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Transition from Diffusive to Displacive Austenite Reversion in Low-Alloy Steel

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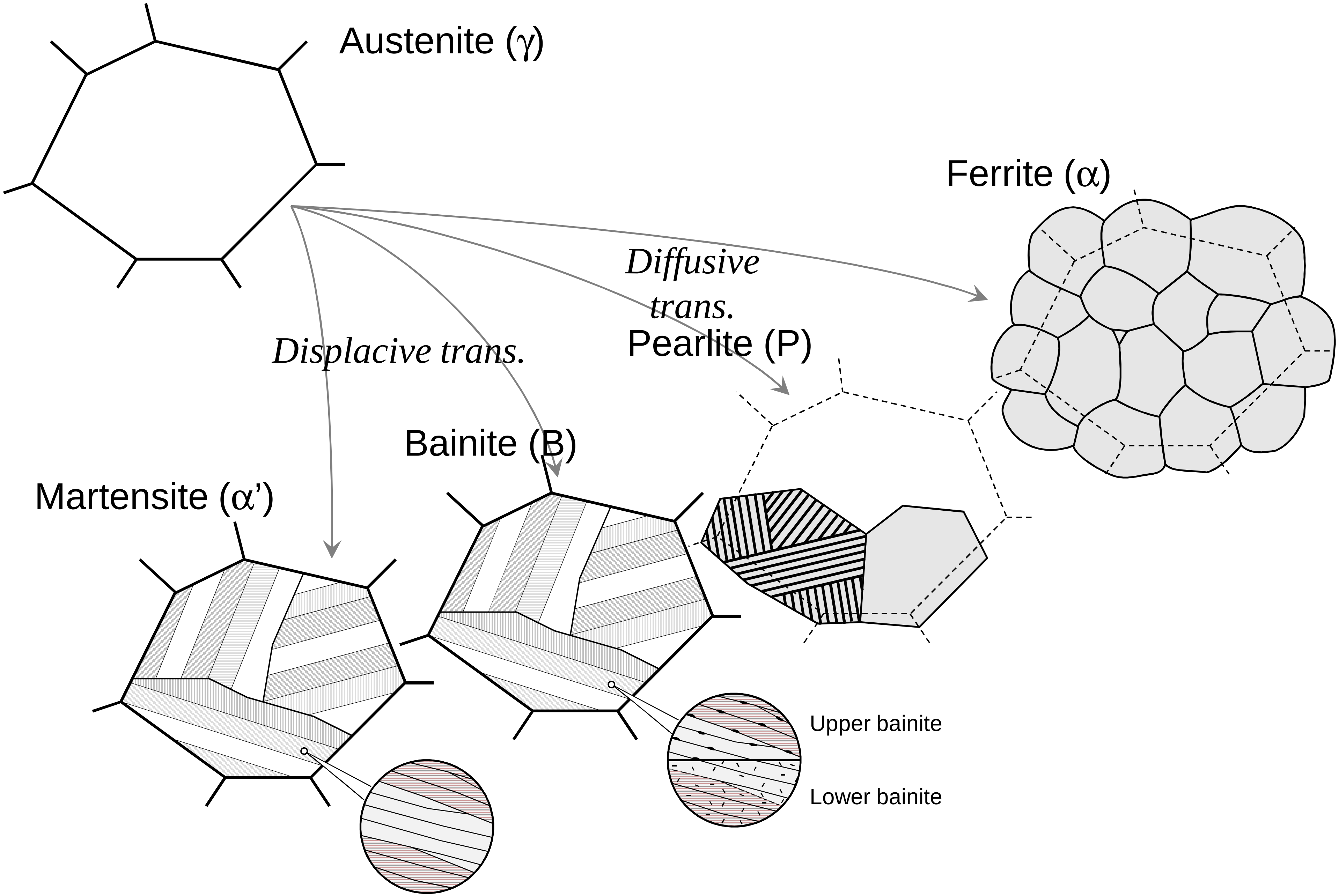
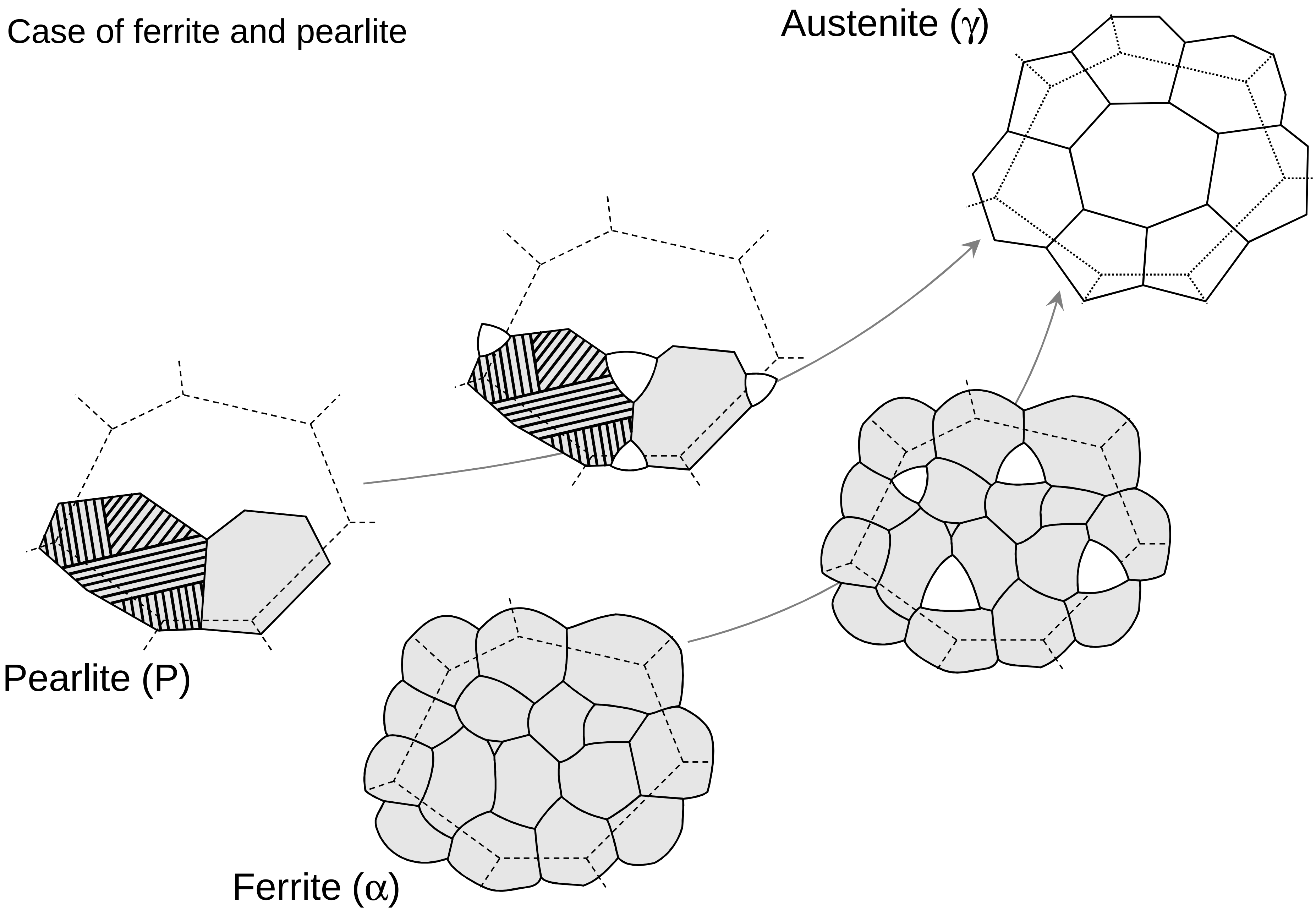
Transformations from austenite on cooling



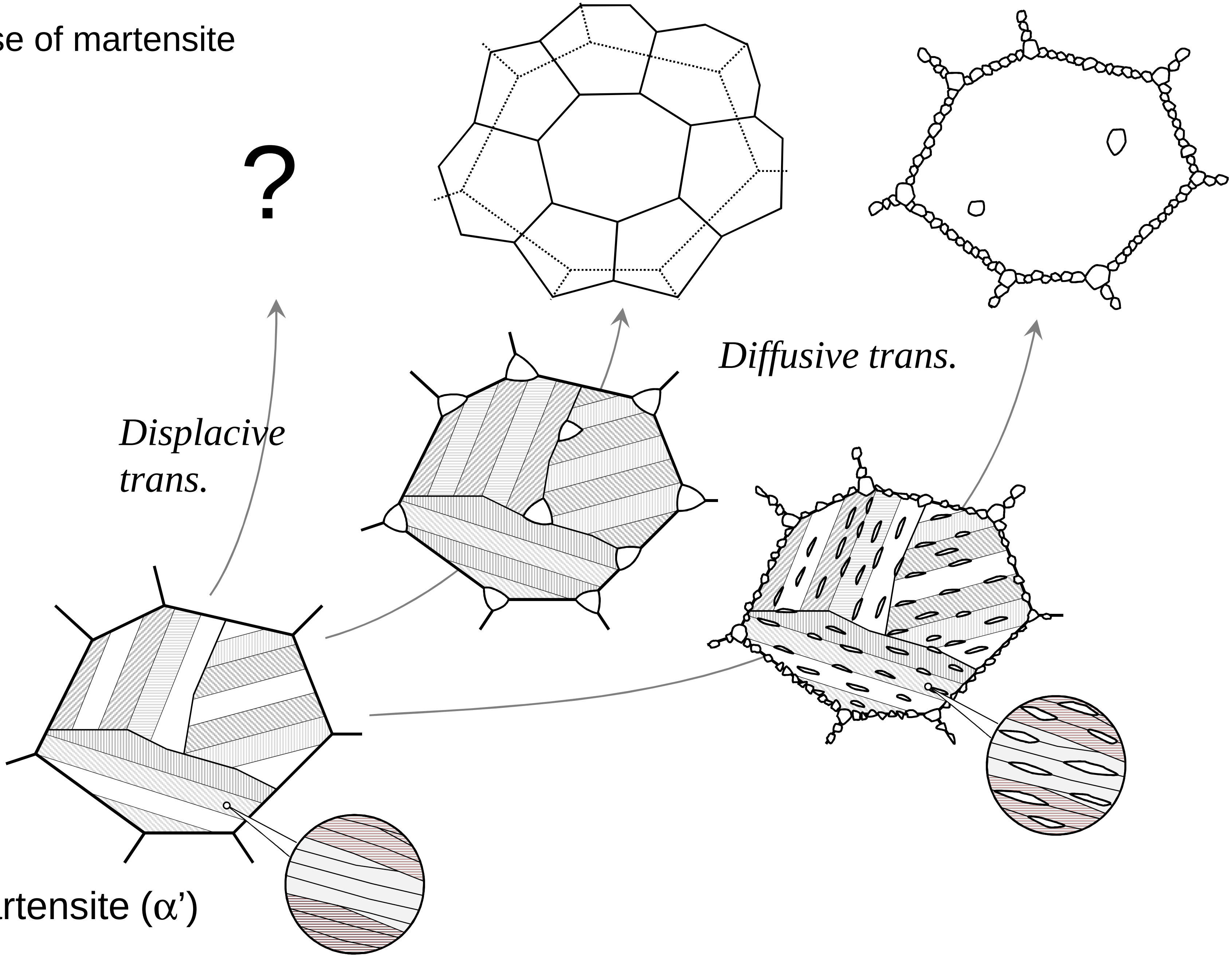
Reverse transformations to austenite on heating

Case of ferrite and pearlite

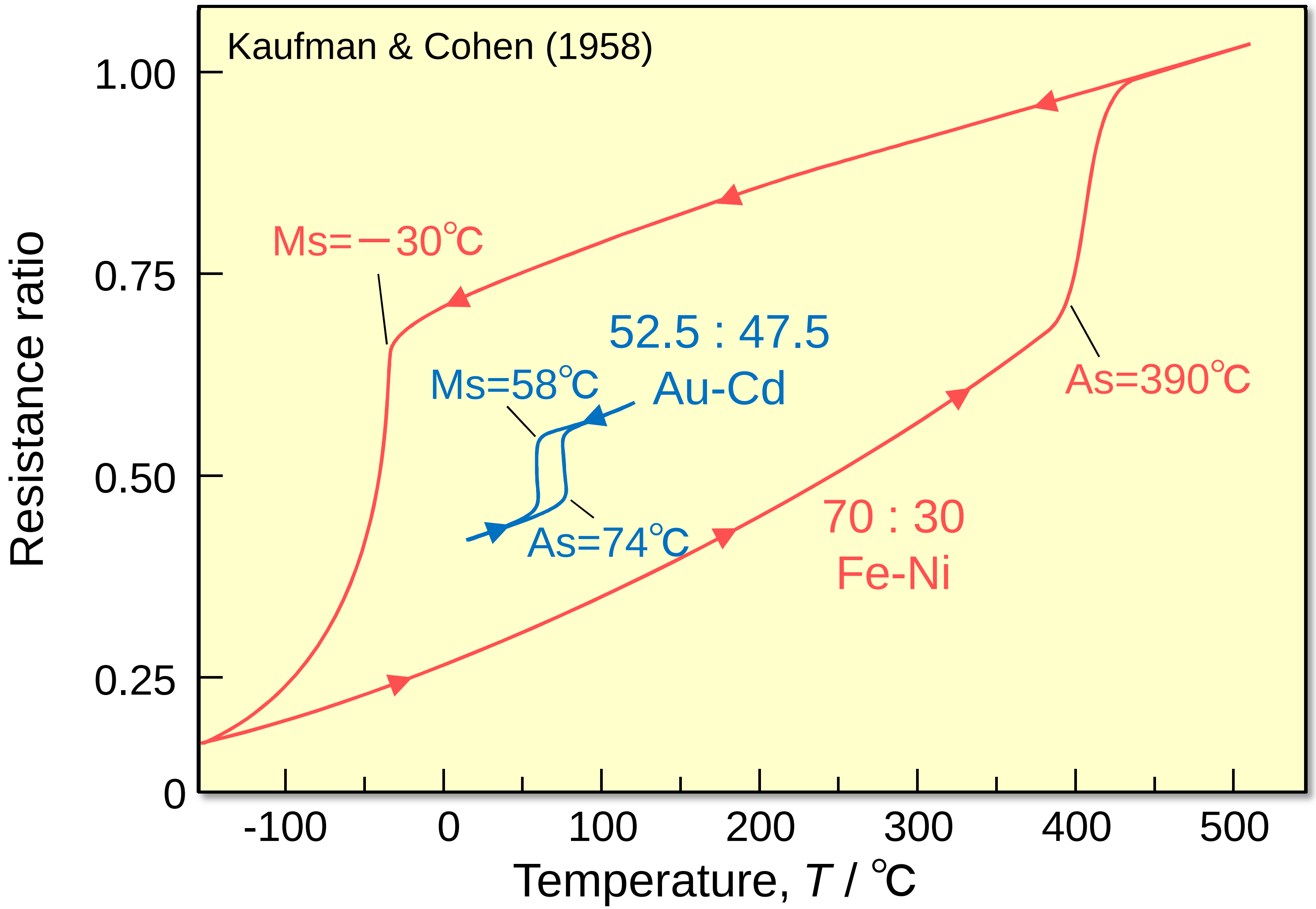


Reverse transformations to austenite on heating (from martensite)

Case of martensite



Thermoelastic and athermoelastic martensitic transformation



Small hysteresis: Thermoelastic martensitic trans.

Large hysteresis: Athermoelastic martensitic trans. → Difficult

界面移動に及ぼす合金元素の効果FIにおける取組

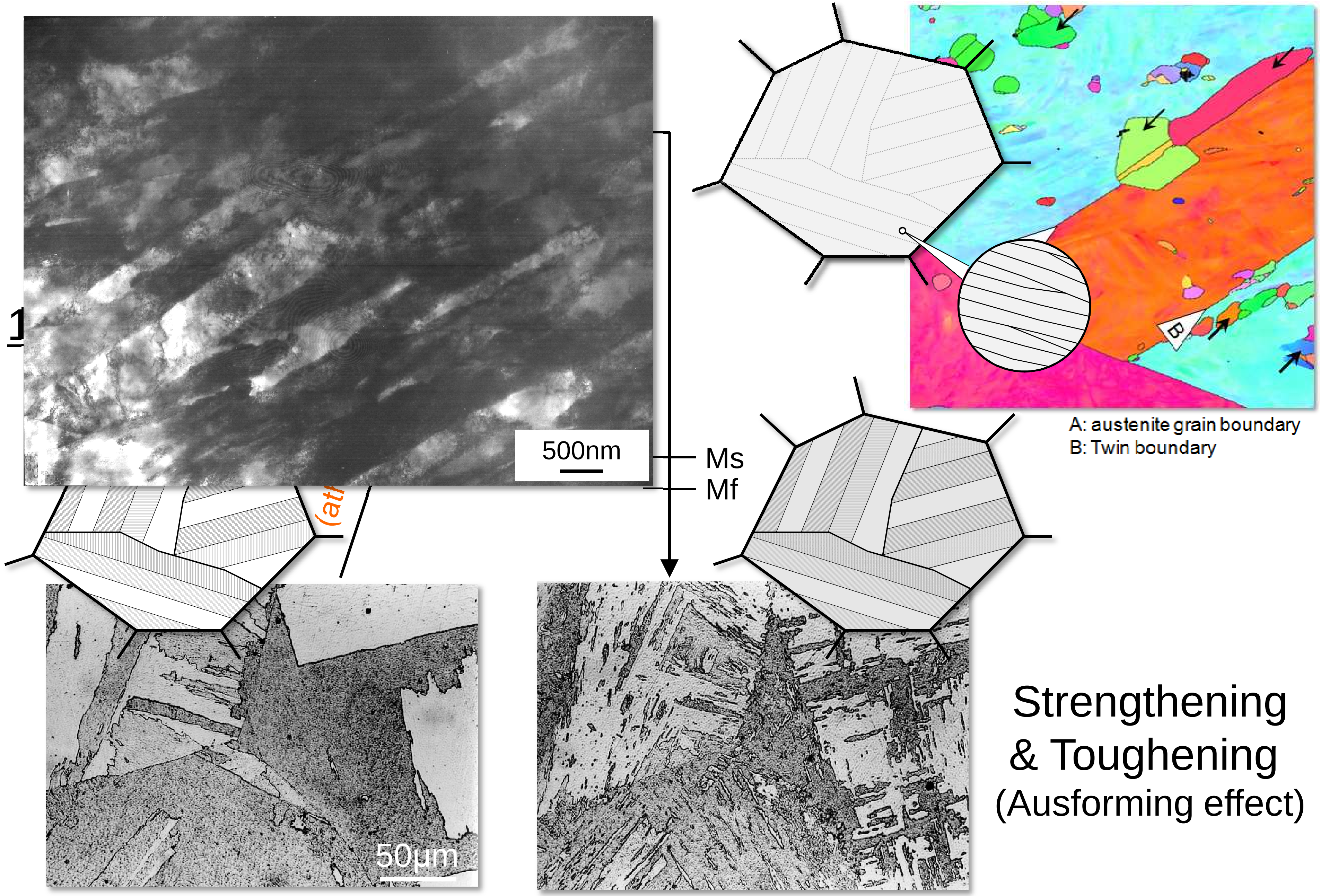
1. Microstructural characterization of austenite formed via martensitic reversion

→ N. Nakada et al.: *ISIJ International*, 53(2013), 1286-1288.

2. Transition of reversion mechanism depending on heating rate in low alloy steel

→ N. Nakada et al.: *ISIJ International*, 53(2013), 2275-2277.

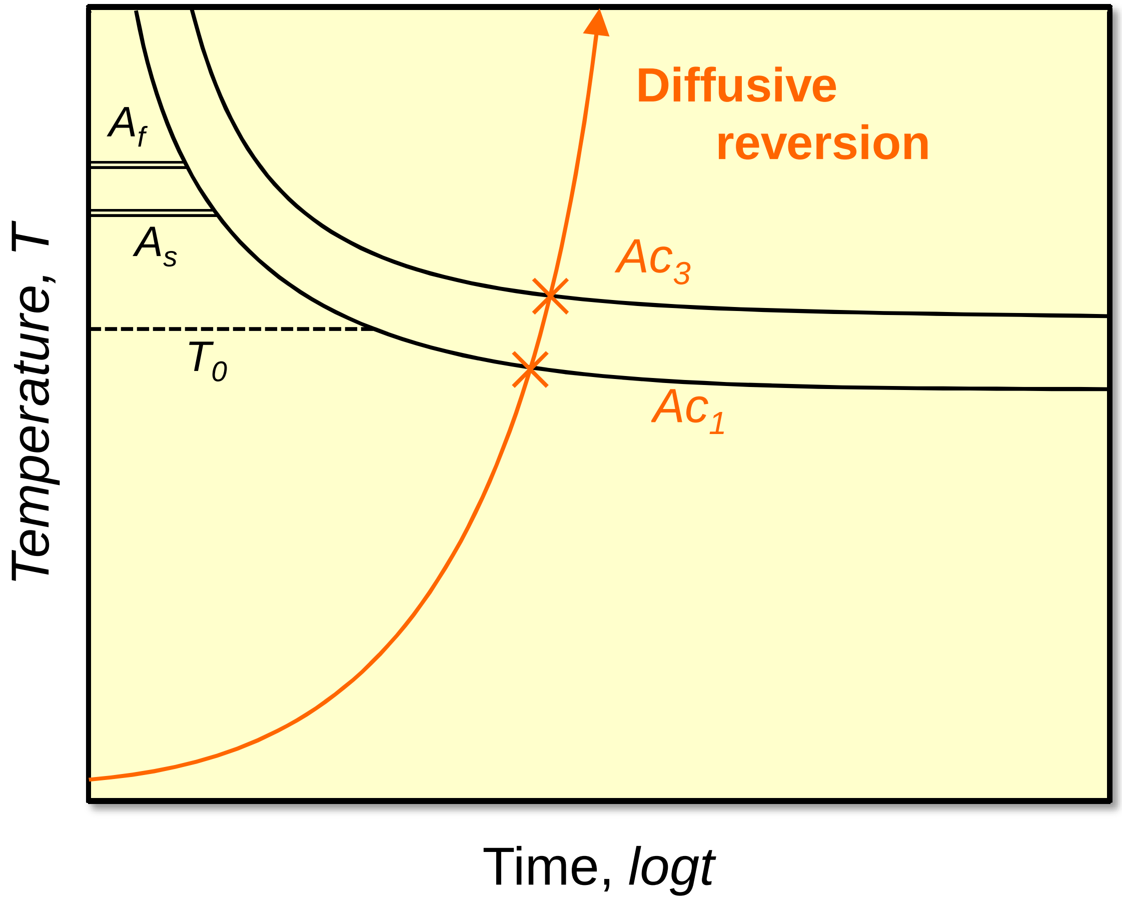
Martensitic reversion in high alloy steel (18Ni-C steel)



Strengthening
& Toughening
(Ausforming effect)

Diffusive vs. Martensitic reversion

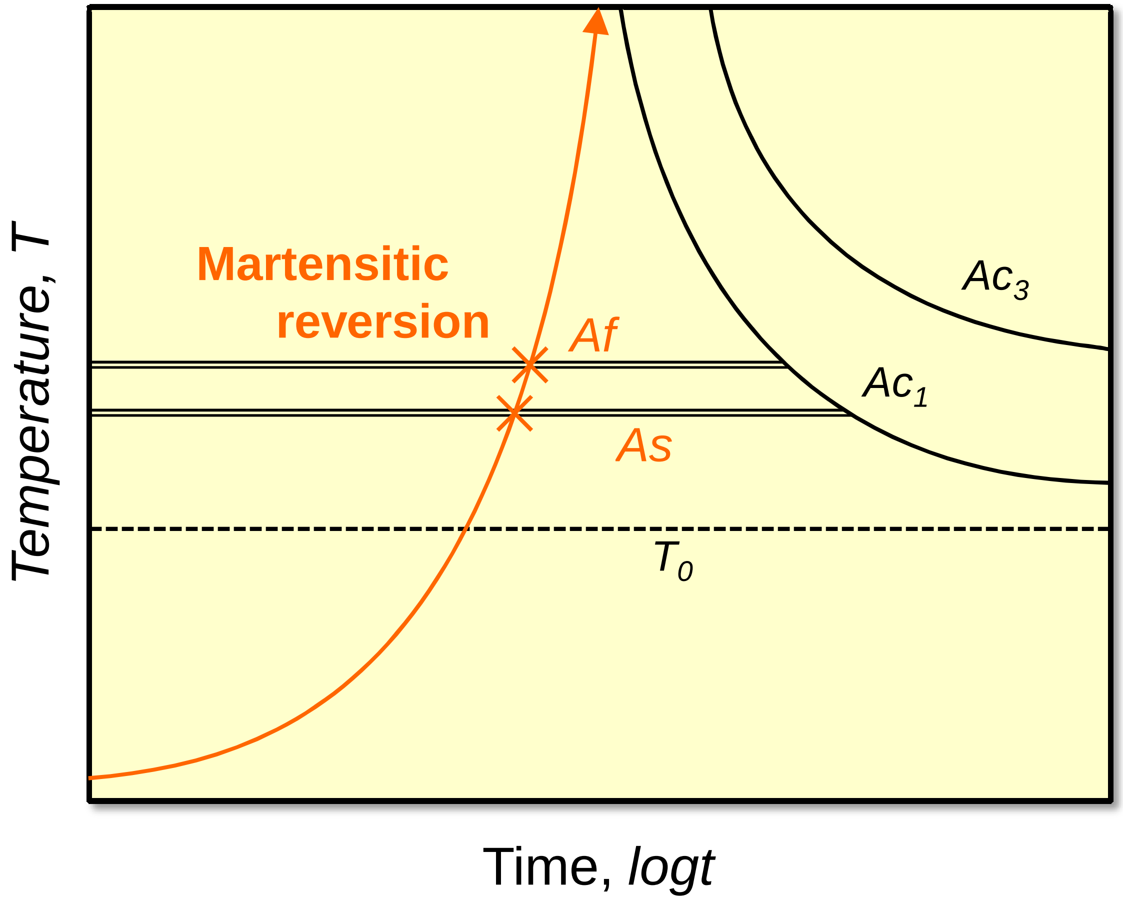
Low alloy steel



Diffusive reversion is major in low martensitic steel,
because atomic diffusion is more easy at higher temperature

Diffusive vs. Martensitic reversion

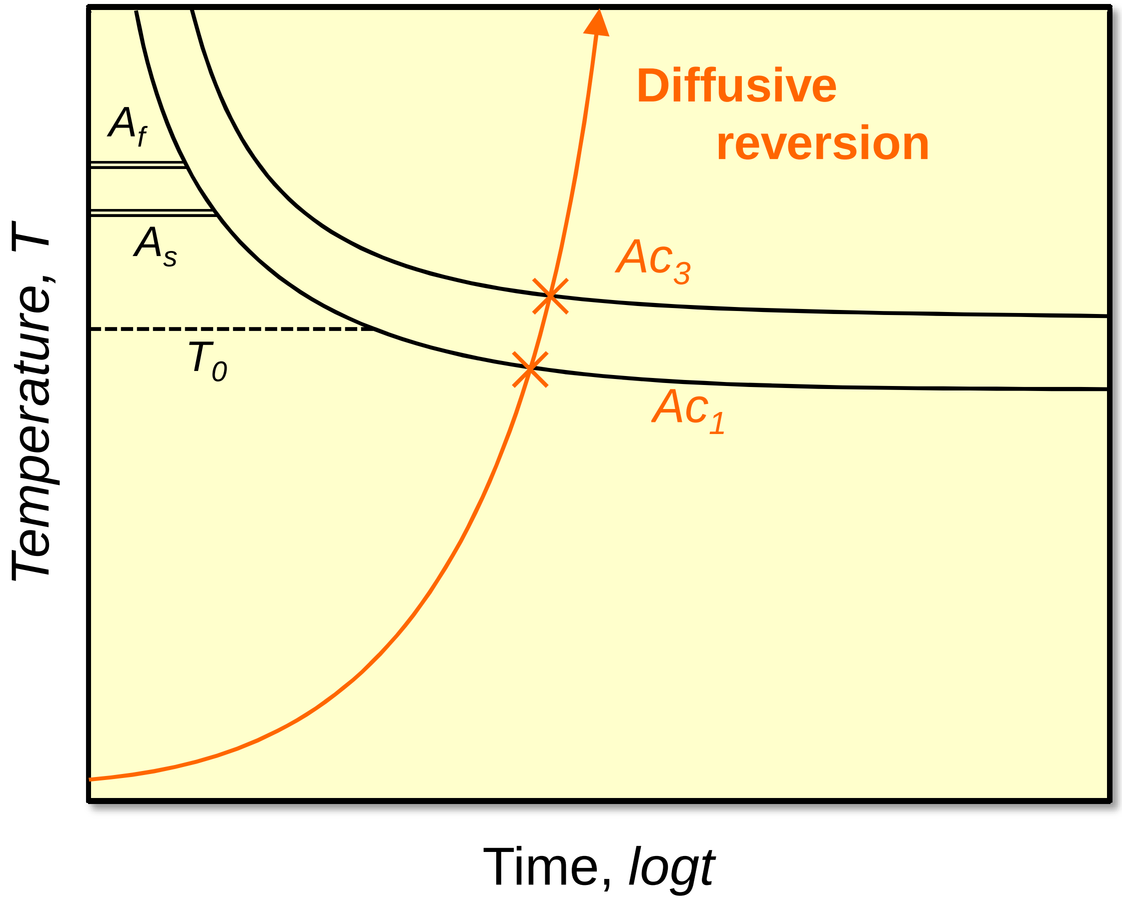
High alloy steel (e.g.18%Ni steel)



Martensitic reversion takes place more easily in martensitic steel with high amount of austenite former element.

Diffusive vs. Martensitic reversion

低合金マルテンサイト鋼



Does reversion mechanism changes depending on hearting rate?
(Martensitic reversion uoccures under ultra-high heating rate.)

Purpose

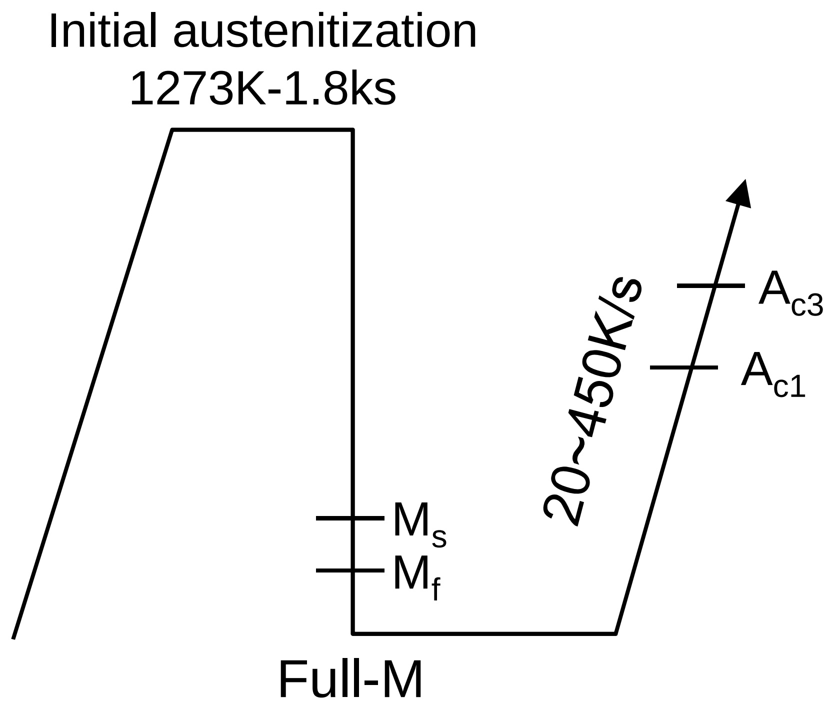
- ✓ To investigate the effect of heating rate on reversion behavior of low alloy martensitic steel.
- ✓ To understand the reversion mechanism in iron and steel with starting lath martensitic structure.

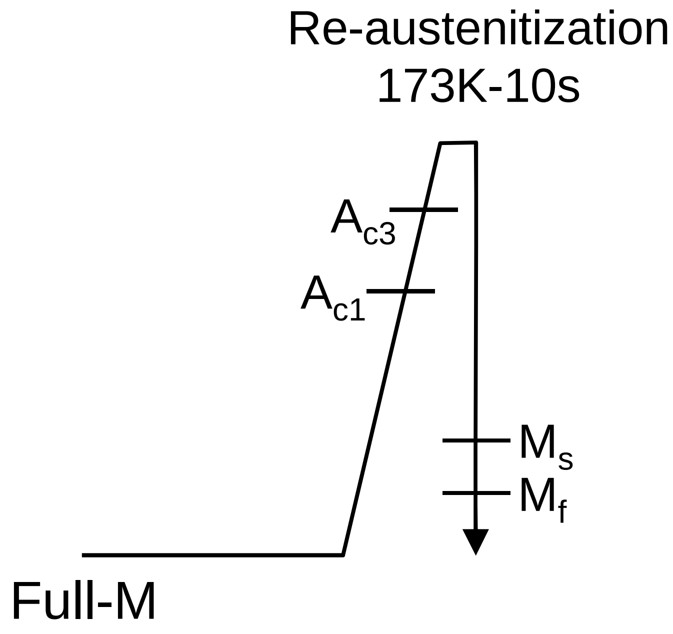
Experimental procedure

Chemical composition (mass%)

	C	Si	Mn	P	S	Al	N
0.15C-5Mn	0.14	0.005	4.97	<0.002	0.0032	0.036	0.0033

T_0=883K(610℃)





Measurement of reversion temp.

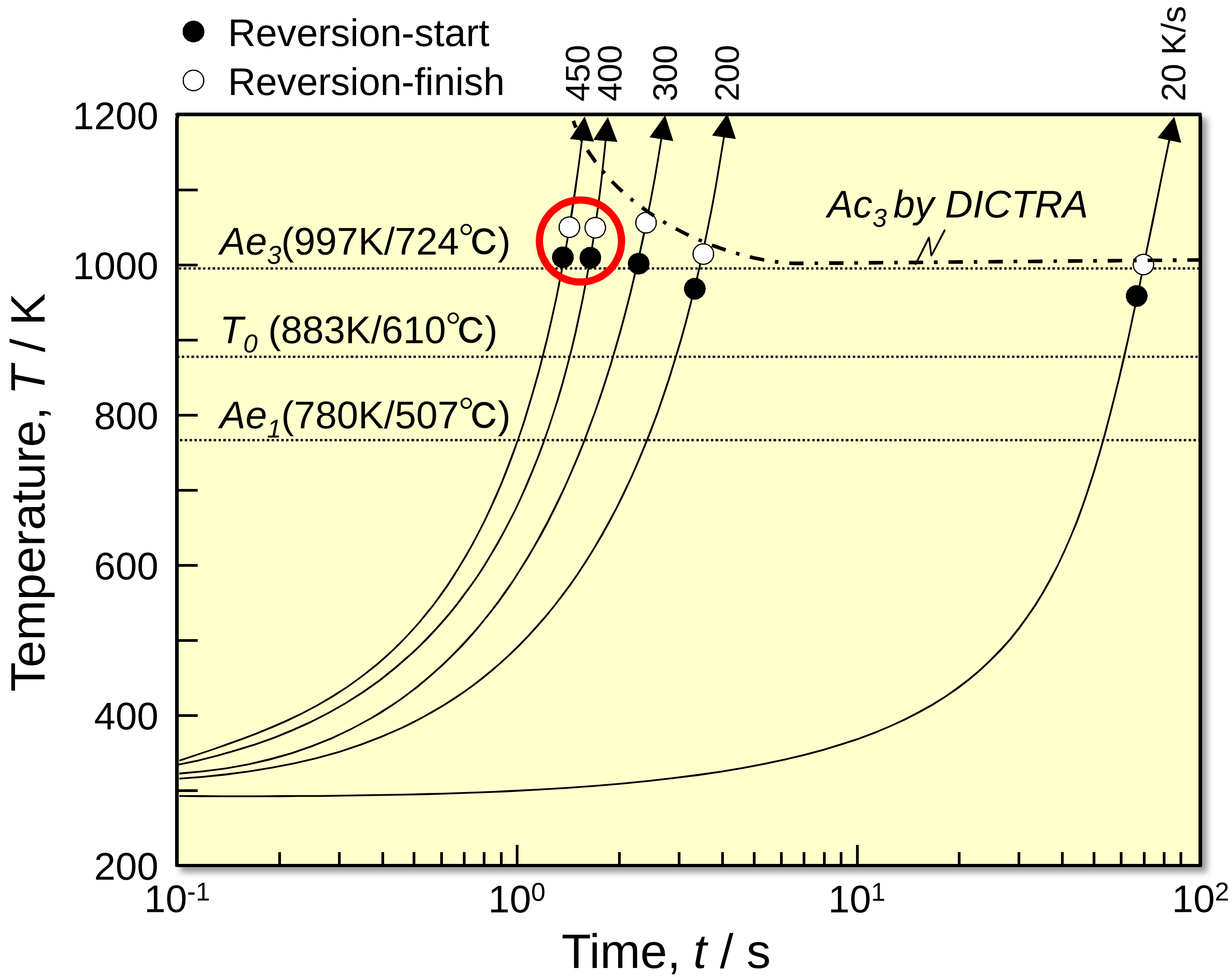
Dilatation test with high-frequency induction heating (ϕ2×10mm)

Microstructural characterization

FE-SEM/EBSD

XRD (dislocation density)

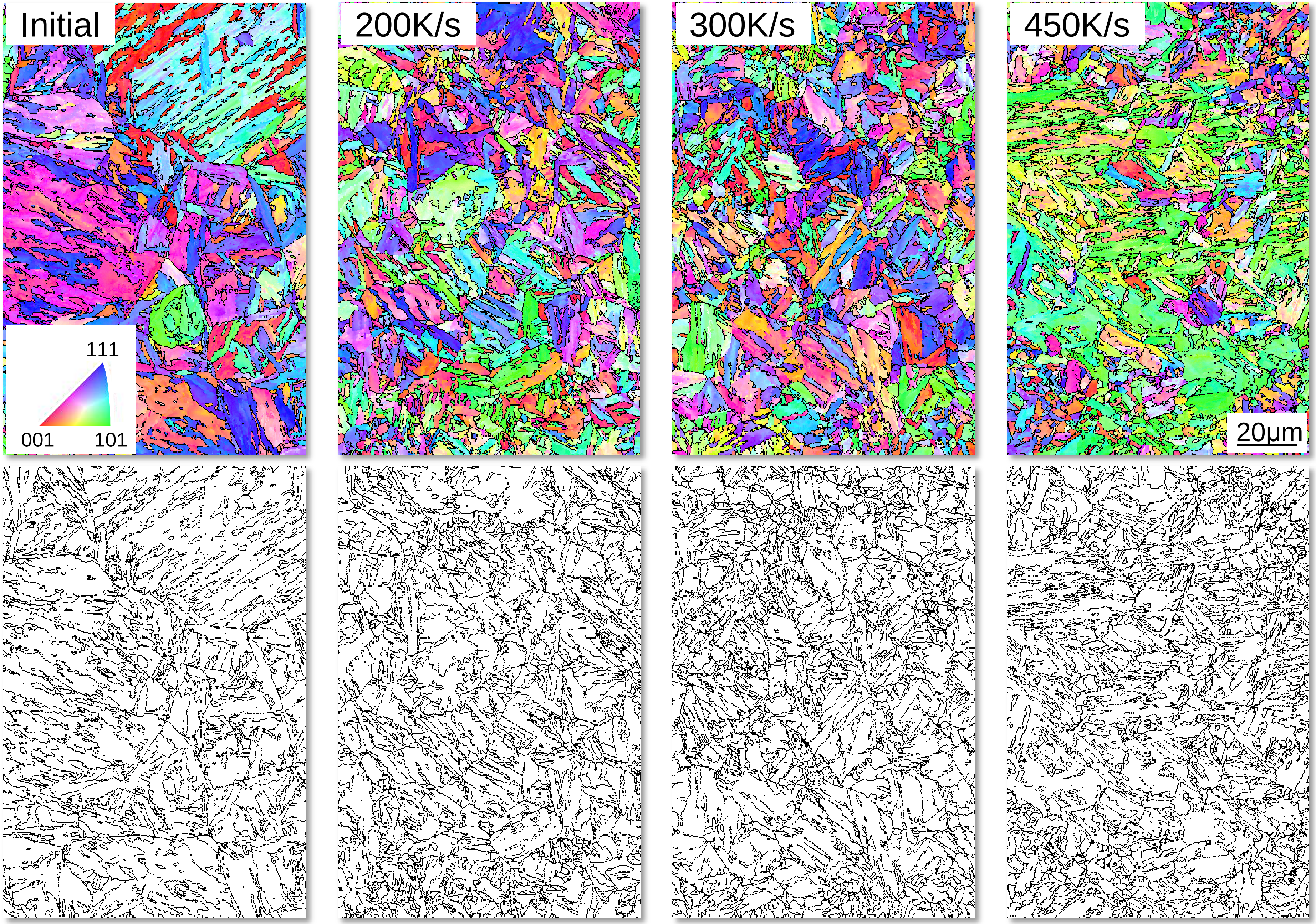
Continuous heating transformation diagram



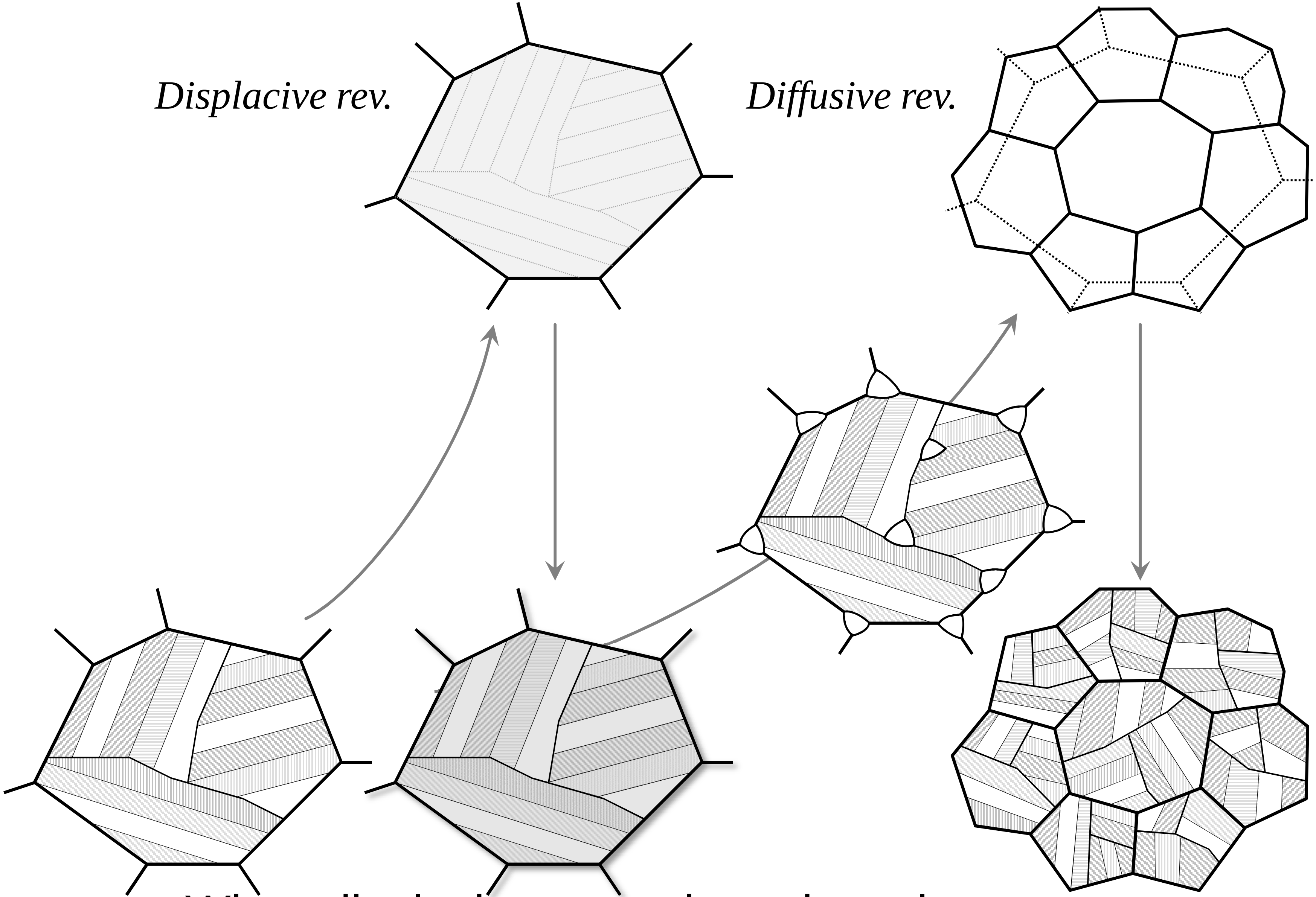
✓ Reversion temperature discontinuously drops over 400K/s

✓ Driving force : 350J/mol @ 1000K (if no carbide precipitation)

Martensitic structure after reversion and quenching

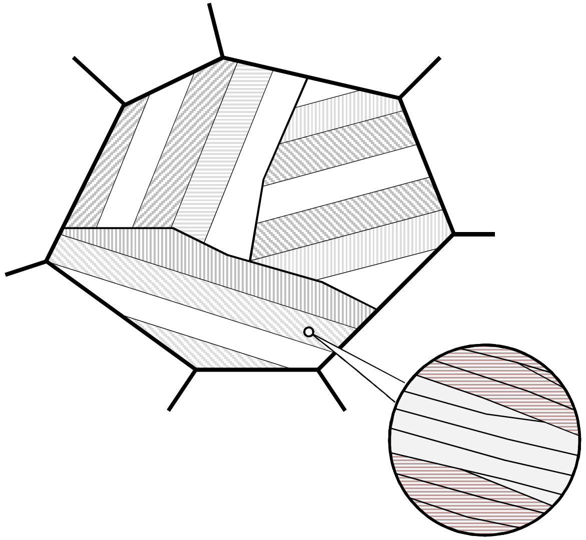


Difference in microstructure between displacive and diffusive rev.



When displacive reversion takes place,
prior austenite grain boundary is carried over.

Characteristic grain boundary misorientation in lath martensite



S. Morito et al.: *Acta Materialia*, **51**(2003), 1789–1799

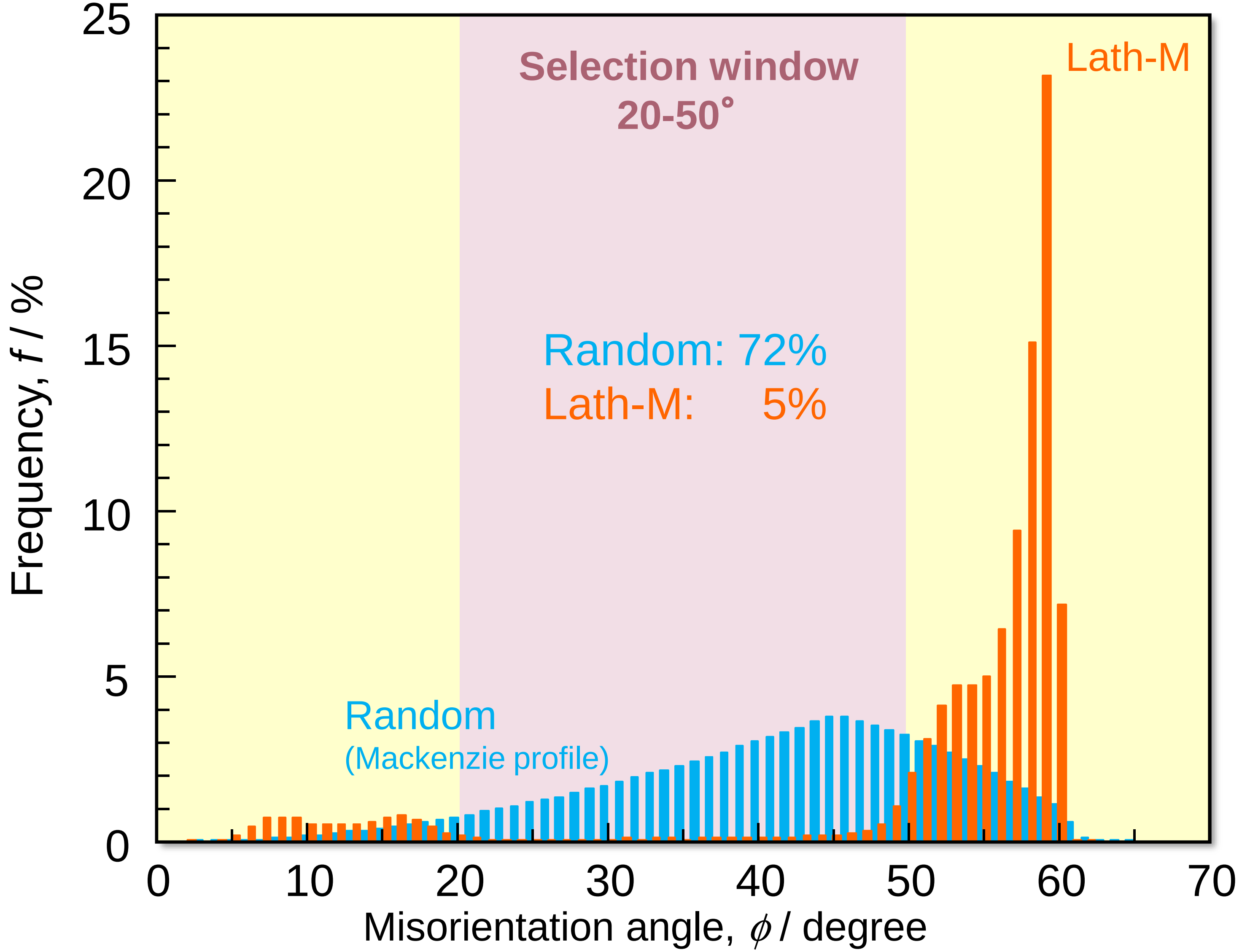
Table 2
Twenty-four variants in K–S relationship

Variant No.	Plane parallel	Direction parallel [γ]//[α′]		Rotation from Variant 1: Axis (indexed by martensite)	Angle [deg.]
V1		[−1 0 1]	//[−1 −1 1]	—	—
V2		[−1 0 1]	//[−1 1 −1]	[0.5774–0.57740.5774]	60.00
V3	(111)γ	[0 1 −1]	//[−1 −1 1]	[0.0000–0.7071-0.7071]	60.00
V4	//(011)α′	[0 1 −1]	//[−1 1 -1]	[0.00000.70710.7071]	10.53
V5		[1 −1 0]	//[−1 −1 1]	[0.00000.70710.7071]	60.00
V6		[1 −1 0]	//[−1 1 −1]	[0.0000–0.7071–0.7071]	49.47
V7		[1 0 −1]	//[−1 −1 1]	[-0.5774–0.57740.5774]	49.47
V8		[1 0 −1]	//[−1 1 −1]	[0.5774–0.57740.5774]	10.53
V9	(1-11)γ	[−1 −1 0]	//[−1 −1 1]	[−0.18620.76660.6145]	50.51
V10	//(011)α′	[−1 −1 0]	//[−1 1 −1]	[−0.4904–0.46250.7387]	50.51
V11		[0 1 1]	//[−1 −1 1]	[0.3543–0.9329–0.0650]	14.88
V12		[0 1 1]	//[−1 1 −1]	[0.3568–0.71360.6029]	57.21
V13		[0 −1 1]	//[−1 −1 1]	[0.93290.35430.0650]	14.88
V14		[0 -1 1]	//[-1 1 -1]	[-0.73870.4625-0.4904]	50.51
V15	(-111)γ	[-1 0 -1]	//[-1 -1 1]	[-0.2461-0.6278-0.7384]	57.21
V16	//(011)α′	[-1 0 -1]	//[-1 1 -1]	[0.65890.65890.3628]	20.61
V17		[1 1 0]	//[-1 -1 1]	[-0.65890.3628-0.6589]	51.73
V18		[1 1 0]	//[-1 1 -1]	[-0.3022-0.6255-0.7193]	47.11
V19		[-1 1 0]	//[-1 -1 1]	[-0.61450.1862-0.7666]	50.51
V20		[-1 1 0]	//[-1 1 -1]	[-0.3568-0.6029-0.7136]	57.21
V21	(11-1)γ	[0 -1 -1]	//[-1 -1 1]	[0.95510.0000-0.2962]	20.61
V22	//(011)α′	[0 -1 -1]	//[-1 1 -1]	[-0.71930.3022-0.6255]	47.11
V23		[1 0 1]	//[-1 -1 1]	[-0.7384-0.24610.6278]	57.21
V24		[1 0 1]	//[-1 1 -1]	[0.91210.41000.0000]	21.06

Block and packet boundaries has identical misorientation,
because they are characterized by a combination of different two K-S variants.

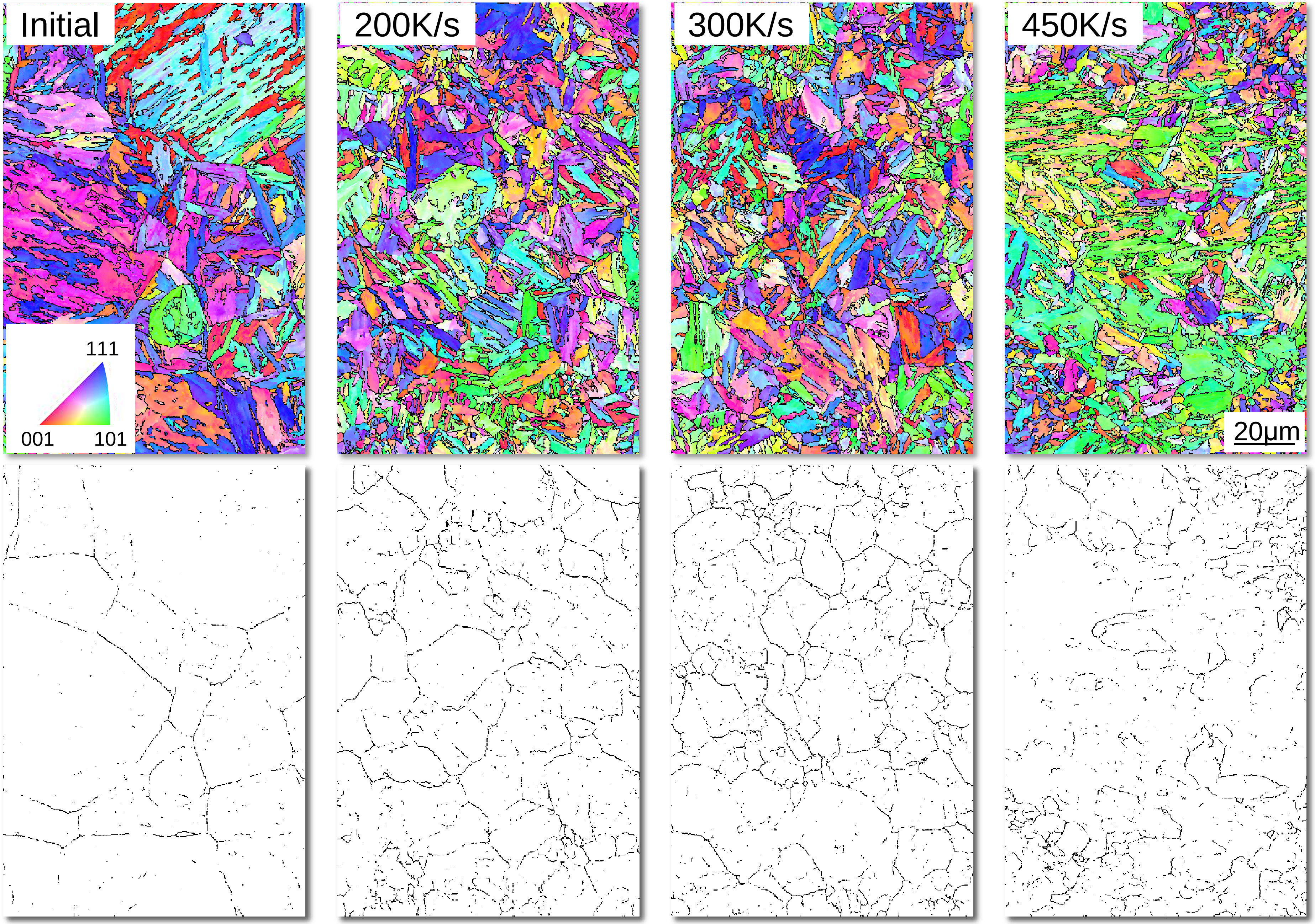
Block boundary： 10.5, 49.5, 60.0°

Distinguish method of prior austenite grain boundary

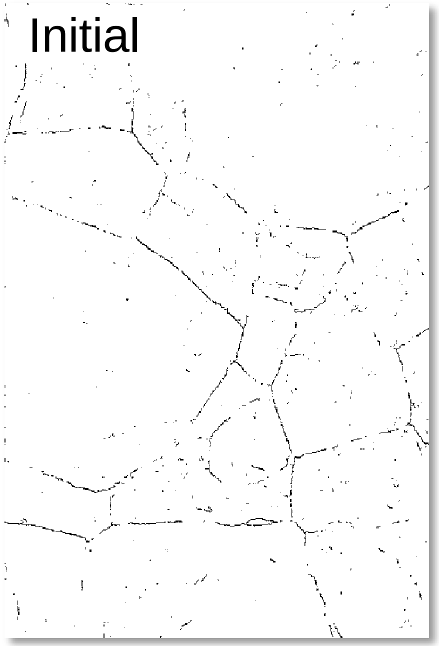


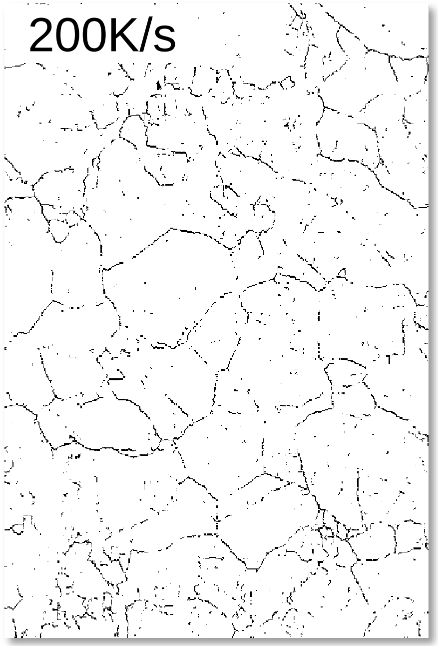
Selected high angle boundary 20~50° → prior austenite GB

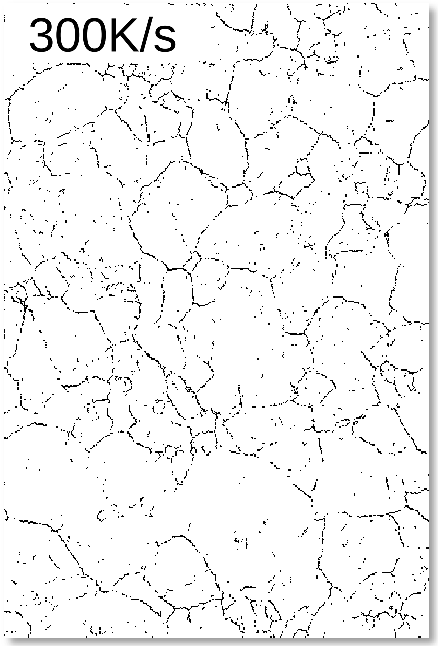
Martensitic structure after reversion and quenching



Martensitic structure after reversion and quenching





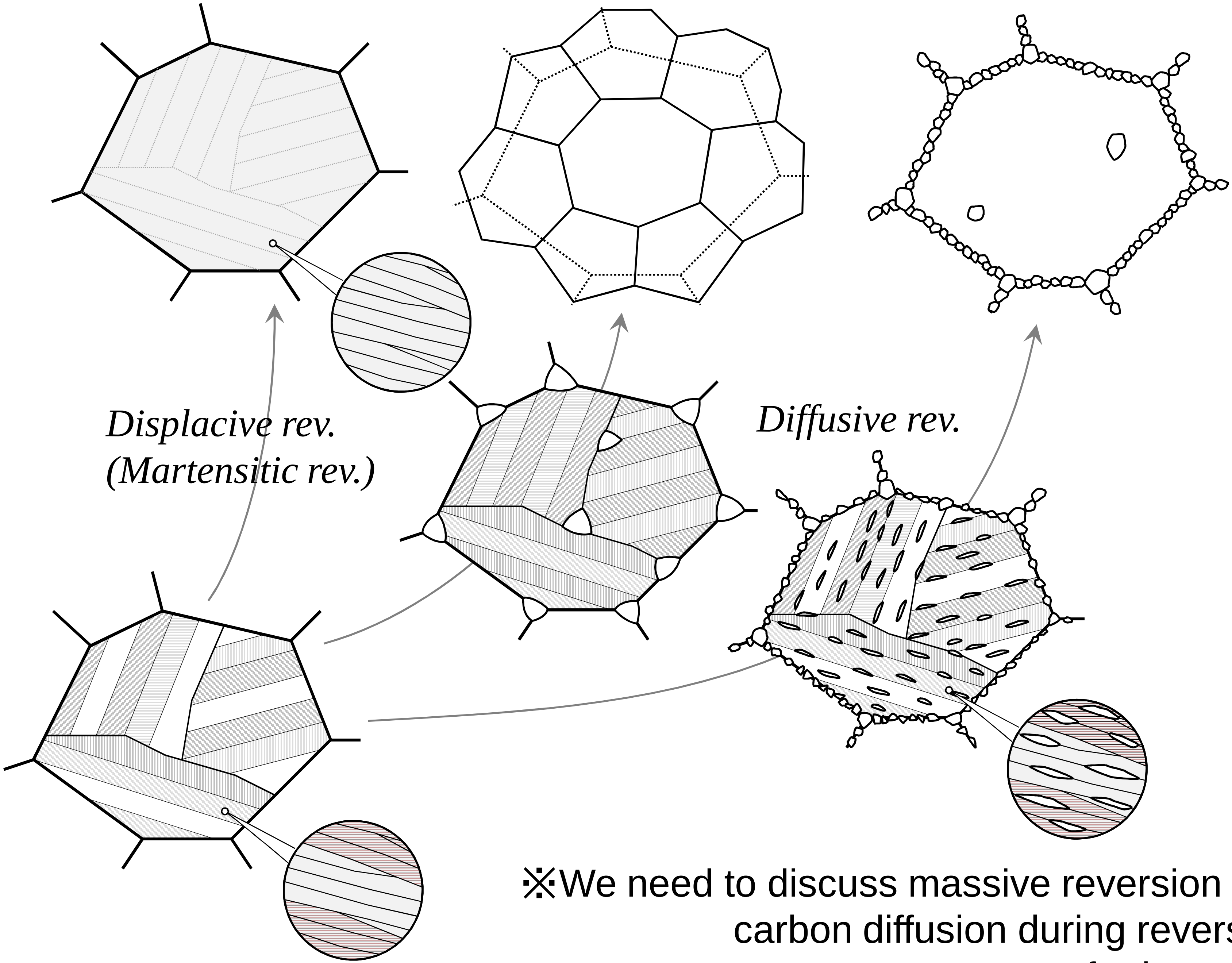


	Initial	200K/s	300K/s	450K/s
Dislocation density (m^{-2})	3.6×10^{15}	3.8×10^{15}	3.7×10^{15}	**4.6×10^{15}**
Hardness (GPa)	3.96	4.00	4.03	**4.48**

Diffusive reversion
(PAG refinement
due to increasing in driving force)

Displacive reversion
(Ausforming effect)
+ recrystallized A

Heating rate dependence of reversion mechanism



※We need to discuss massive reversion and carbon diffusion during reversion

Conclusions

For understanding the reversion mechanism in steel, the effect of the heating rate on austenite reversion behavior was investigated in 0.15%C-5%Mn steel. The results obtained are summarized as follows:

1. Martensitic reversion can take place even in low alloy steel, if the heating rate is significantly high.

2. Reversion temperature is continuously increased with increasing heating rate in the case of diffusive reversion, but it is kept constant in the case of martensitic reversion.

3. Martensitic steel through martensitic reversion has coarser prior austenite grain structure, higher density dislocations and higher strength.