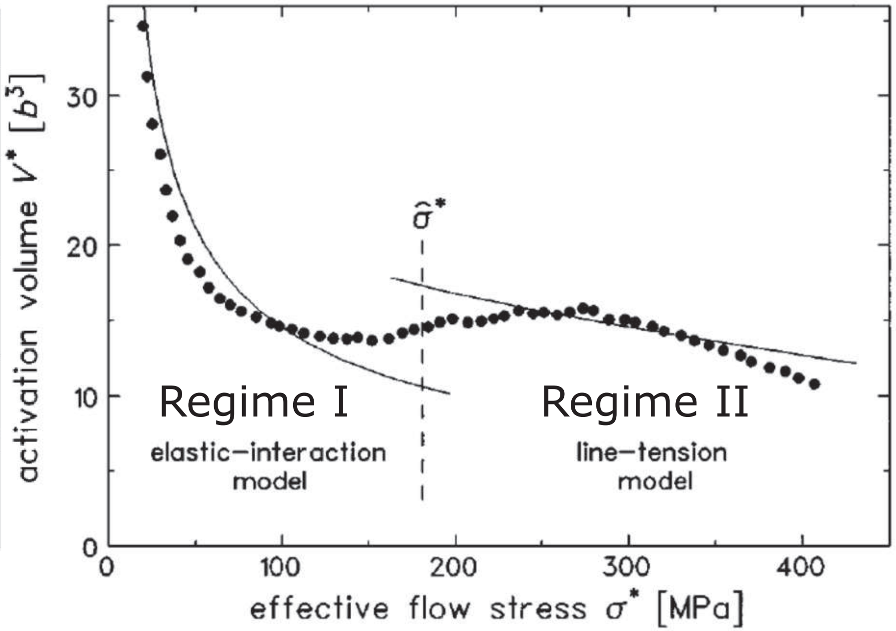
Activation enthalpy

$$6L\ _4 6\left(F\frac{*}{G6}^{a}\right)$$

Activation volume

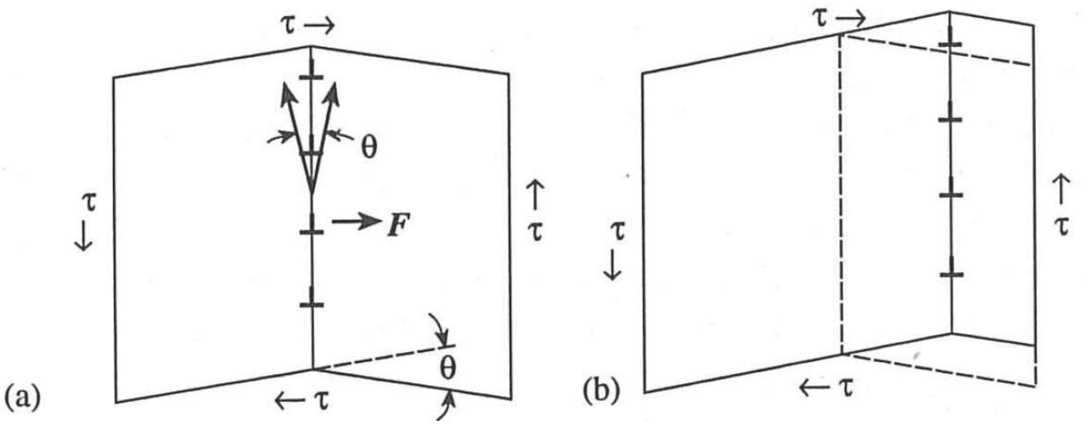
$$V\ \ L\ F\frac{*}{Œ}^{a}$$





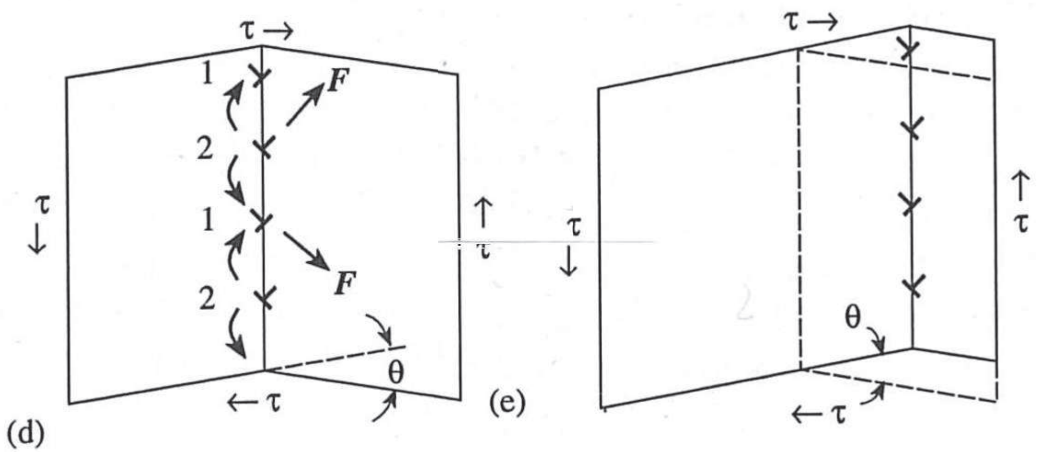
kp=kink pair
Hollang(1997)

Small-angle grain boundary



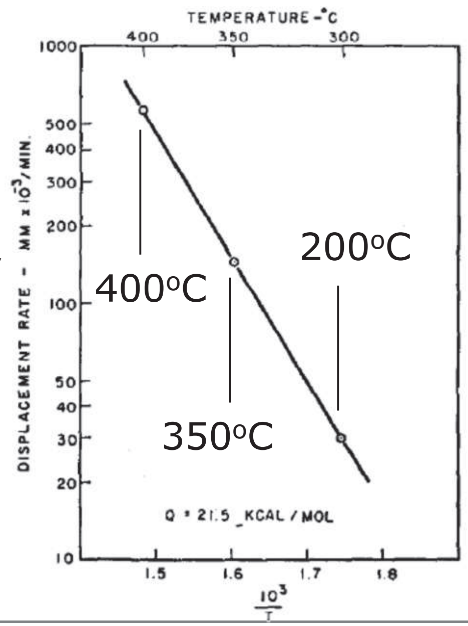
athermal

glide



climb

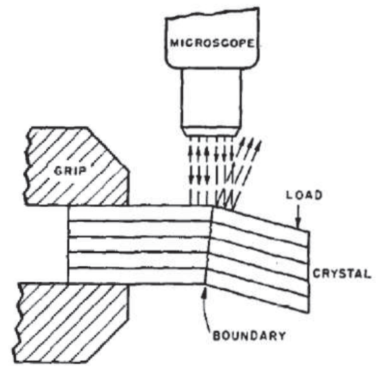
logv



400°C

350°C

200°C



Zn

Stress=8psi

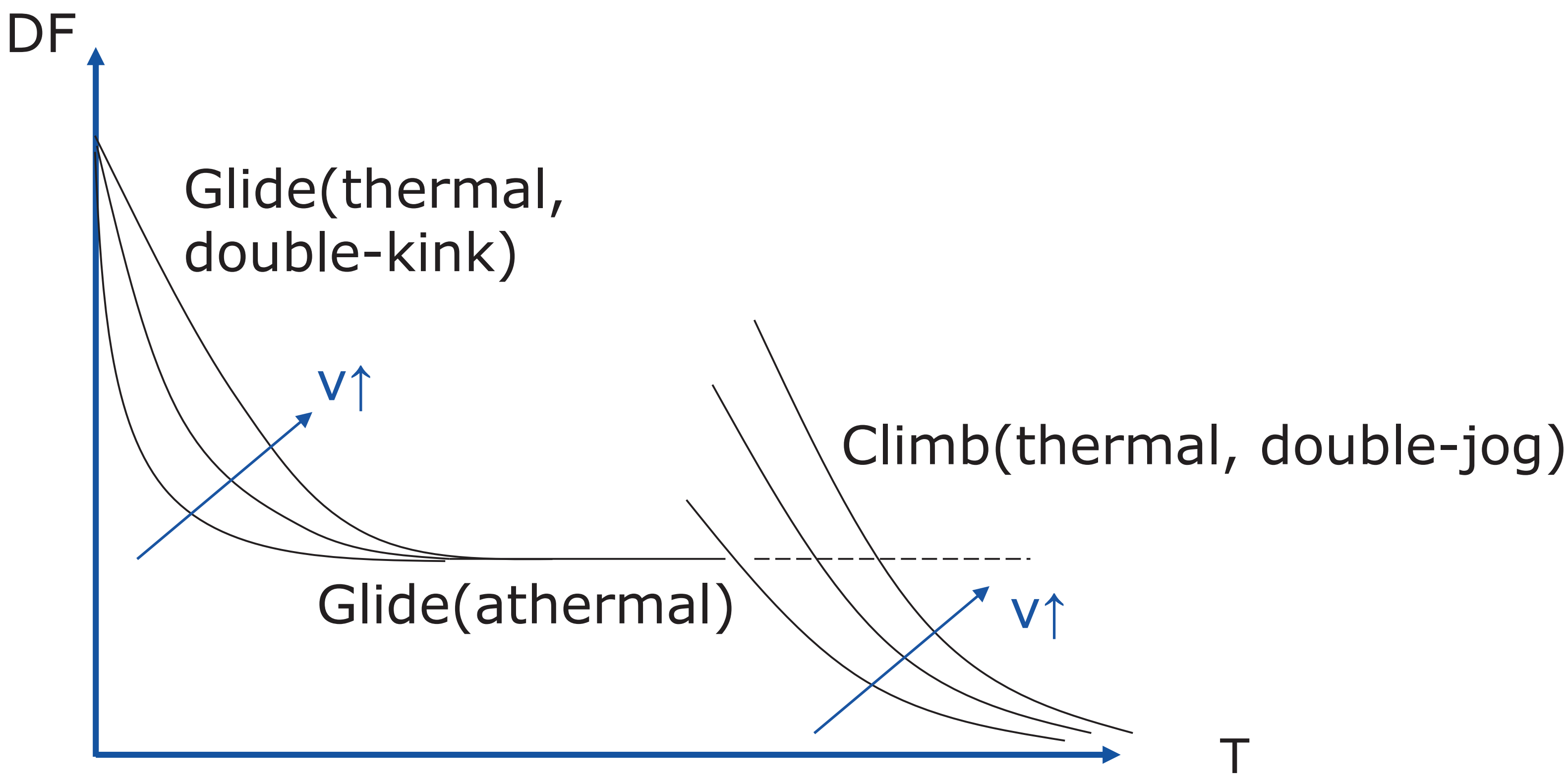
Q=21.5kcal/mol

~Q(self-diffusion)

1000/T

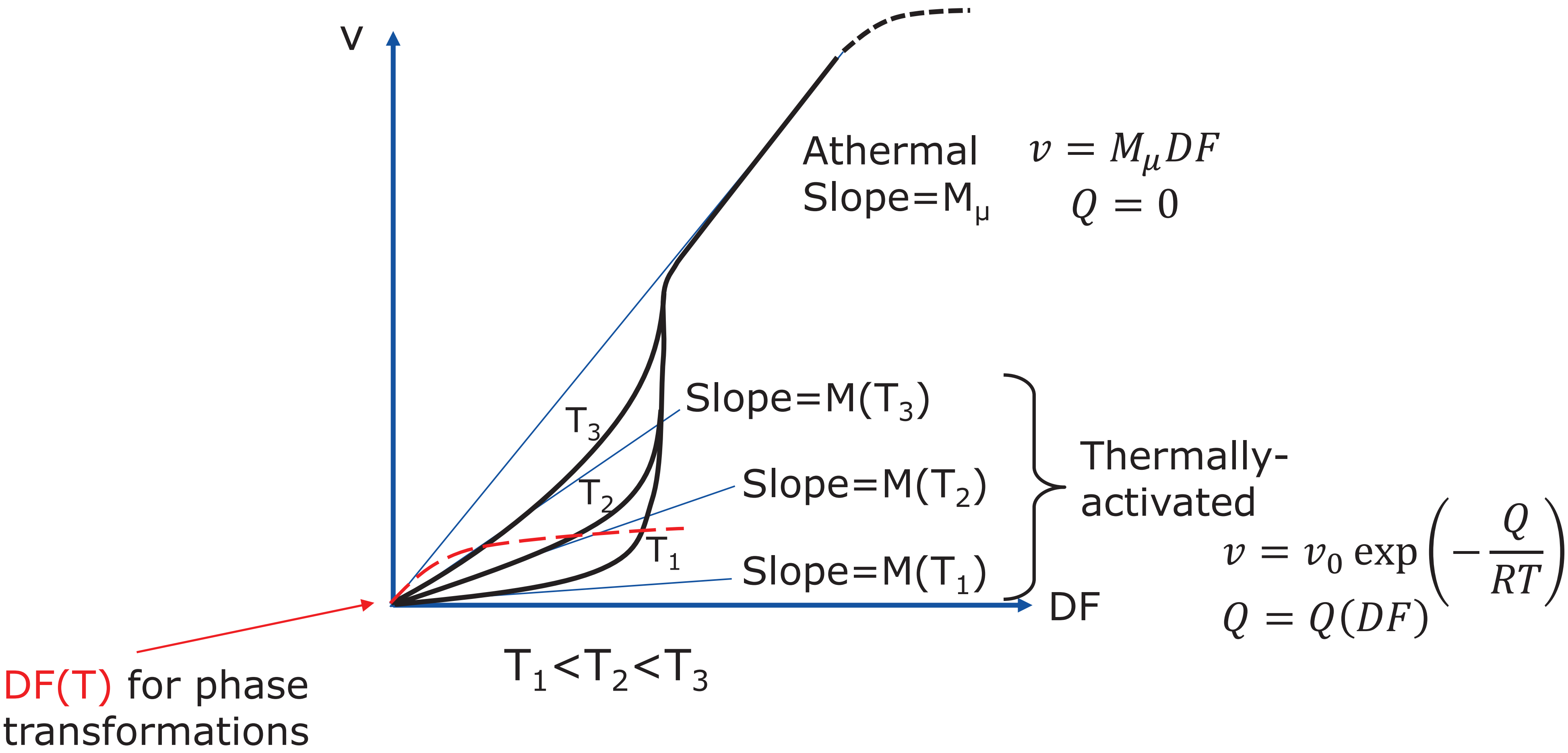
Li et al. Acta Metall. 1(1953)223

V(T,DF), dislocation or SAGB

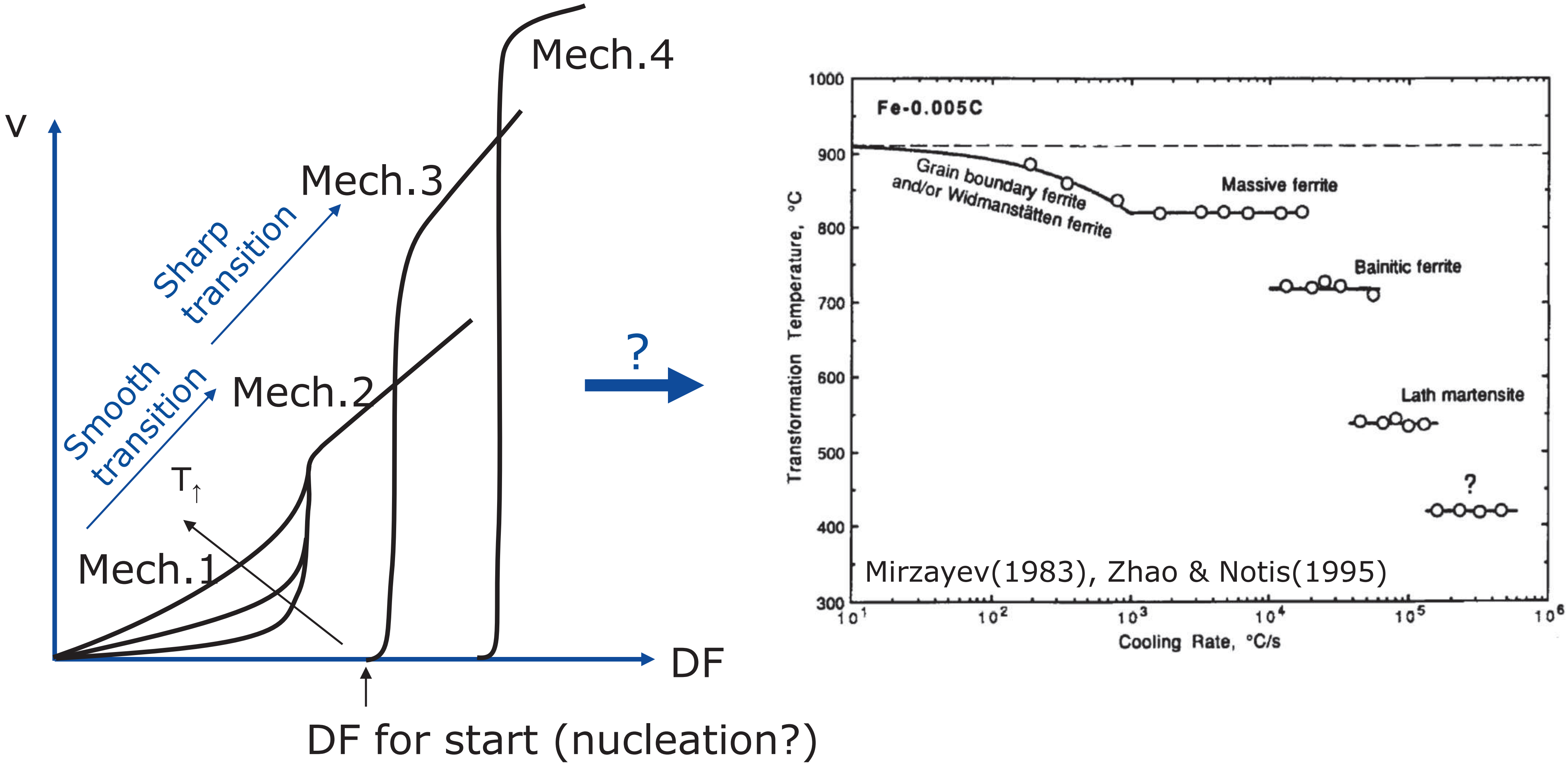


And other mechanisms (atomic shuffle...)

V(T,DF), phenom.

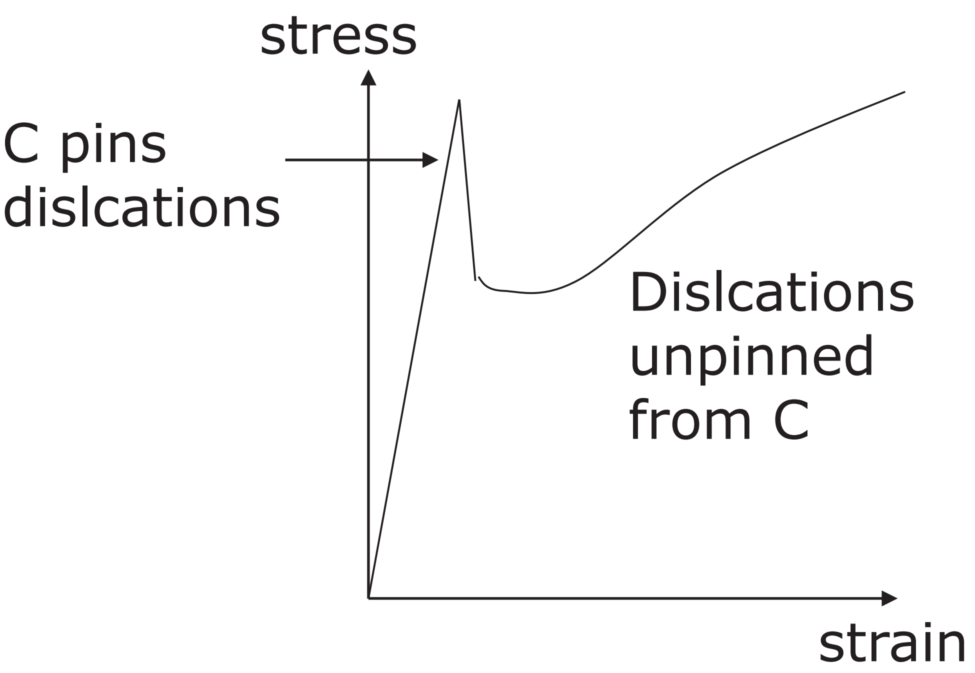

V
Athermal
Slope=M_μ
$v = M_\mu DF$
$Q = 0$
T_3
T_2
T_1
Slope=$M(T_3)$
Slope=$M(T_2)$
Slope=$M(T_1)$
Thermally-activated
$v = v_0 \exp\left(-\frac{Q}{RT}\right)$
$Q = Q(DF)$
DF
$T_1 < T_2 < T_3$
DF(T) for phase transformations

Multiple mechanisms?

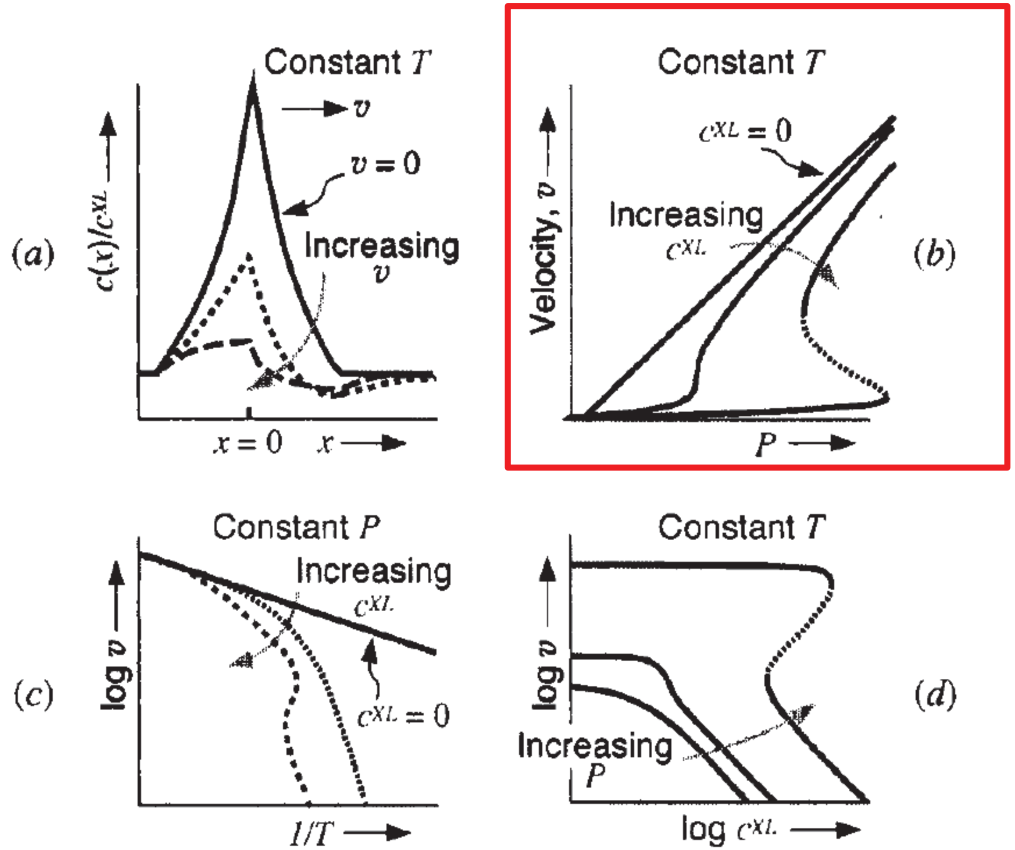


Solute interactions with...

- Dislocation:
  - Yielding phenomena and strain aging



- Interface (Cahn, Hillert&Sundman...)
  - Low-velocity-high-drag to high-velocity-low drag



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Interface velocity as drag-mode filter

1 interface + 1 solute:

Intrinsic behavior → High velocity, low drag
→ Low velocity, high drag

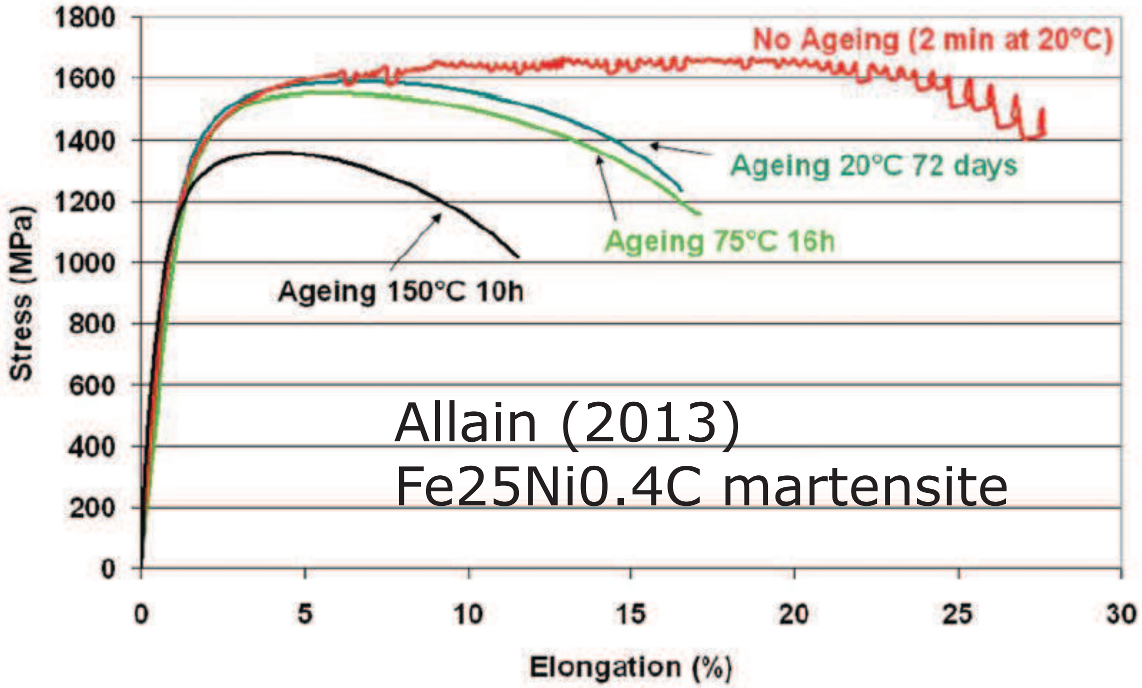
1 interface + 2 solutes(C,M)

Intrinsic behavior → High velocity, low (C,M) drag
→ Medium velocity, high C drag, low M drag
→ Low velocity, high (C,M) drag

2 interfaces + 2 solutes: up to 6 options?

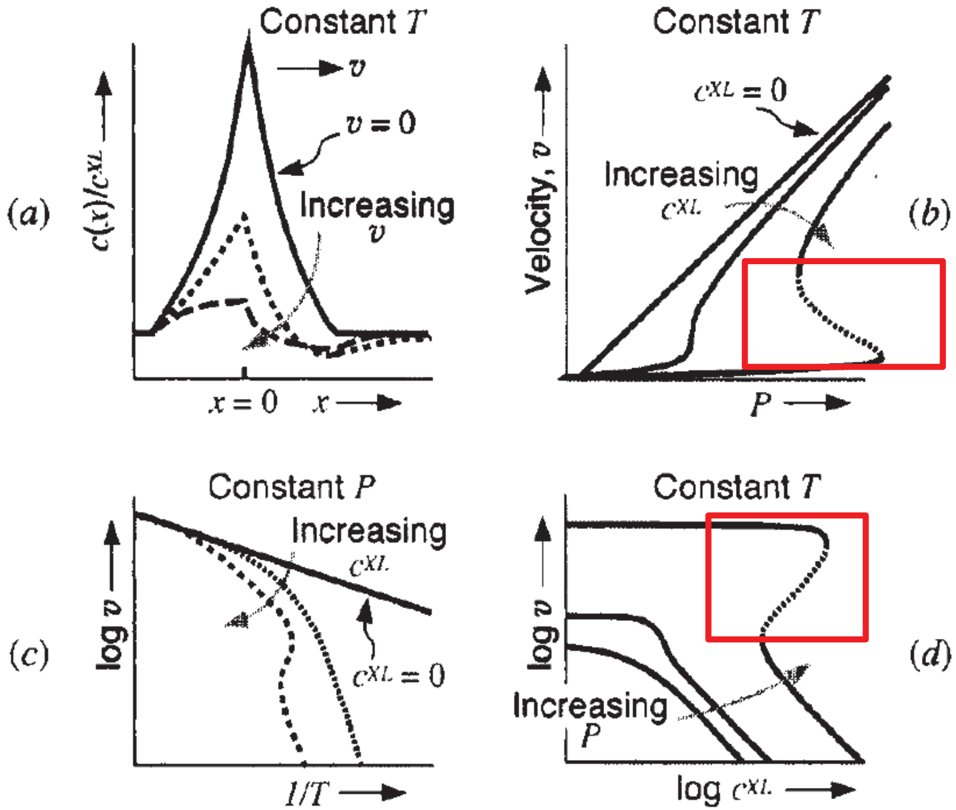
Solute interactions with…

- Dislocation:
  - Serrated flow (Portevin-le Chatelier effect)
  - quasi-periodic arrest and release processes

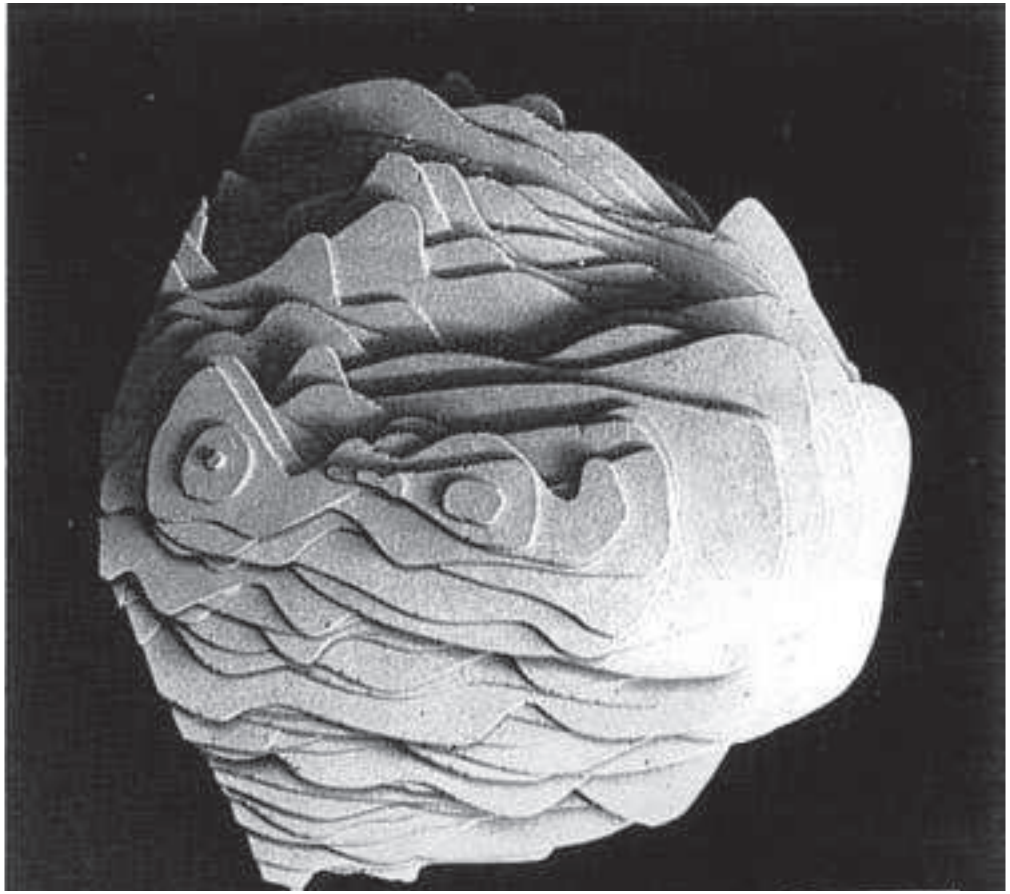


Allain (2013)
Fe25Ni0.4C martensite

- Interface ?:
  - Non-steady-state solution, loss of stability



Anisotropy



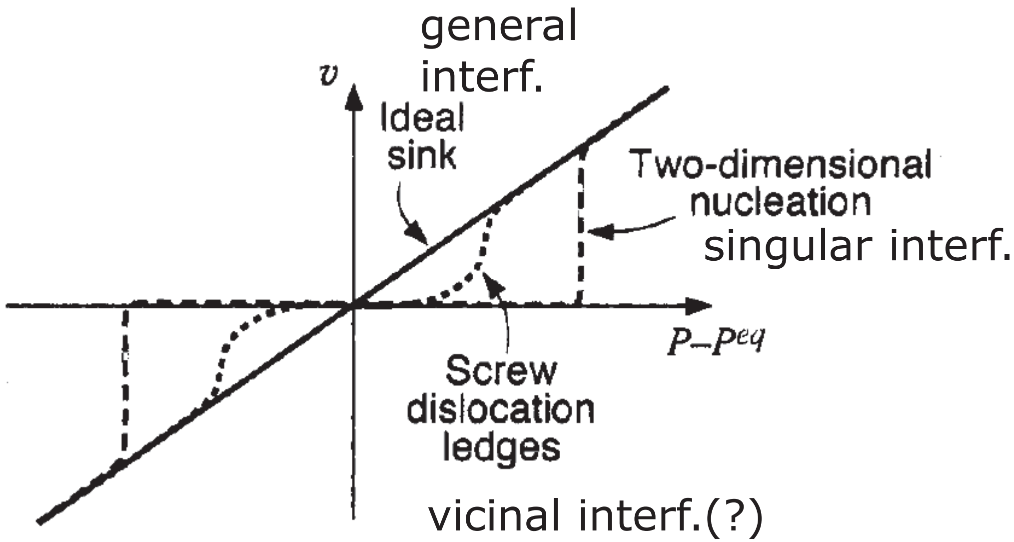
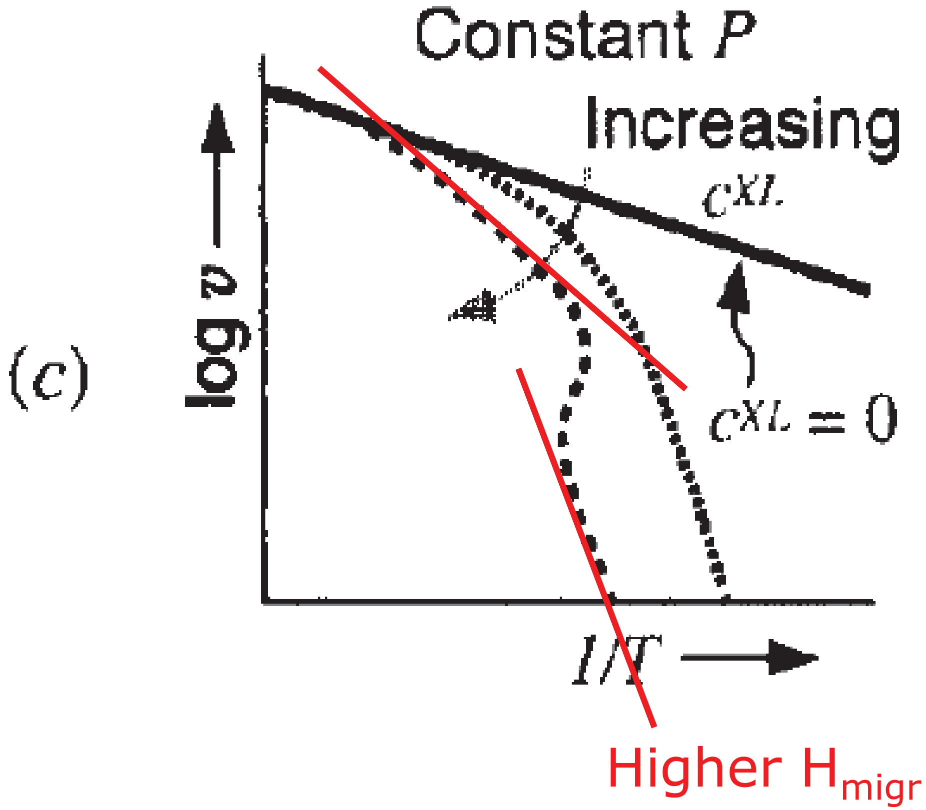


FIGURE 3.93 Reconstruction from many field ion micrographs of a heavily ledged Co_2Ta precipitate. (From Hildon, A. et al., *J. Microsc.*, 99, 41, 1973. With permission from John Wiley & Sons.)

Aaronson, Enomoto, Lee, Mechanisms of Diffusional Phase Transformations in Metals and Alloys (2010)

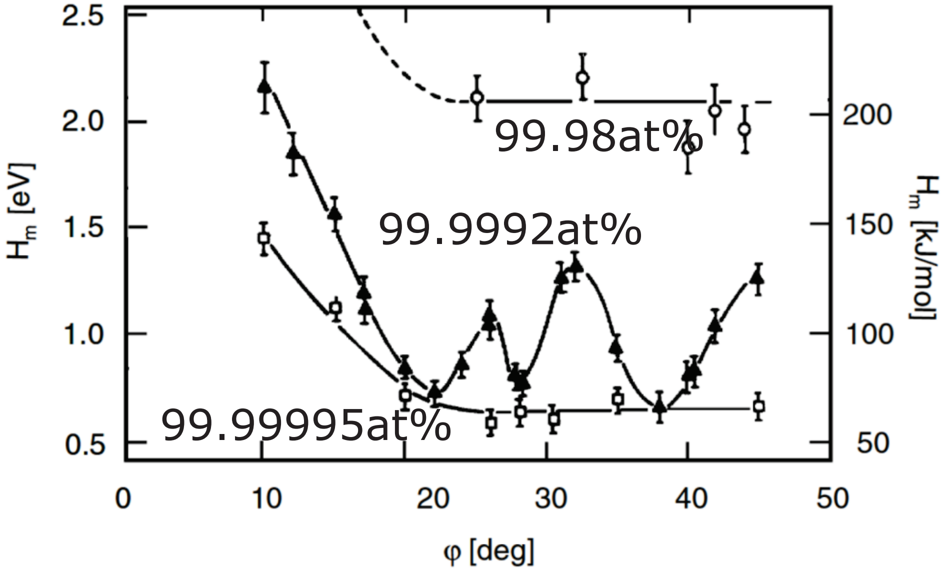
Anisotropic solute-drag



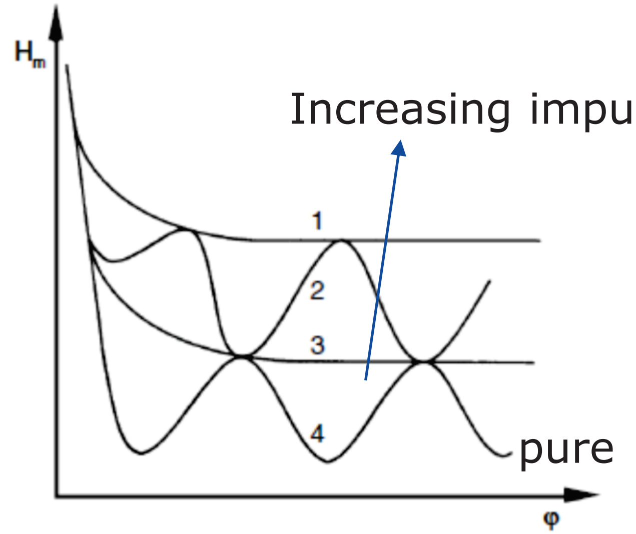
Reminder:

- Base-c ↗, H_{migr} ↗
- Low-velocity-high-drag has higher H_{migr}

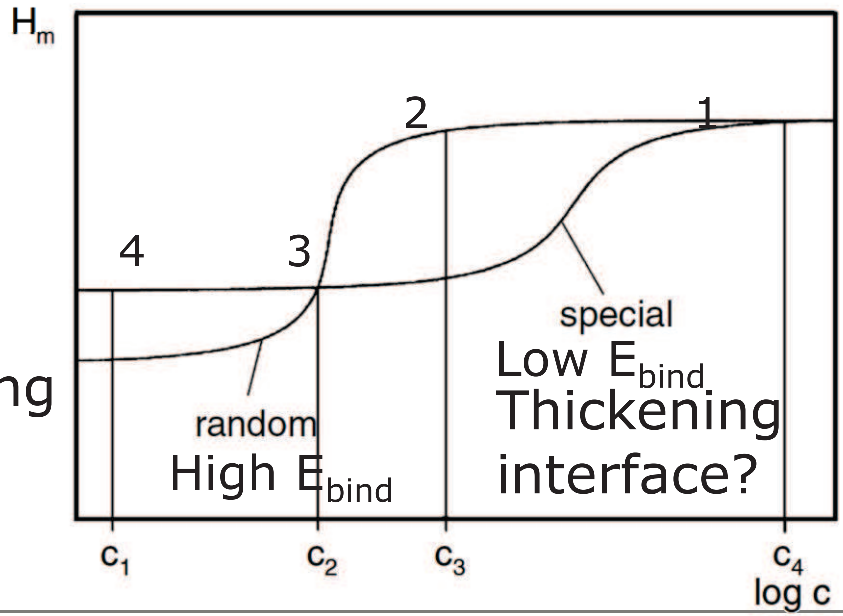
Anisotropic solute-drag



Activation energy of GB migration, <100> tilt GB in Al



Lengthening interface?



Gottstein, Shvindlerman (2010)

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Summary (Part II)

Unary system:

- V(DF) relationship can be nonlinear and depends on interfacial structure
- V(T): thermal→athermal transition exists
  - Need Q(DF) when DF is large
- Multiple relationships possible
- Dislocation dynamics and other interfaces inspire laws of solid-solid intrinsic interface (clean) and solute-element interactions with it