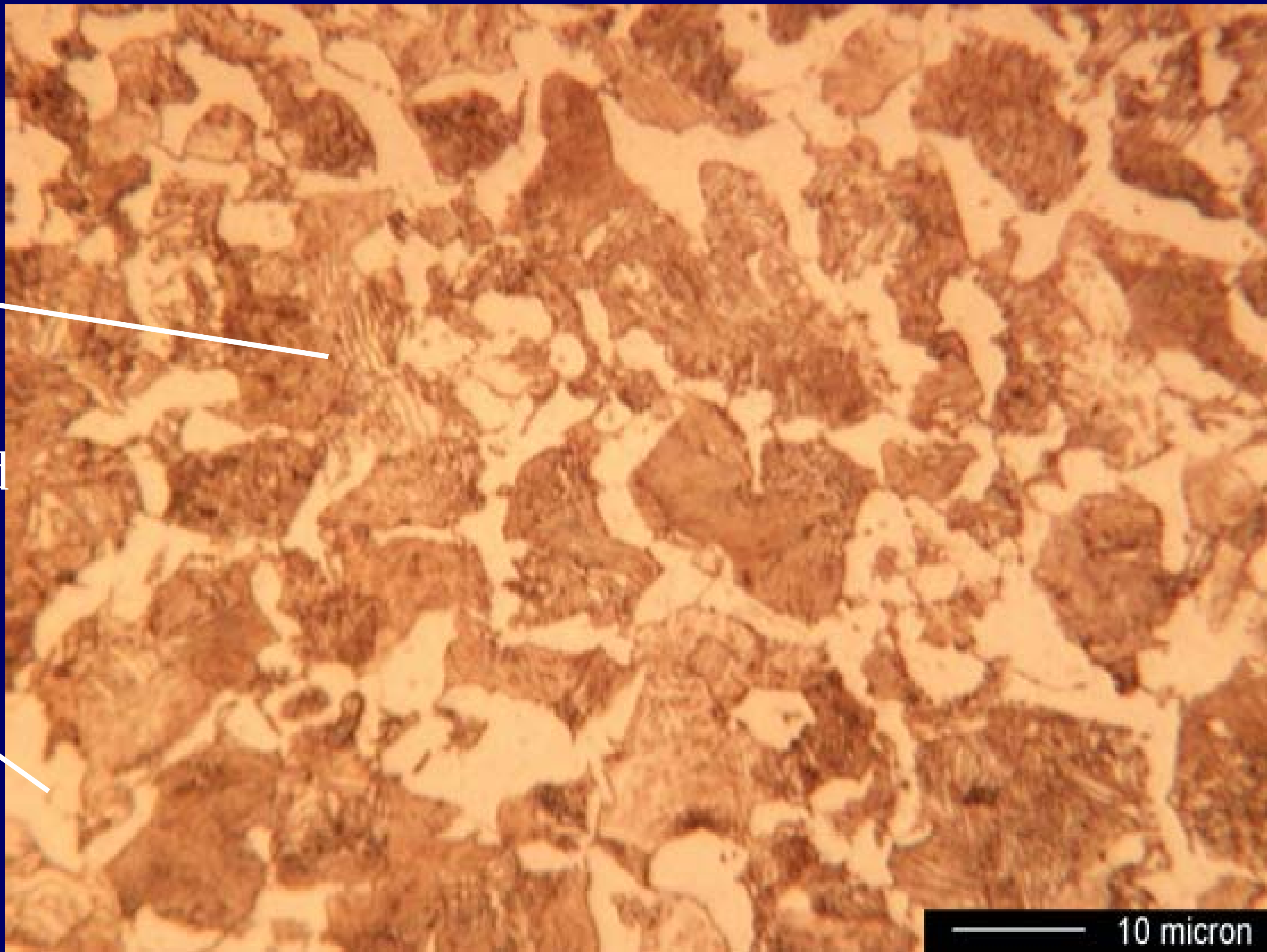
Hypoeutectoid Steels (C_C<0.76%)

(⇔ hypereutectoid)

Ck45
Cc=0.45%

dark
pearlite:
lamellae
of Fe_3C and
ferrite

light
α ferrite



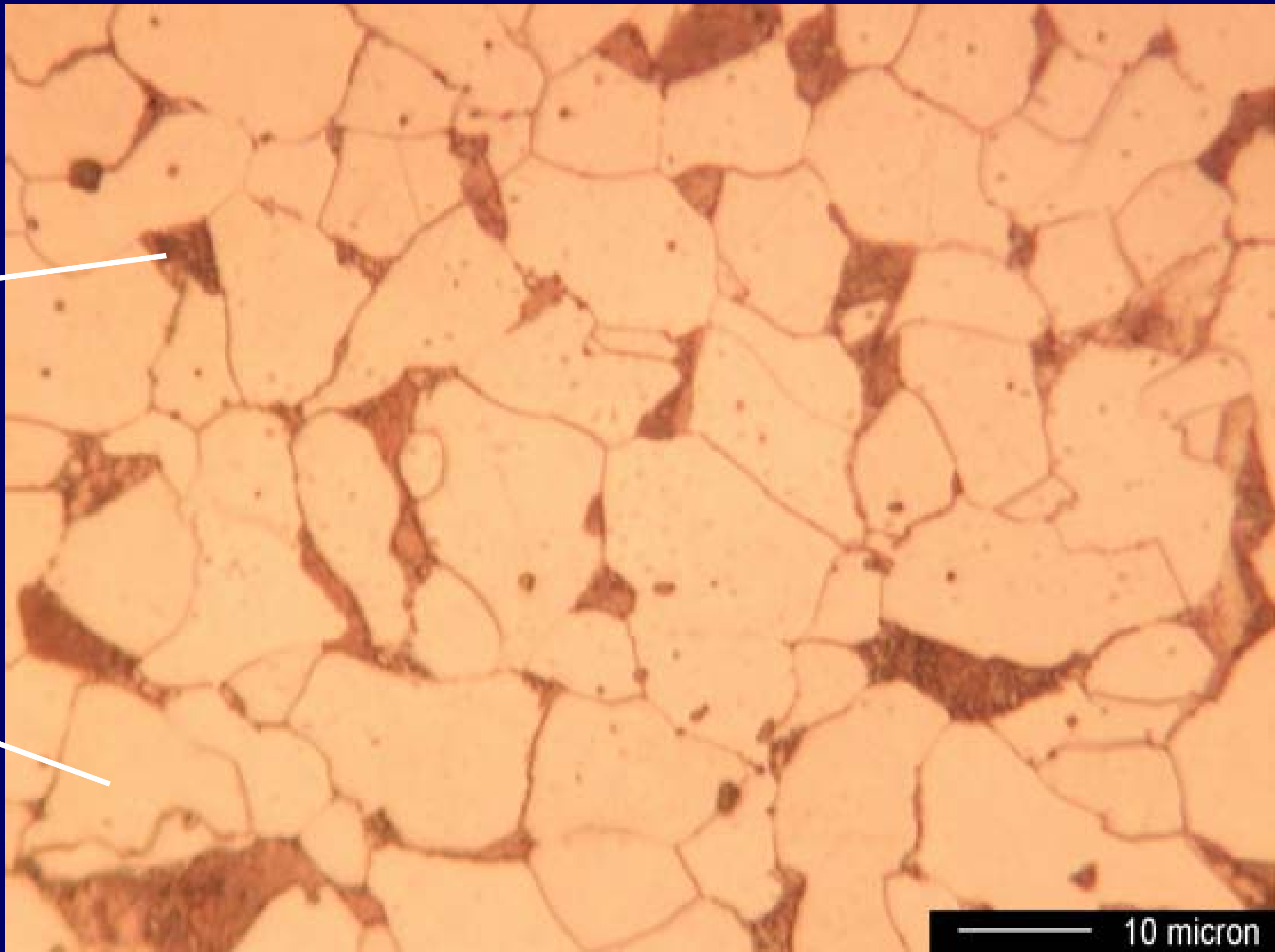
Hypoeutectoid Steels (C_C<0.76%)

(⇔ hypereutectoid)

Ck15
Cc=0.15%

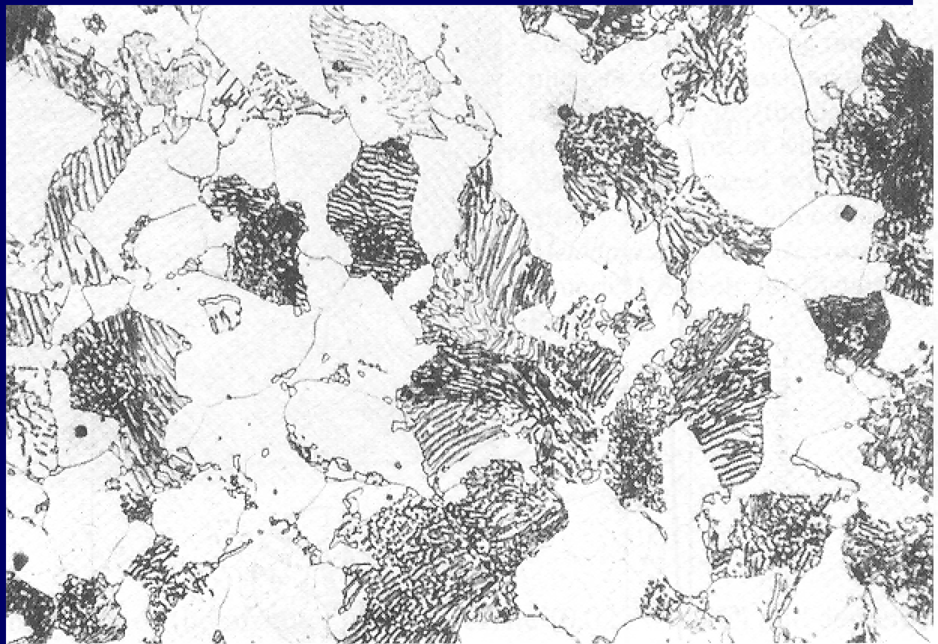
dark
pearlite:

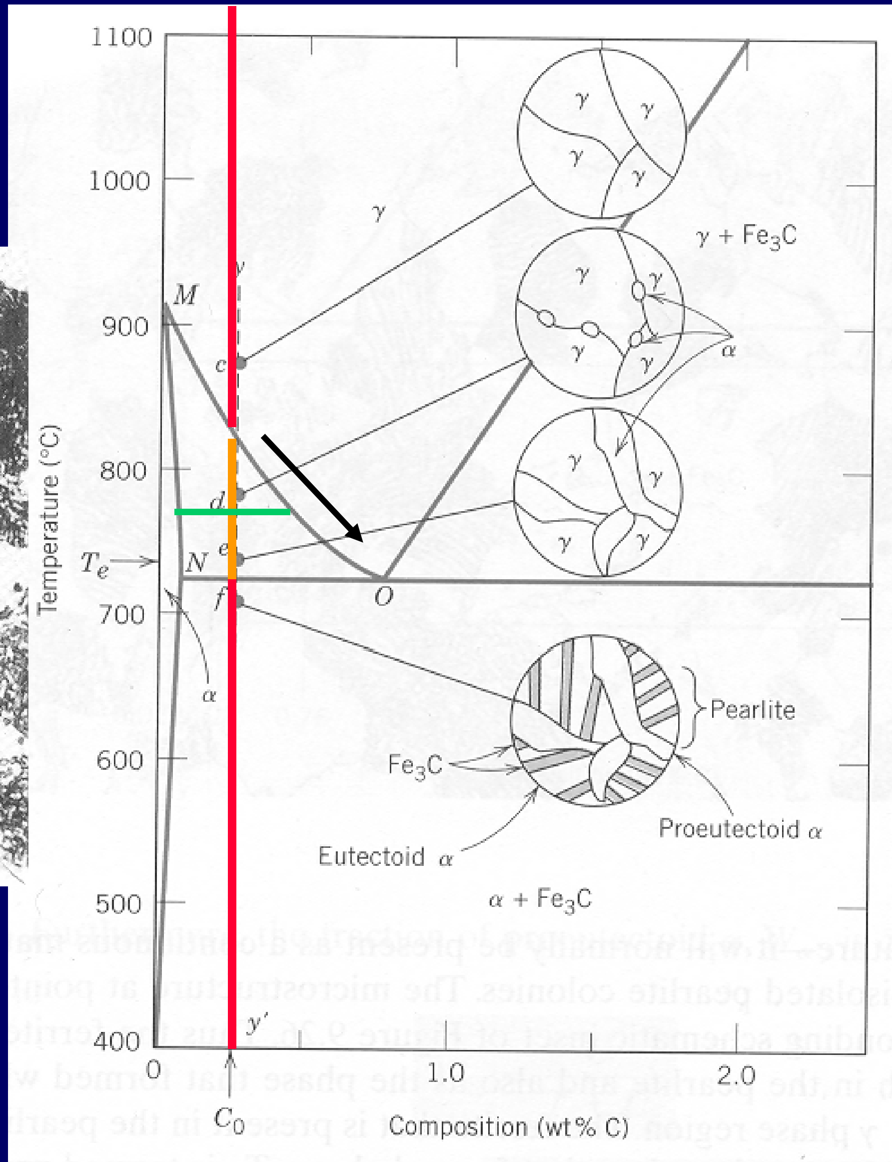
light
α ferrite



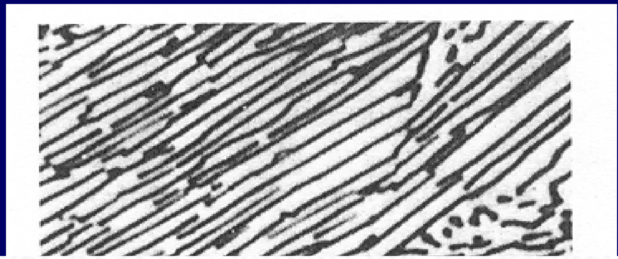
Hypo-Eutectoid Transformation

Ferrite + Pearlite

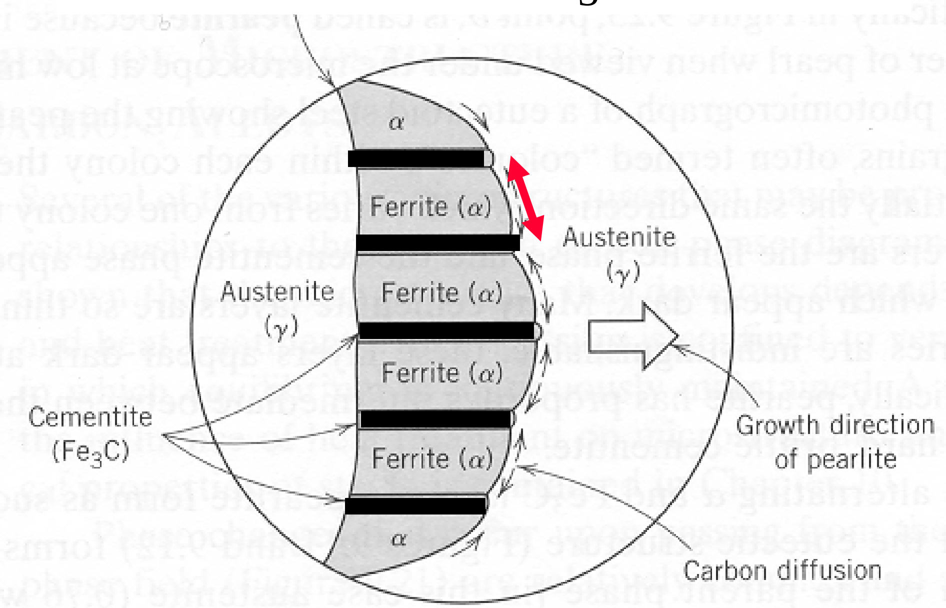


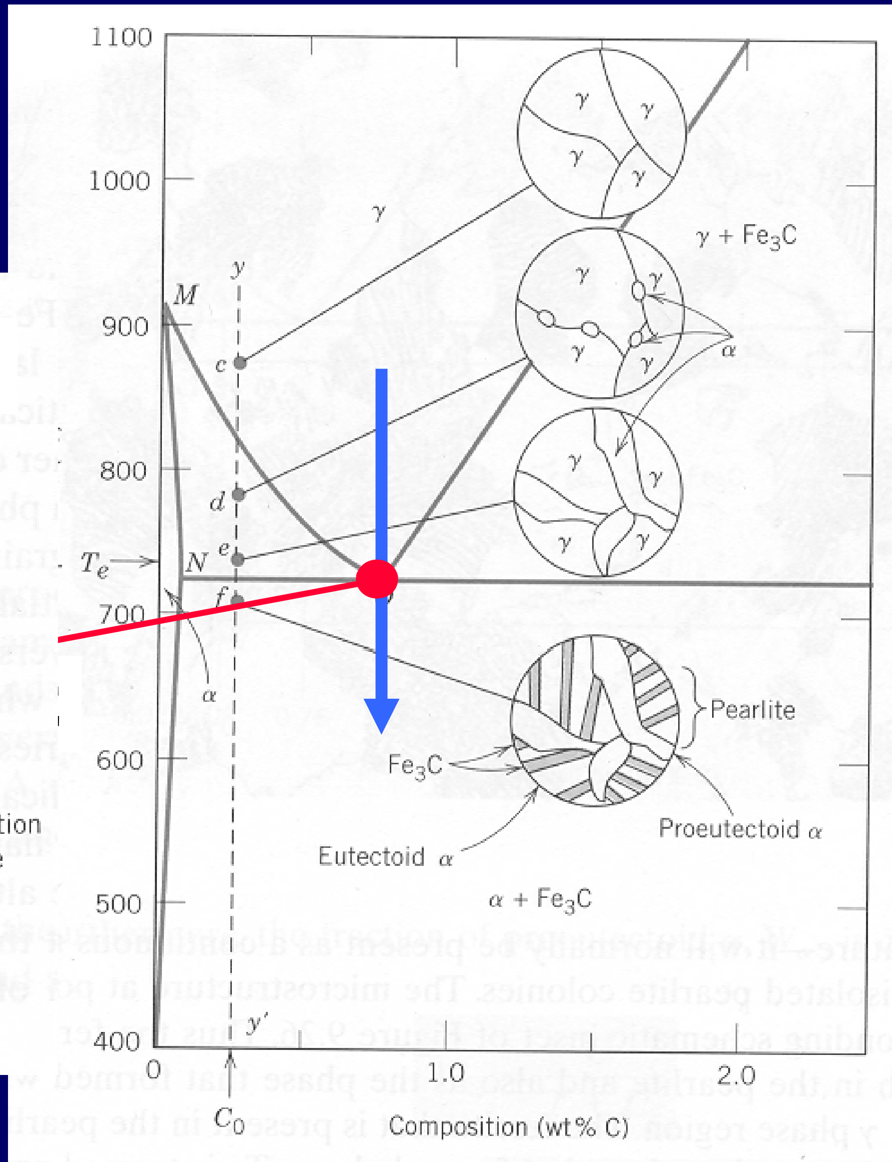


Eutectoid Transformation: Pearlite



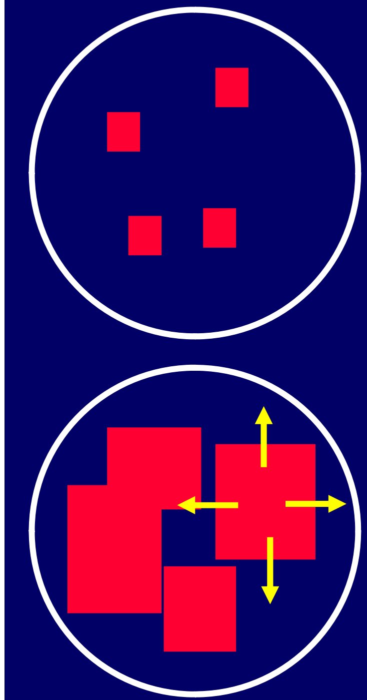
diffusion: C into Fe_3C lamellae





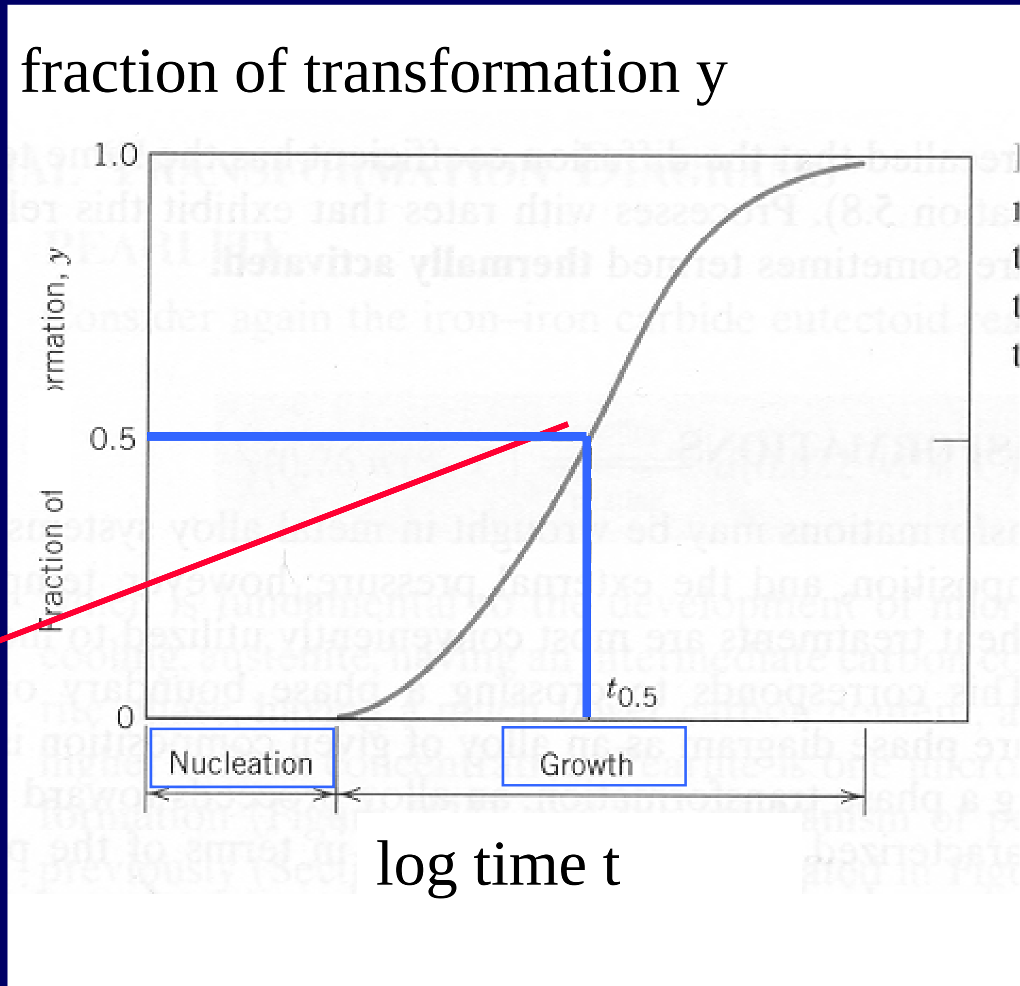
not instantaneously!! -> f(time)

Phase Transformation



nucleation
(e.g. at phase/grain boundaries)

growth
(volume of parent phase disappears)



kinetics: $y=1-\exp(-kt^n)$
(Avrami equation)

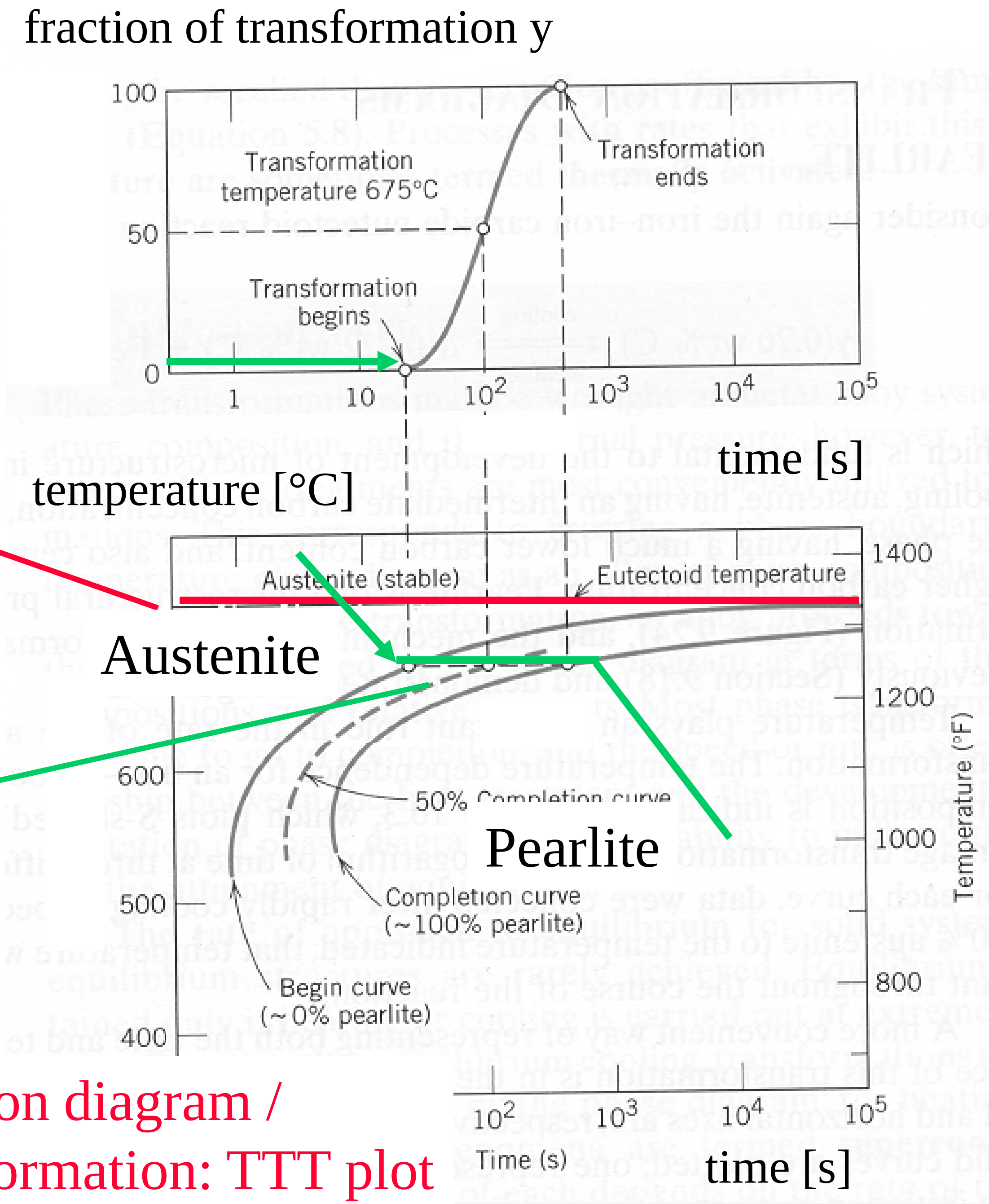
rate r: $r=1/t_{0.5}$

$r=A\exp(-Q/RT)$ Arrhenius relationship: thermally activated processes

Pearlite Formation - Isothermal Transformation

equilibrium according to Fe-C phase diagram
(even normal cooling: 10-20K below equilibrium)

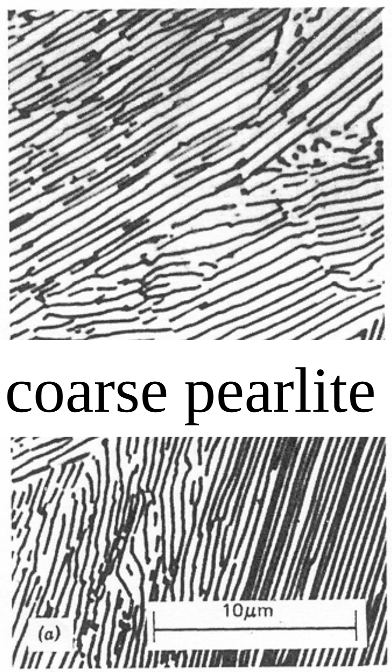
rapid cooling to 675°C isothermal pearlite formation



isothermal transformation diagram /
time temperature transformation: TTT plot

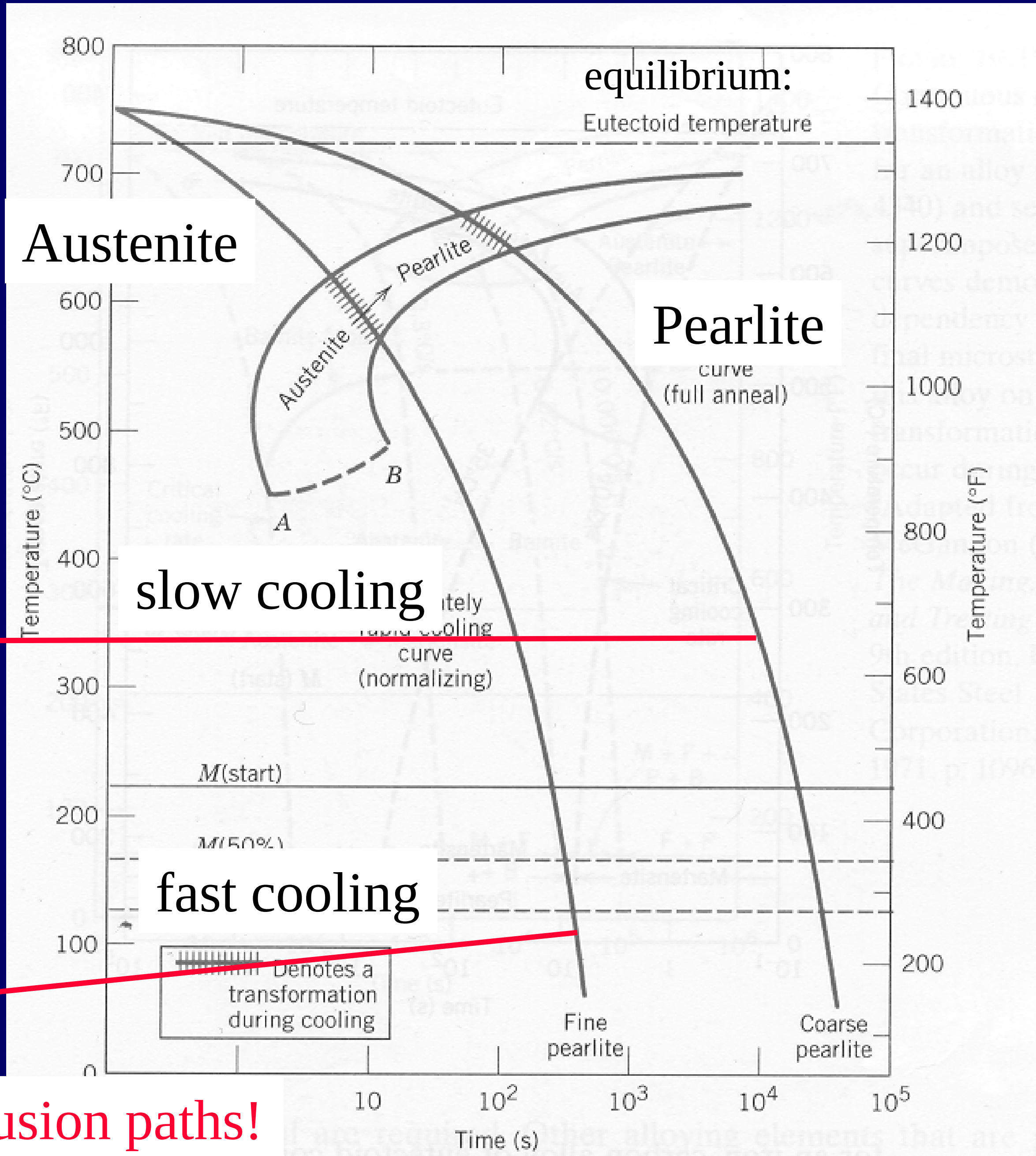
Alteration in Microstructure

continuous cooling transformation (CCT)



coarse pearlite

fine pearlite



lower T => shorter diffusion paths!

Bainite Formation

pearlite formation:

increasing thermodynamic driving force

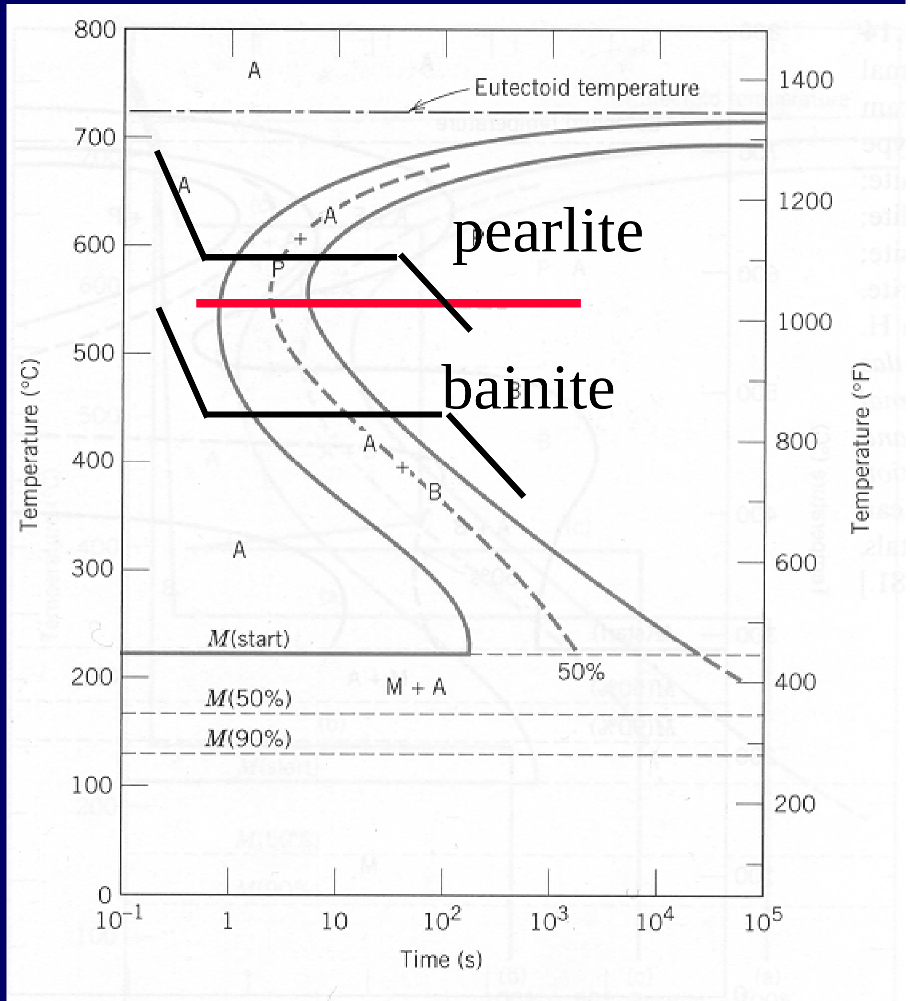
faster reaction

coarse => fine pearlite

bainite formation:

lower T: decreasing C diffusivity

very fine Fe_3C needles in α ferrite



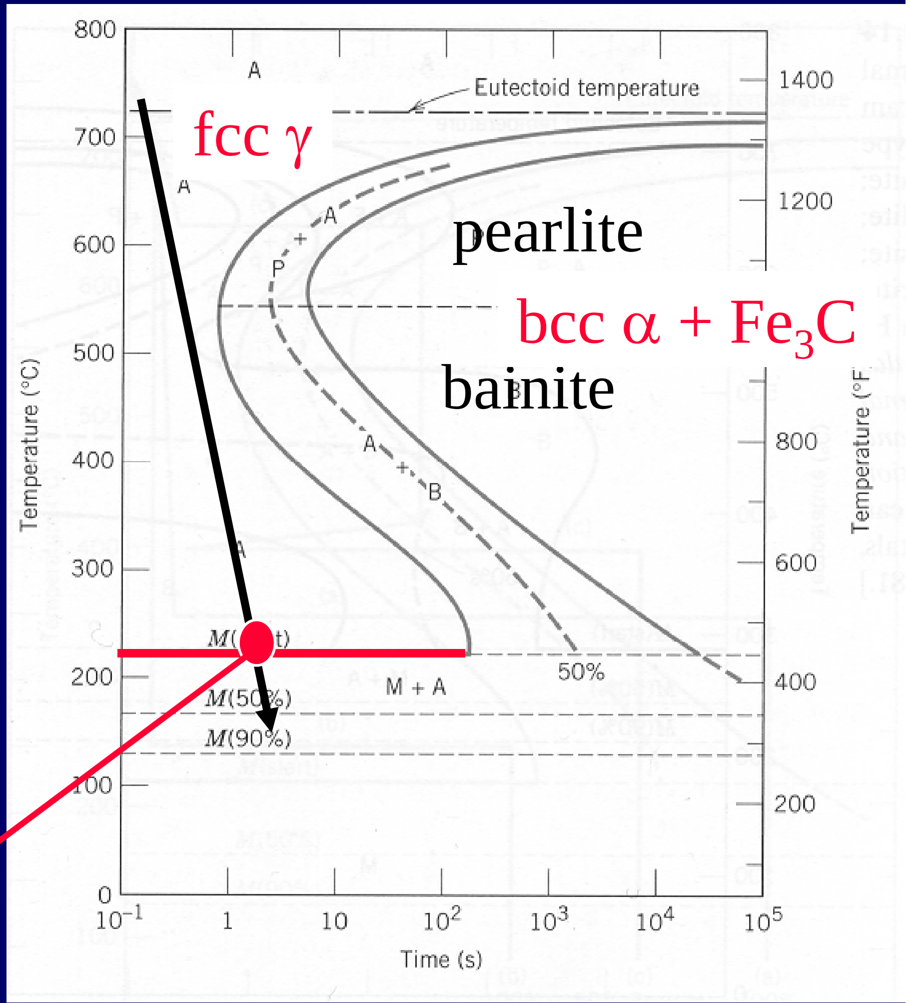
Martensite Formation

very fast cooling to RT
(no intersection with
transformation " nose")

C diffusion becomes extremely
slow -> negligible!!

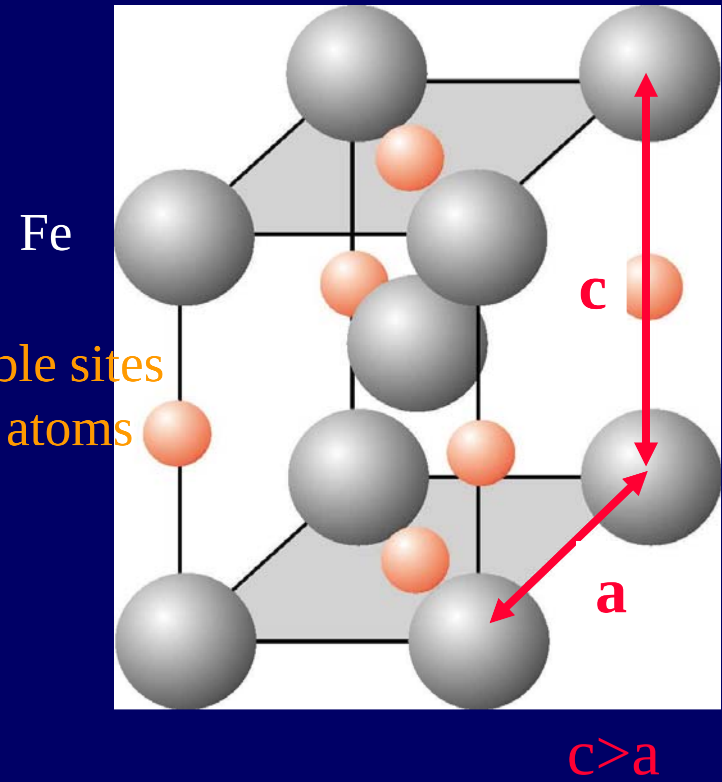
thermodynamic driving force for
fcc=> bcc transformation increases

fcc turns in bct martensite lattice
almost instantaneously:
=> C remains dissolved interstitially



Martensite Formation

bct unit cell of martensite
supersaturated solid solution



=> high strength
=> brittle

martensite plates / austenite

Heat Treatment – Mechanical Properties

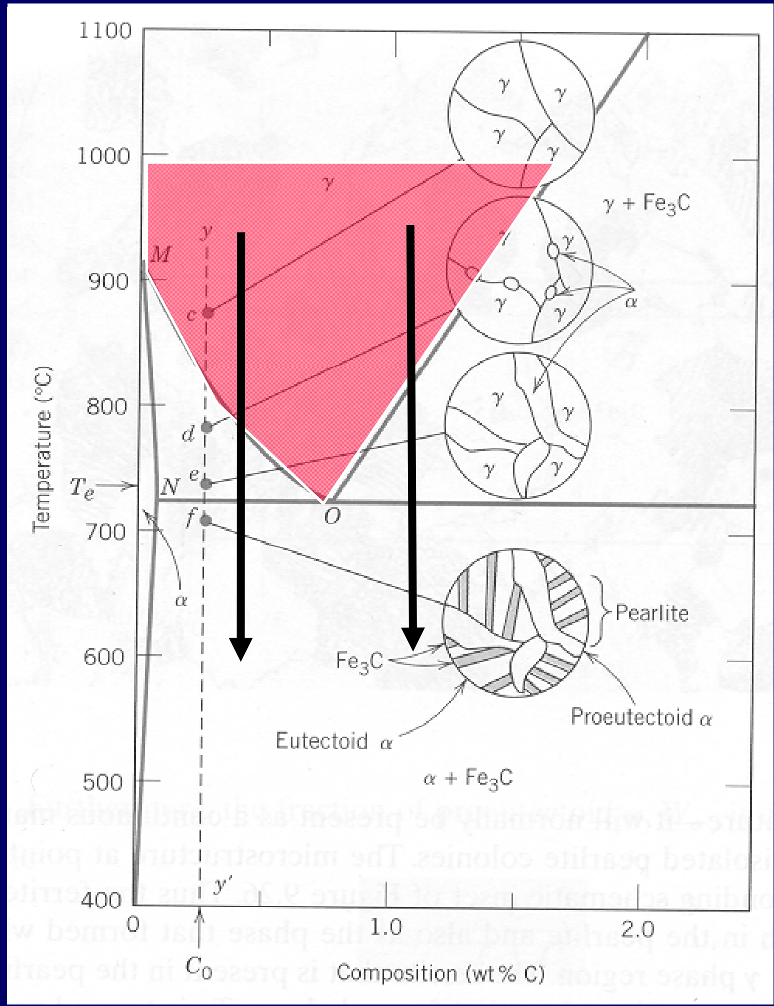
Normalizing (Austenite)

slow cooling:
hypo-eutectoid: α-ferrite+pearlite
hyper-eutectoid: pearlite + Fe_3C

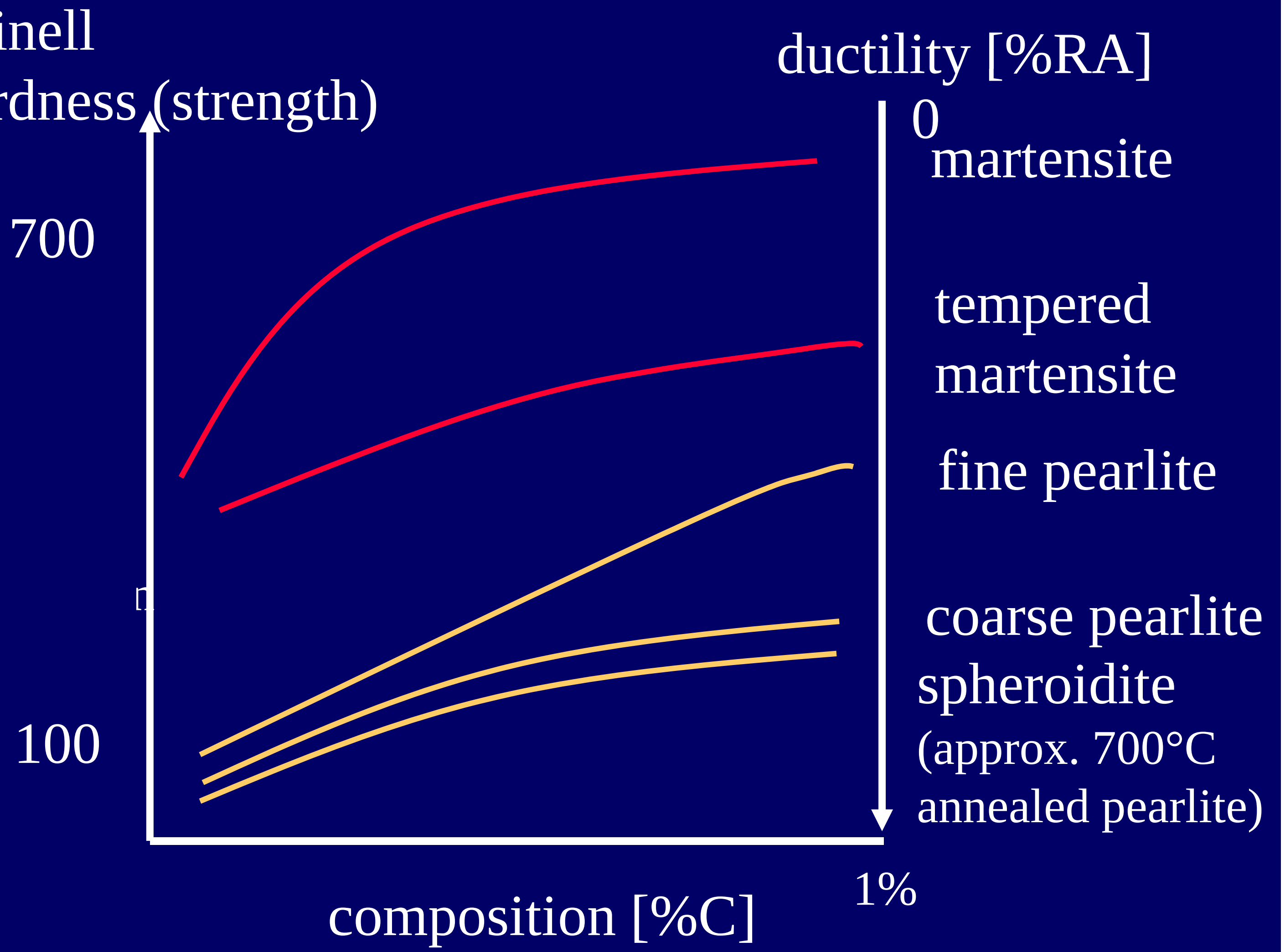
moderate cooling:
bainite

fast cooling:
martensite

reheat (250°C-600°C)
tempered martensite

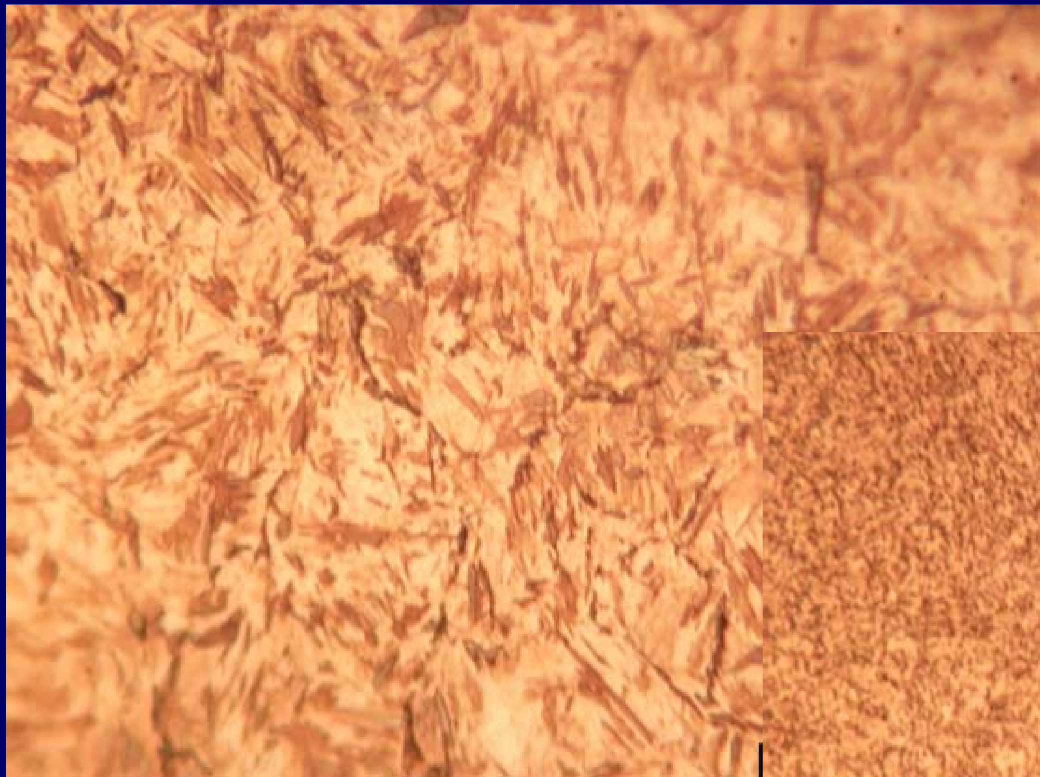


Mechanical Properties



martensite
=>no ductility
=>C blocks dislocation
motion

Tempered Martensite



reheating (650°C)

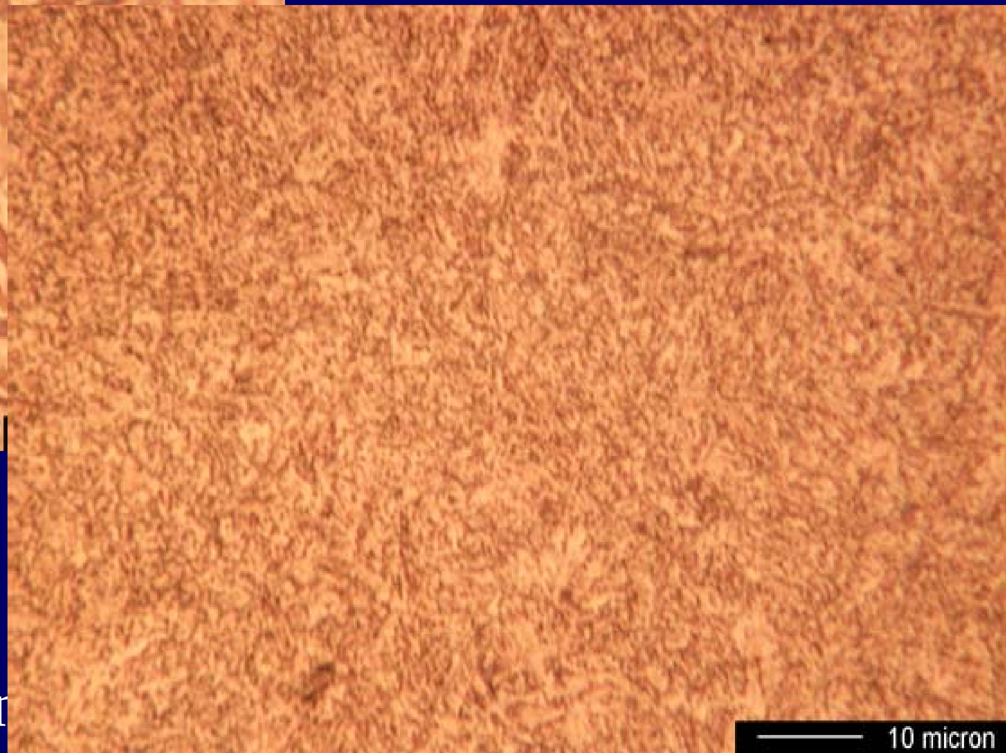
=>C diffusion is possible

=>fine-dispersed Fe_3C precipitates

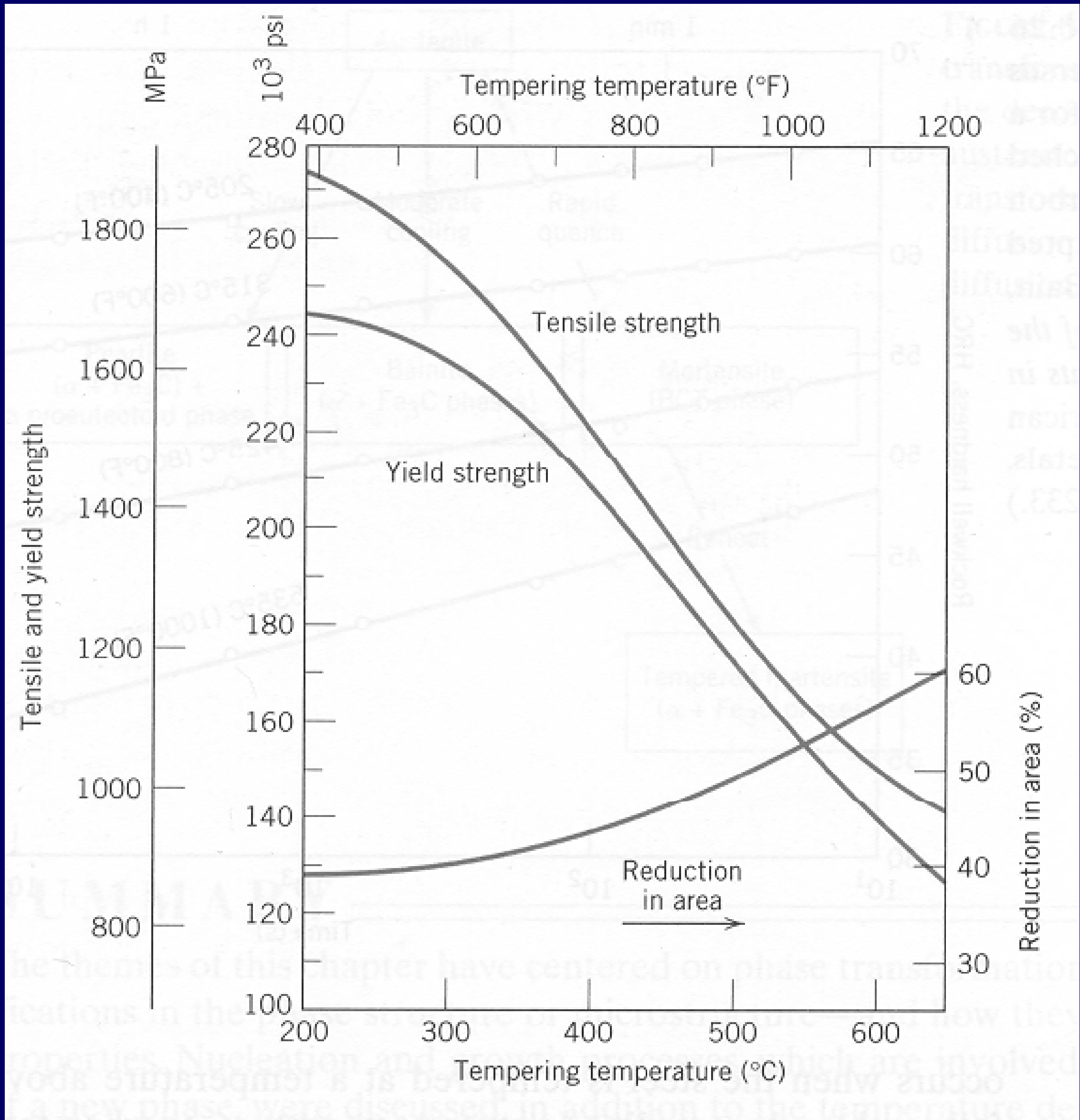
normalized (austenite)

↓

water-quenched (=> marter



Tempered Martensite



good combination of
1 strength
and
2 ductility

Strengthening Mechanisms in Metals

1 grain size reduction

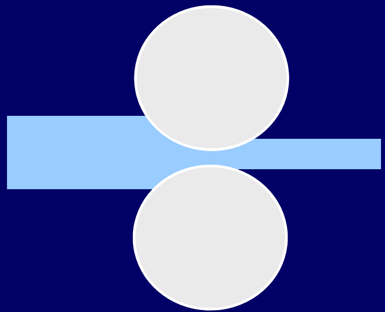
grain boundary acts as barrier to dislocation motion
due to: direction change (misorientation)
dicontinuity of slip planes
=> Hall-Petch relationship: $\boldsymbol{\sigma_Y = \sigma_0 + k_Y d^{-1/2}}$

how can the grain size be modified?
control of solidification rate (fast)
avoid grain growth (high temperatures)
plastic deformation + heat treatment (recovery + recrystallization

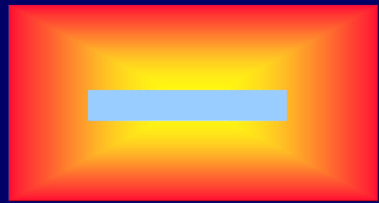
2 Strain Hardening/Work Hardening

increase in dislocation density

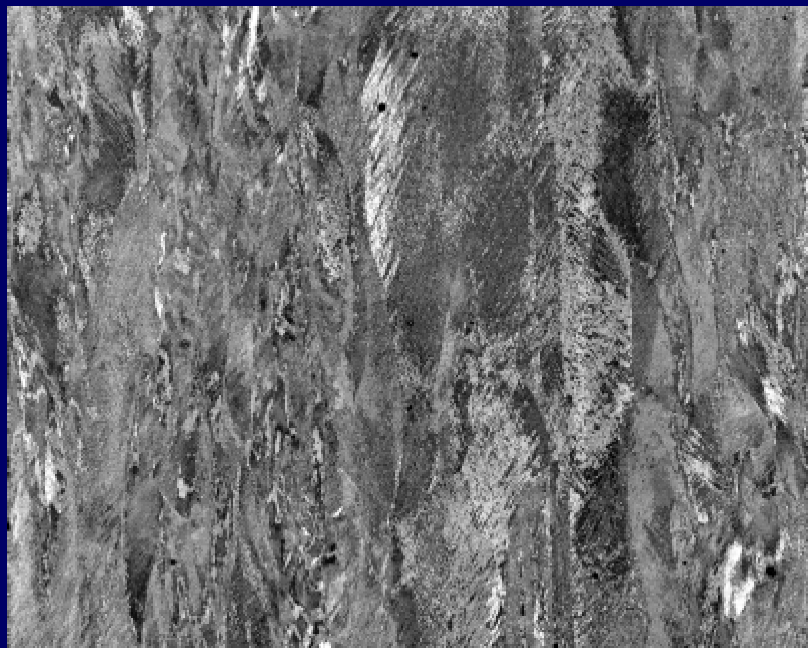
Recovery and Recrystallization



e.g. rolling:
stored internal strain energy



heat treatment:
rearrangement of dislocations nucleation and growth of new grains



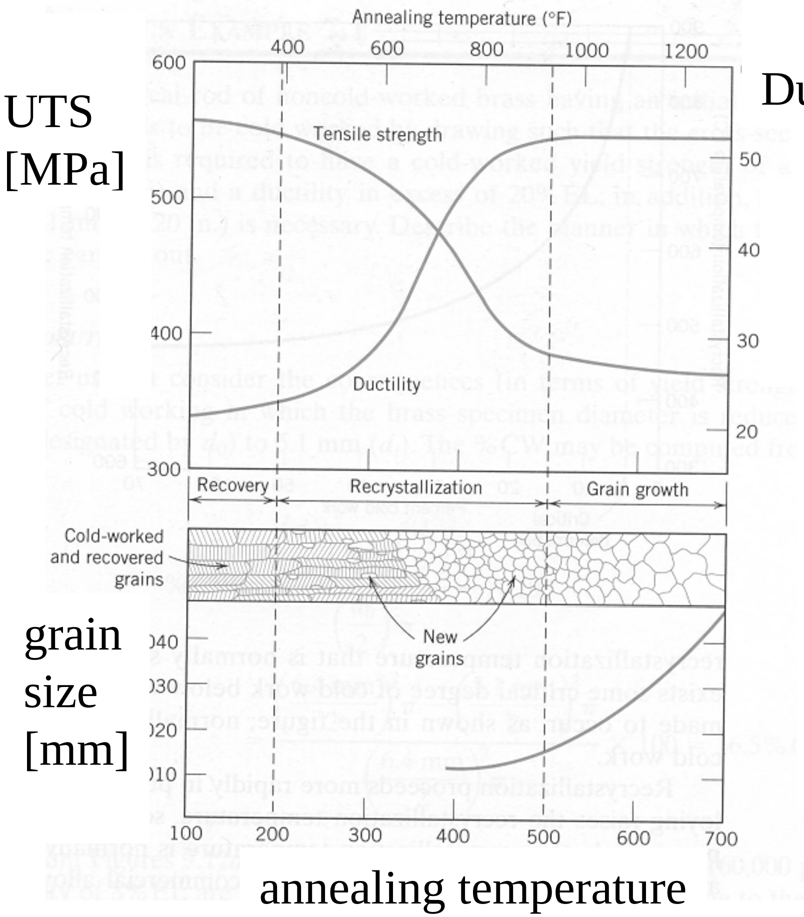
in-situ recrystallization in the SEM

Recrystallization Temperature

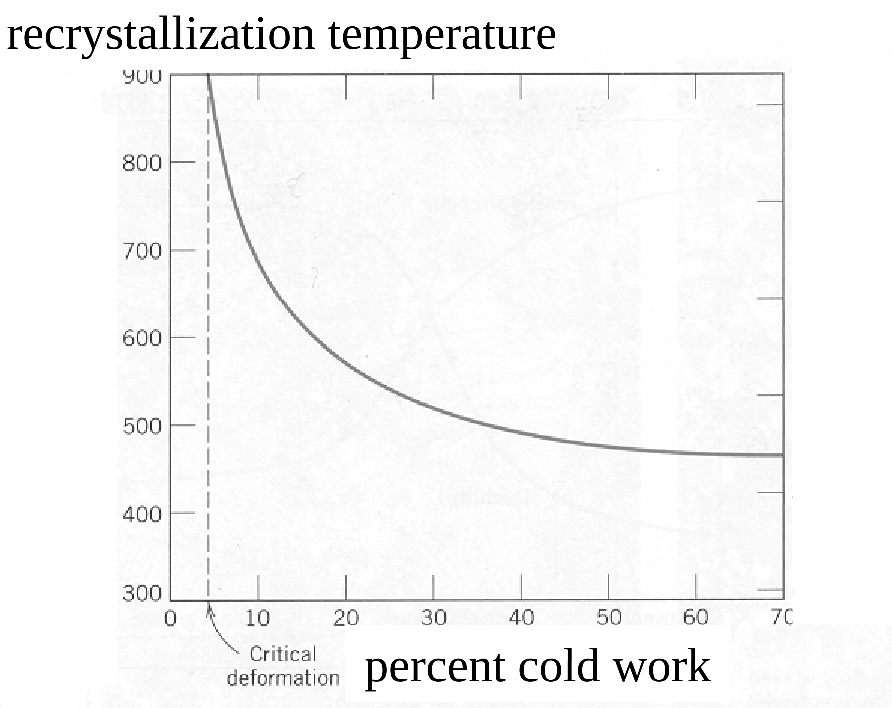
= new grain formation (recrystallization) finished after 1h

depends on: degree of cold work

in-situ recrystallization during *hot working* (e.g. hot rolling)



Ductility



Strengthening Mechanisms in Metals

3 solid solution strengthening

by alloying elements

lattice strains ⇔ restrict dislocation motion

4 precipitation hardening

incoherent precipitates: e.g. carbides in steels,

=barriers to dislocation motion/constraints

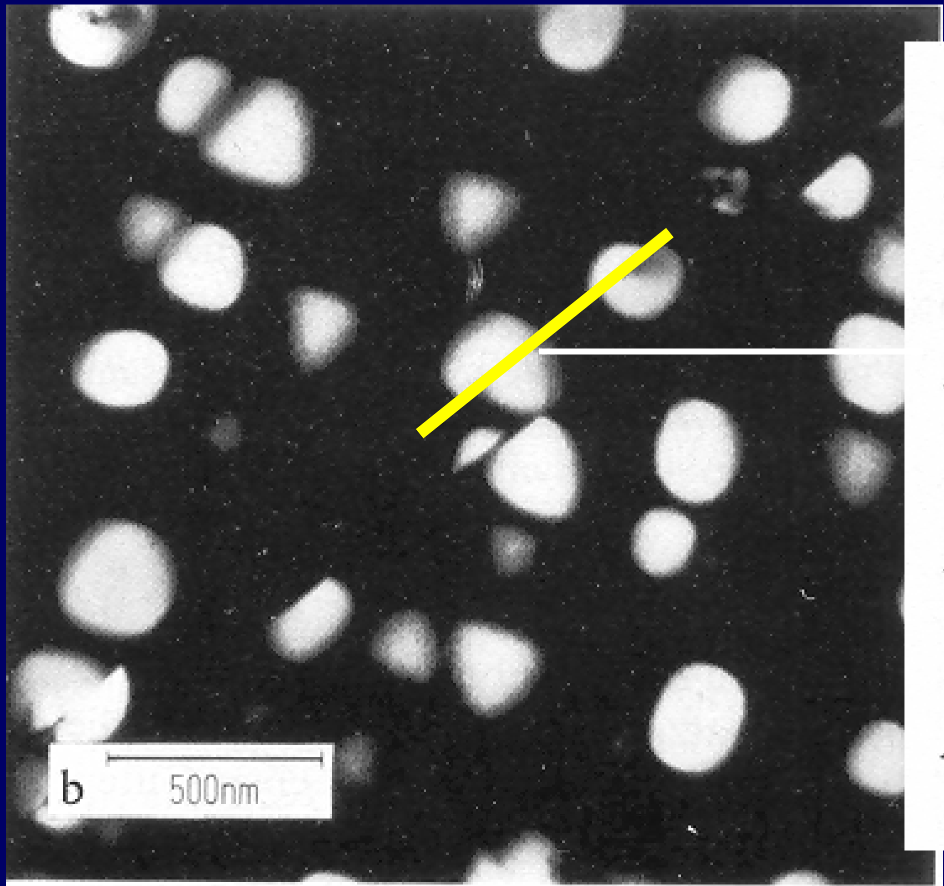
coherent precipitates: e.g. γ' phase in Ni-base superalloys

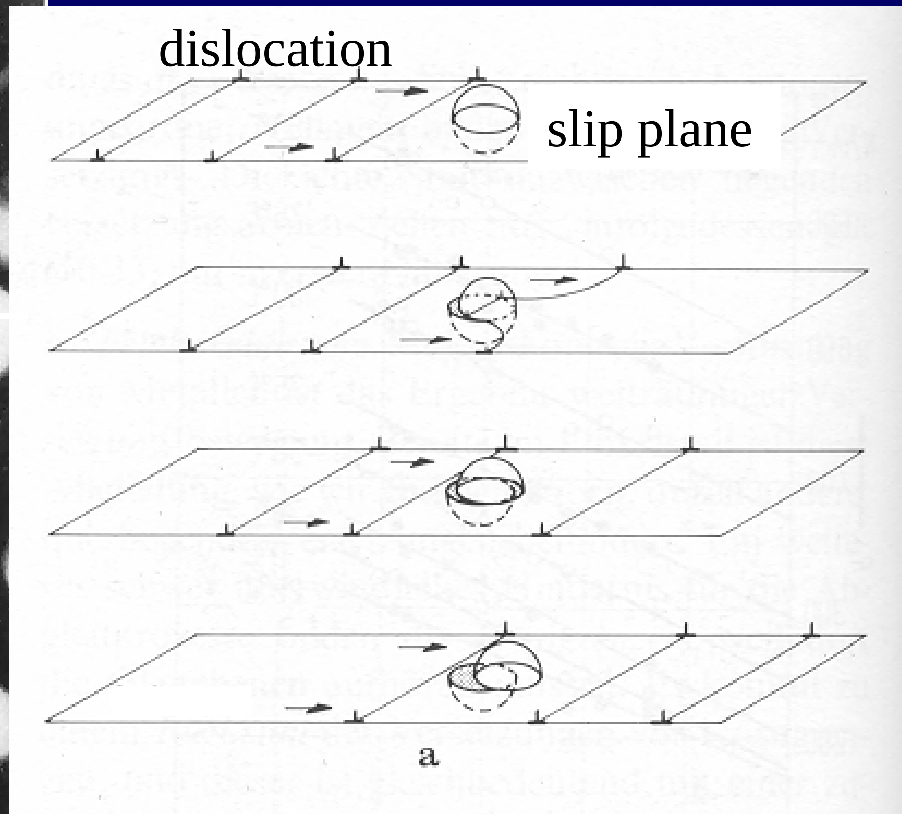
or Θ'' phase in Al-Cu alloys

=cutting – barrier effect by disrupting the order/new interfaces

Precipitation Hardening

cutting coherent γ´particles (Ni_3Al) in Ni-base superalloys





→ generation of disorder