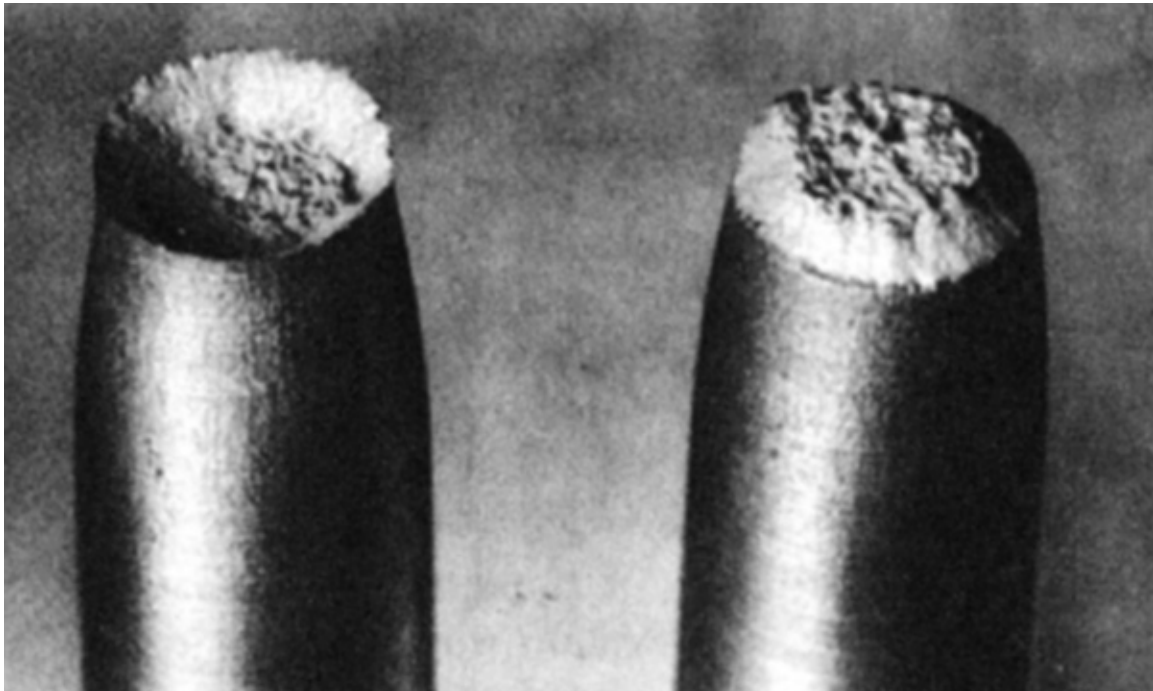


# Fracture Processes and Fractography

MSE C212 / ME C225



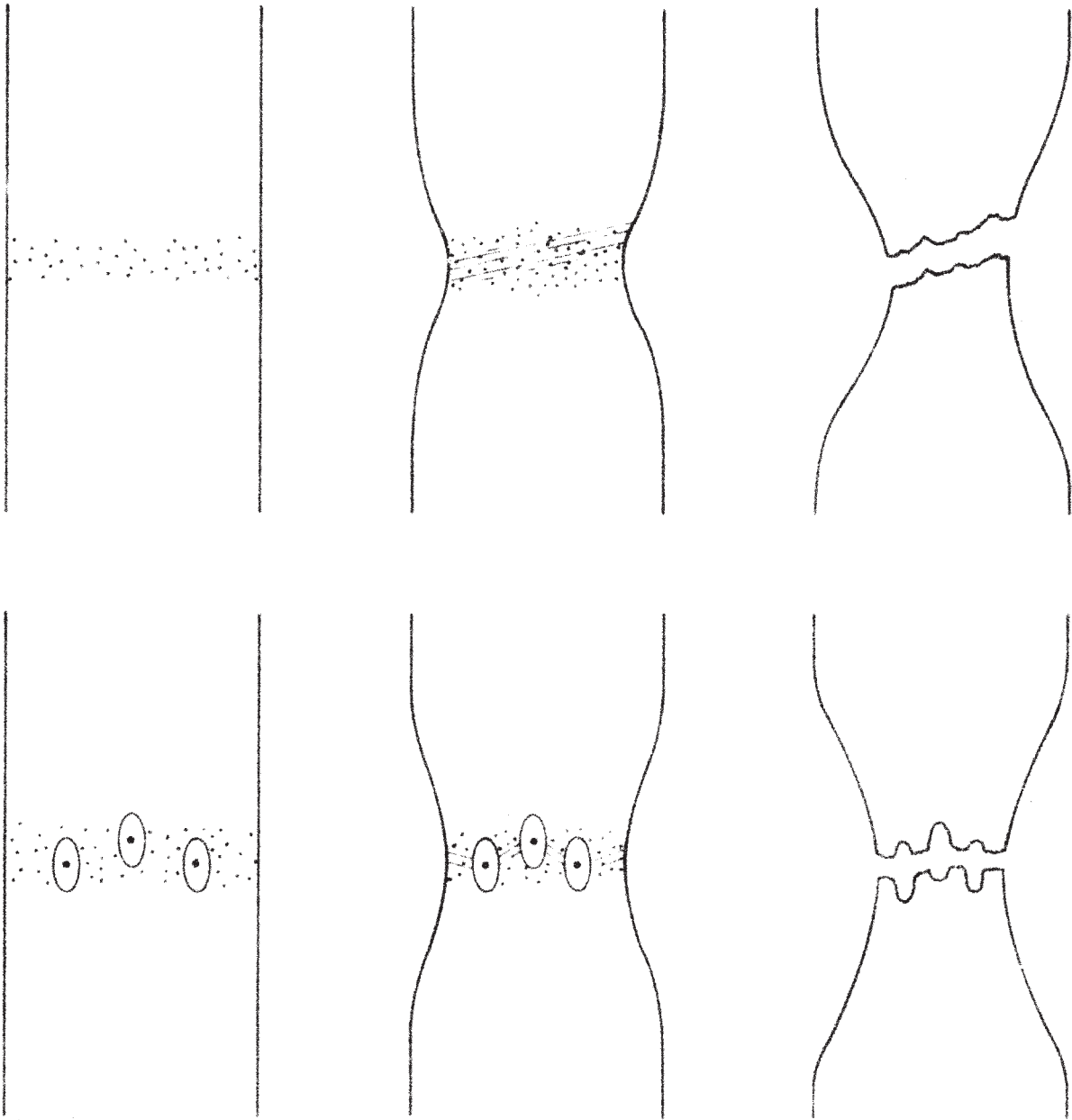
W.F. Hosford, *Mechanical Behavior of Materials*, p. 214

Classic cup-cone fracture, shown here in specimens of aluminum bronze (Cu-6% Al). Center flat region is "woody," a common visual term which often but not always corresponds to MVC fracture.



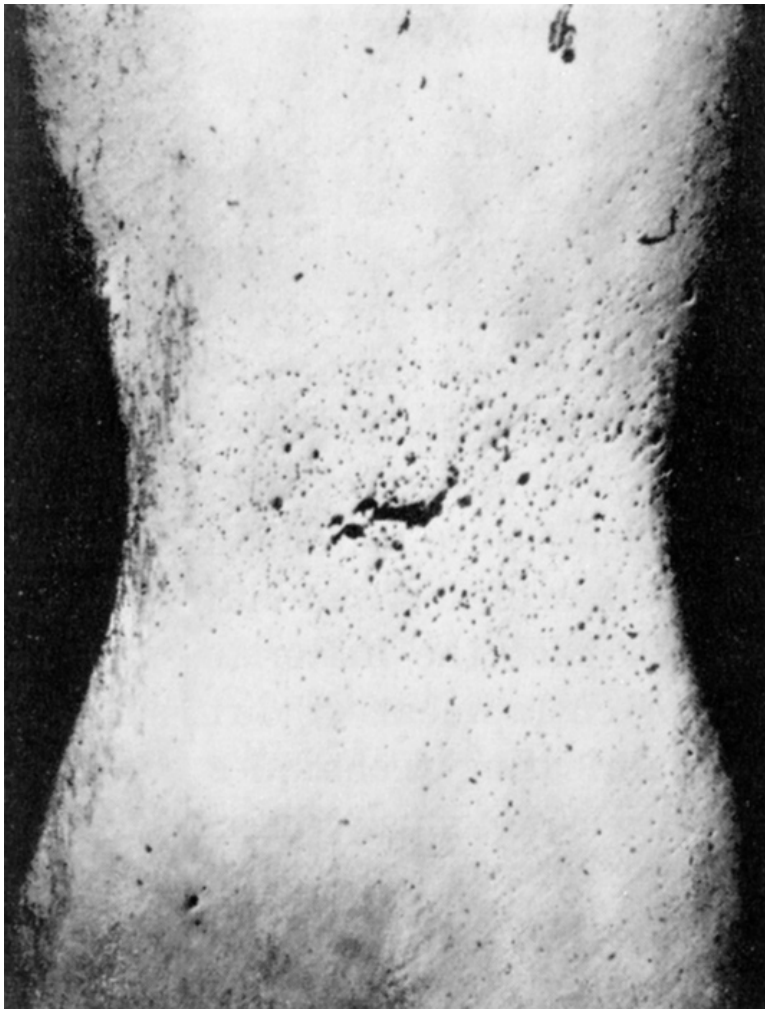
FIG. 16.10. Typical tensile fractures. (a) Wrought iron (ragged fracture showing slag). (b) Heat-treated alloy steel (perfect cup and cone). (c) Heat-treated alloy steel (rosette fracture). (d) Duralumin, heat-treated (shear fracture). (e) Gray cast iron (granular fracture). (Cowdrey and Adams, 1935. Courtesy of Wiley.)

from F.A. McClintock and A.S. Argon, *Mechanical Behavior of Materials*, Addison-Wesley, 1966, p. 528.



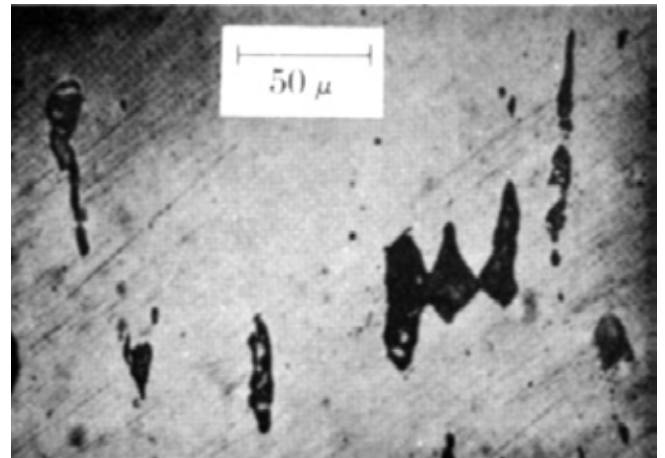
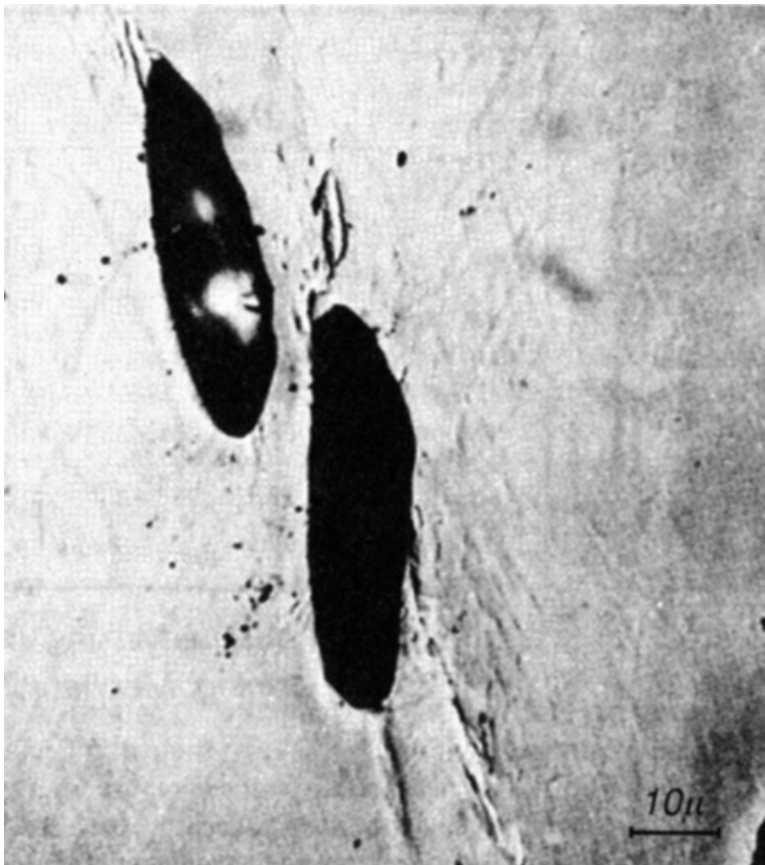
(Top) Profuse hole nucleation reduces stiffness of material, accentuates shear localization, and can produce unstable shear fractures, although locally the fracture is entirely MVC.

(Bottom) The same process can occur late in the growth process of large voids, producing the same kind of shear fracture between macrovoids.



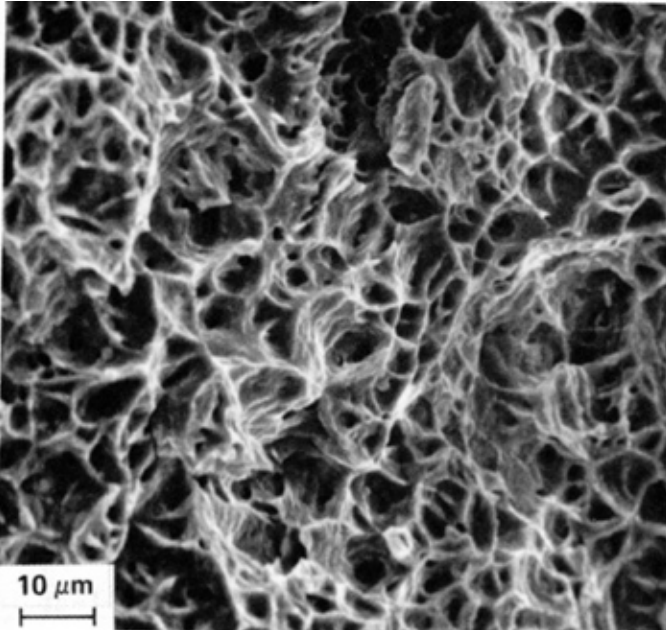
Sectioning tensile specimens during the necking process can reveal void accumulation in the specimen center.

Left and below, K.E. Puttick, *Phil. Mag.* vol. 4, p. 964, 1959.

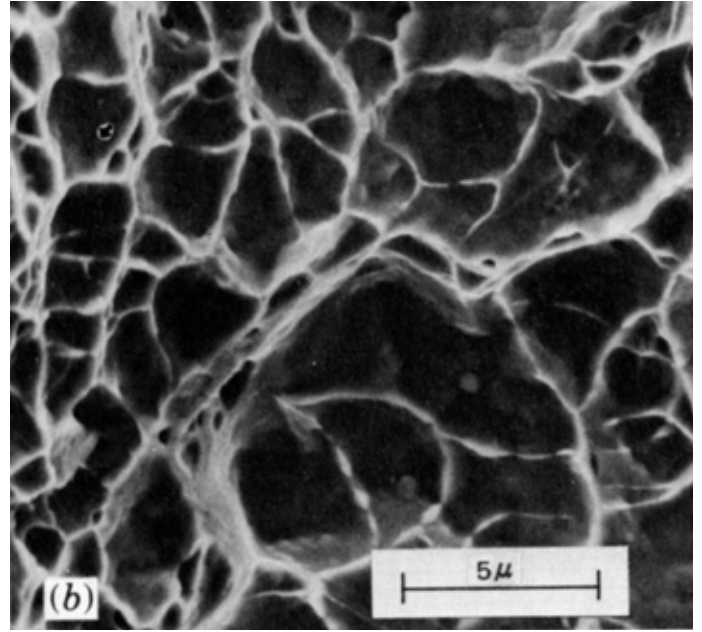


The photo at left shows the development of shear bands between coalescing microvoids in copper.

Left: H.C. Rogers, *Trans. AIME*, vol. 218, p. 498, 1966.

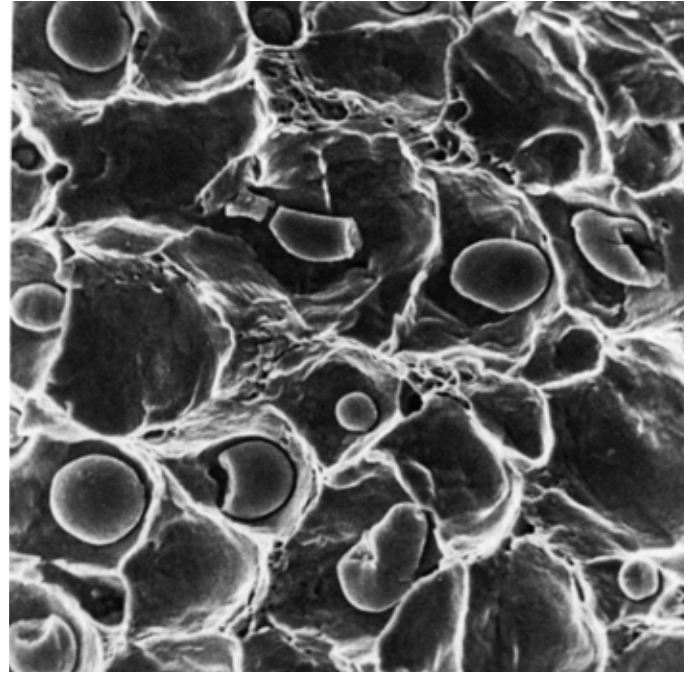
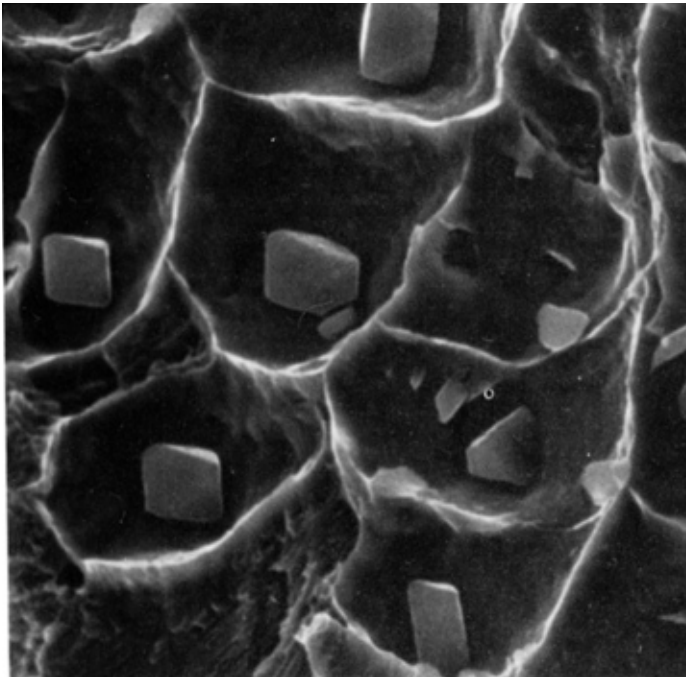


1020 steel: D. Eliezer, 1981



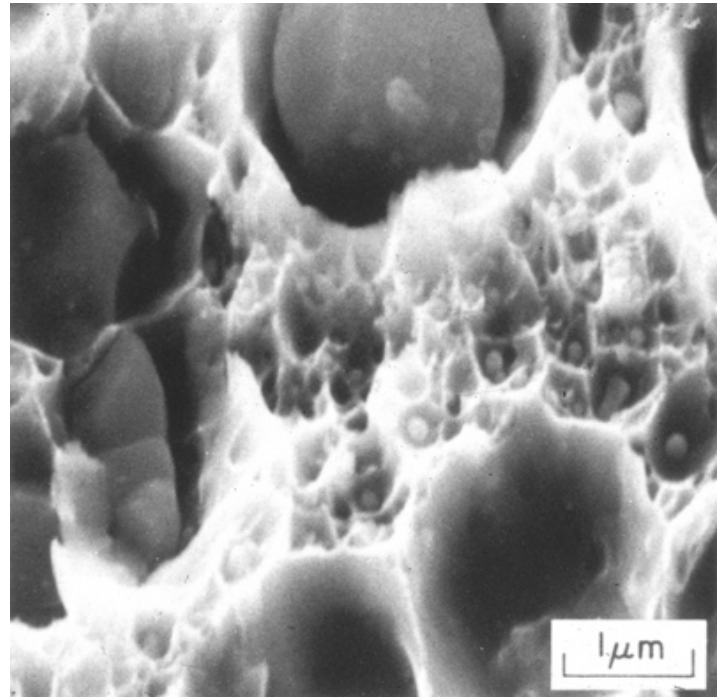
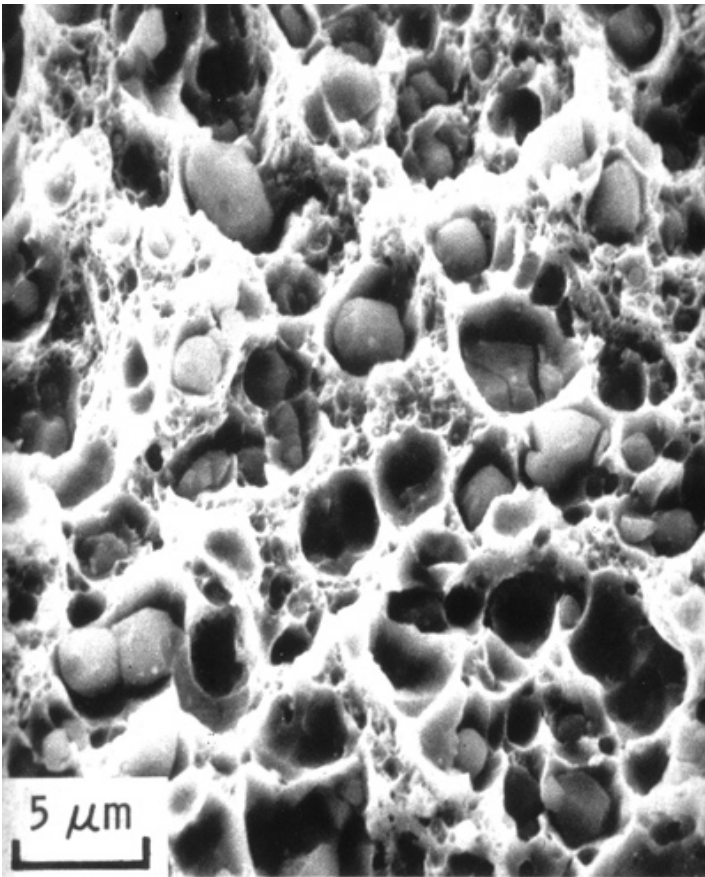
R.W. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials* (3rd ed.), p. 255

Sometimes initiating particles are visible on the fracture surfaces within microvoids. Note difference in magnification between these two photos.



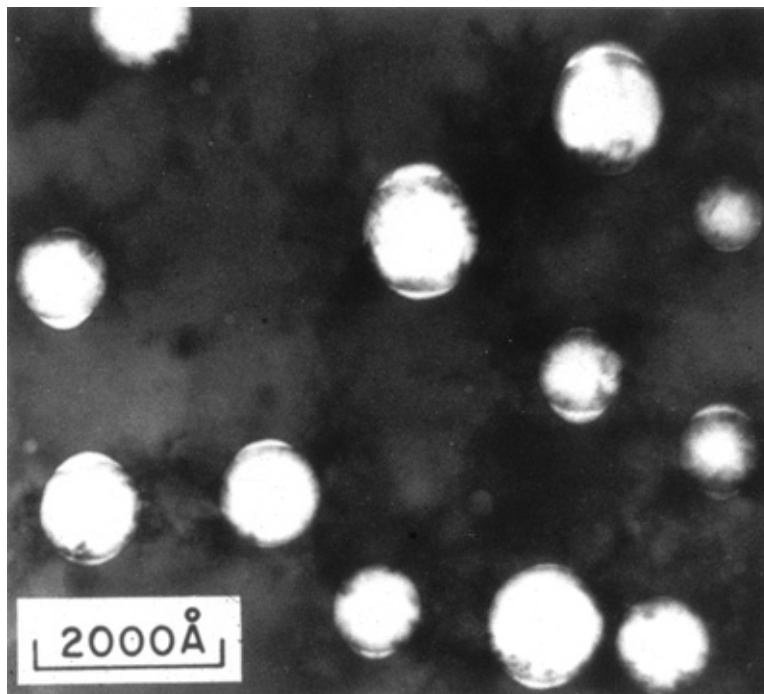
T.J. Baker and J.A. Charles, *J. Iron Steel Inst.*, vol. 210, pp. 702–706, 1972.

When particles are plentiful, void growth is minimal and particles are more readily observed on the fracture surface. These are not representative views; almost all microvoids contain particles.

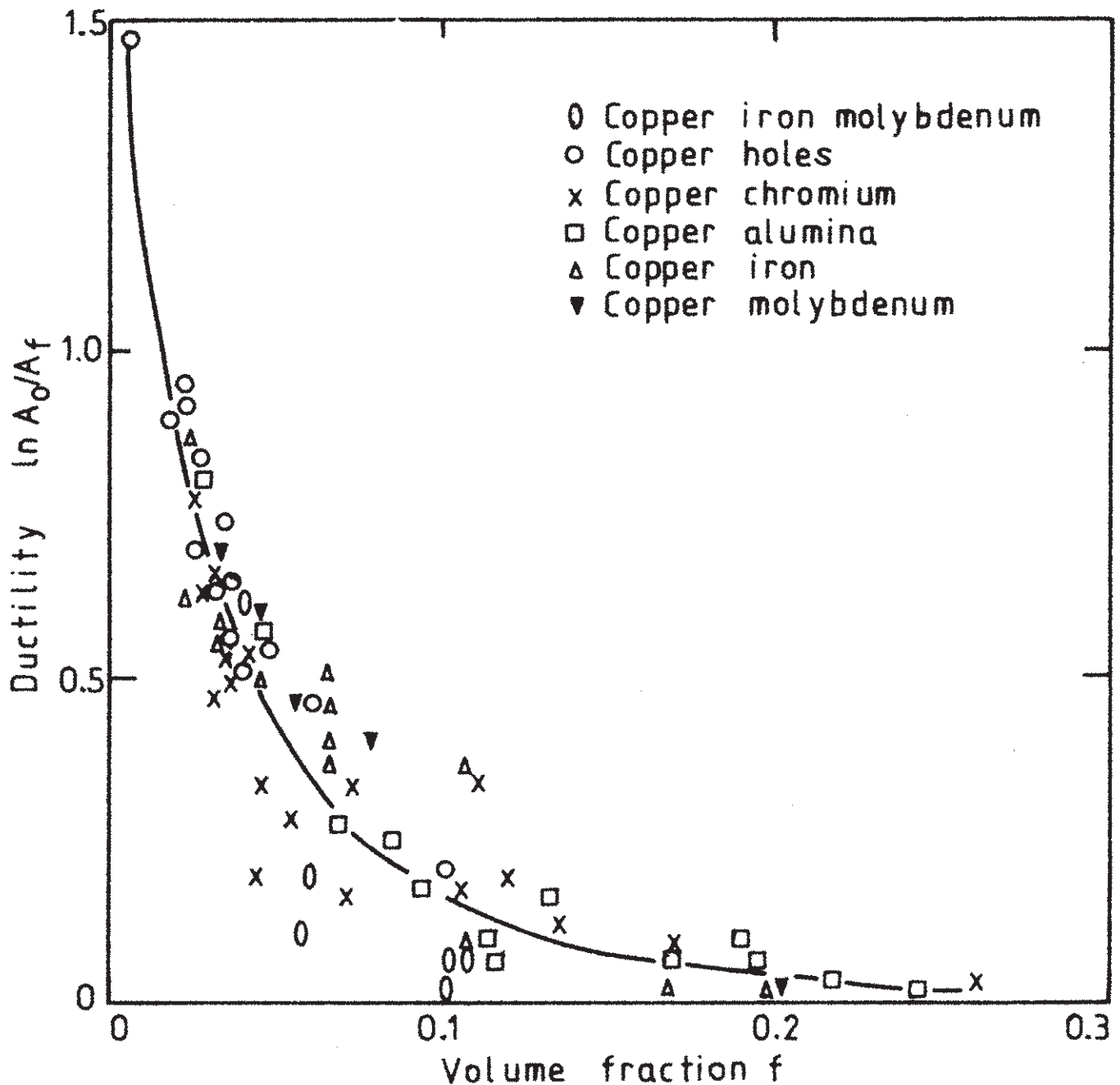


Nickel-20% Cr-2% ThO<sub>2</sub>: large particles are thoria; small ones nucleating voids between large voids are mostly nickel oxide.

A.W. Thompson, *Met. Trans.*, vol. 5, p. 1855 (1974).



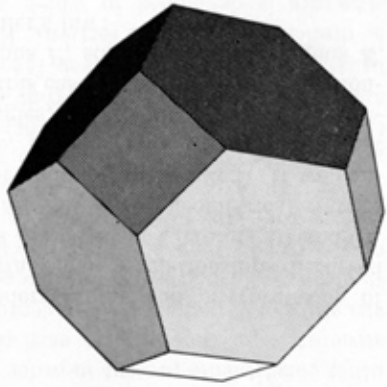
Demonstration of separation at tensile poles (loading direction vertical) of silica spheres in a copper matrix. Material prepared by internal oxidation of Cu-0.3% Si alloy, strained in tension. I.G. Palmer and G.C. Smith, in *Oxide Dispersion Strengthening*, Gordon & Breach, New York, 1968, p. 253.



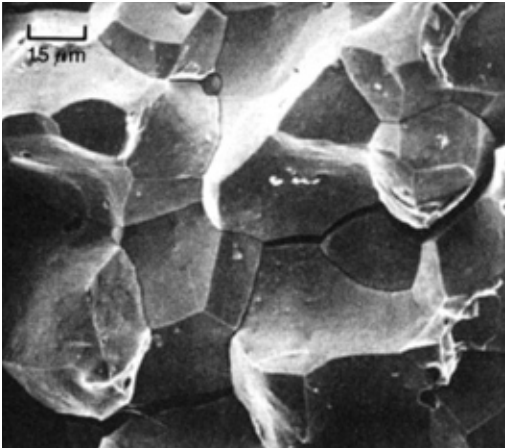
B.I. Edelson and W.M. Baldwin, Trans. ASM, vol. 55, pp. 230-250, 1962.

The volume fraction of second-phase initiators of microvoids is the only essential factor: everything from actual voids ("holes"), to weakly bonded particles like molybdenum, to strongly bonded ones like alumina, all play the same role in ductile fracture by MVC. All particles were at least as large as 5 μm, were essentially spherical, and, compared to natural second-phase interfaces, not truly high in interfacial strength: thus materials with different particle shapes, smaller sizes, and higher interfacial strength may not follow this curve. For most materials, however, this "master curve" is normally observed.

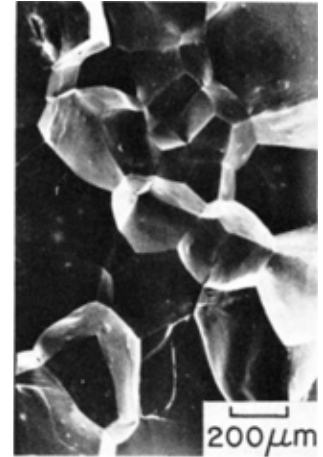
## Intergranular Fracture



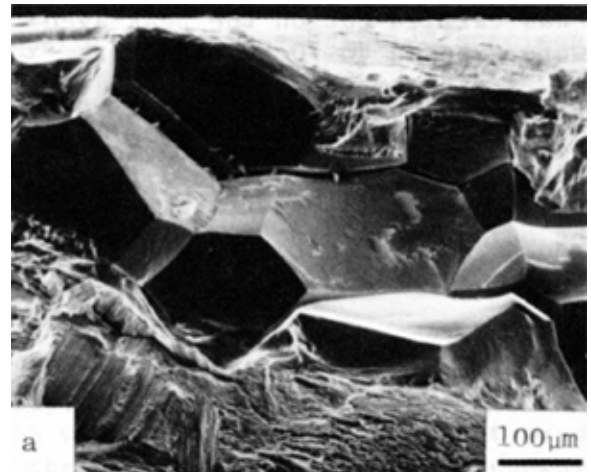
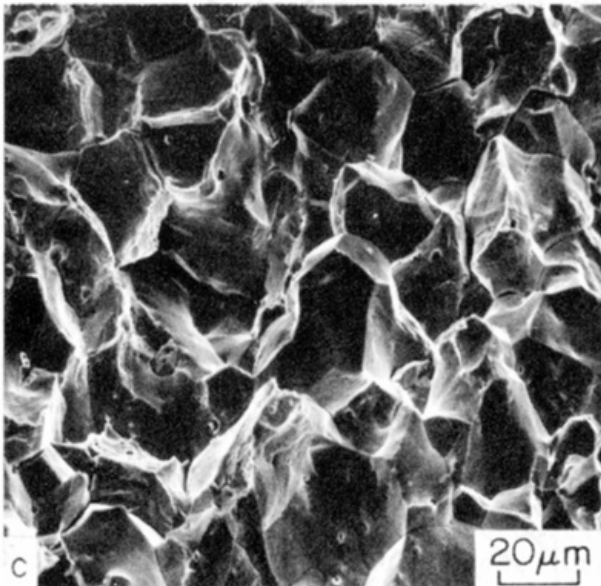
The tetradaidecahedron (14 sides) shown at left is the ideal grain shape; it fills space and approximates the surface-to-volume ratios observed for actual grains.



Actual IG (intergranular) fractures often reveal grain shapes reminiscent of the ideal solid. Note secondary cracking.



Left, Hosford, p. 220  
Right, Meshii, et al., 1981

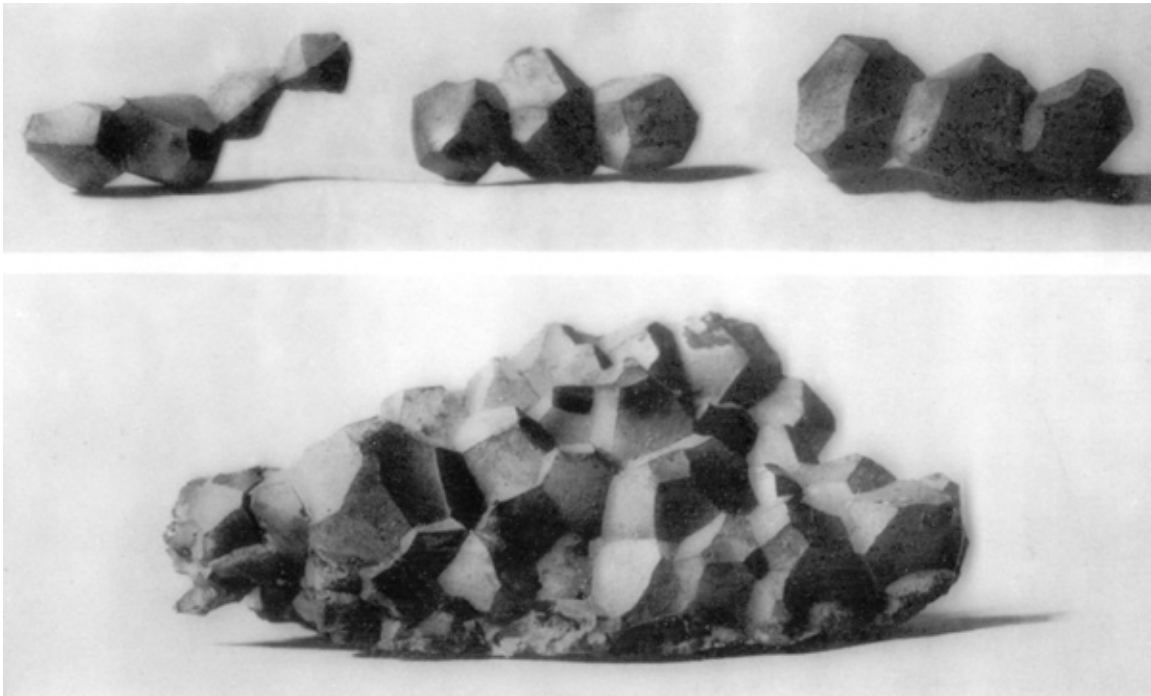


Aluminum alloy: S.W. Ciaraldi, J.L. Nelson, R.A. Yeske, E.N. Pugh, 1981

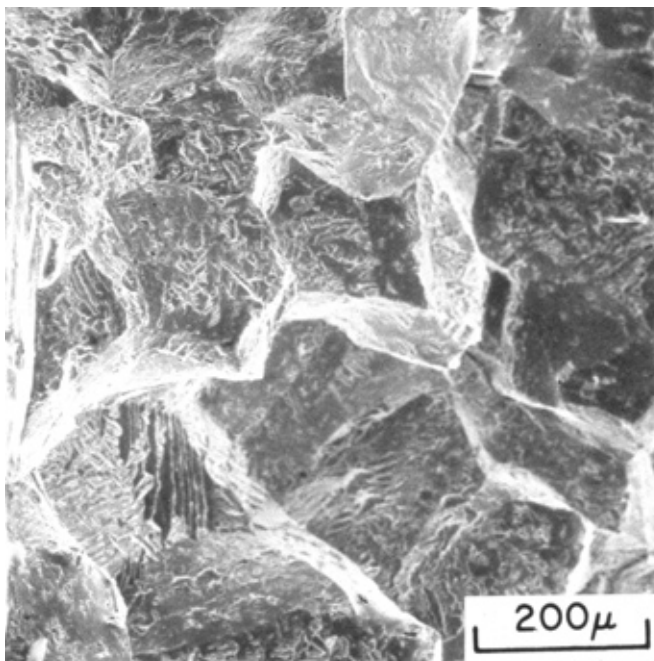
Nickel: Thompson, 1979

Fractures containing intergranular facets may include transgranular regions which have failed by other modes, or deformed grains (suggesting plastic flow prior to or during fracture). Photo at right shows a crack at the specimen surface, which maintained the IG mode for only a few grains.

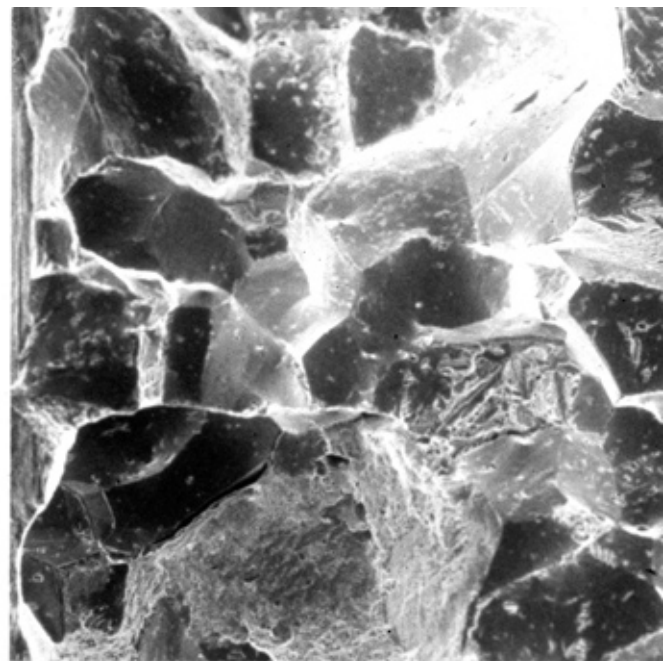




Very coarse grains in an as-cast metal. Grain shapes resemble the tetrakaidecahedron model in many cases.

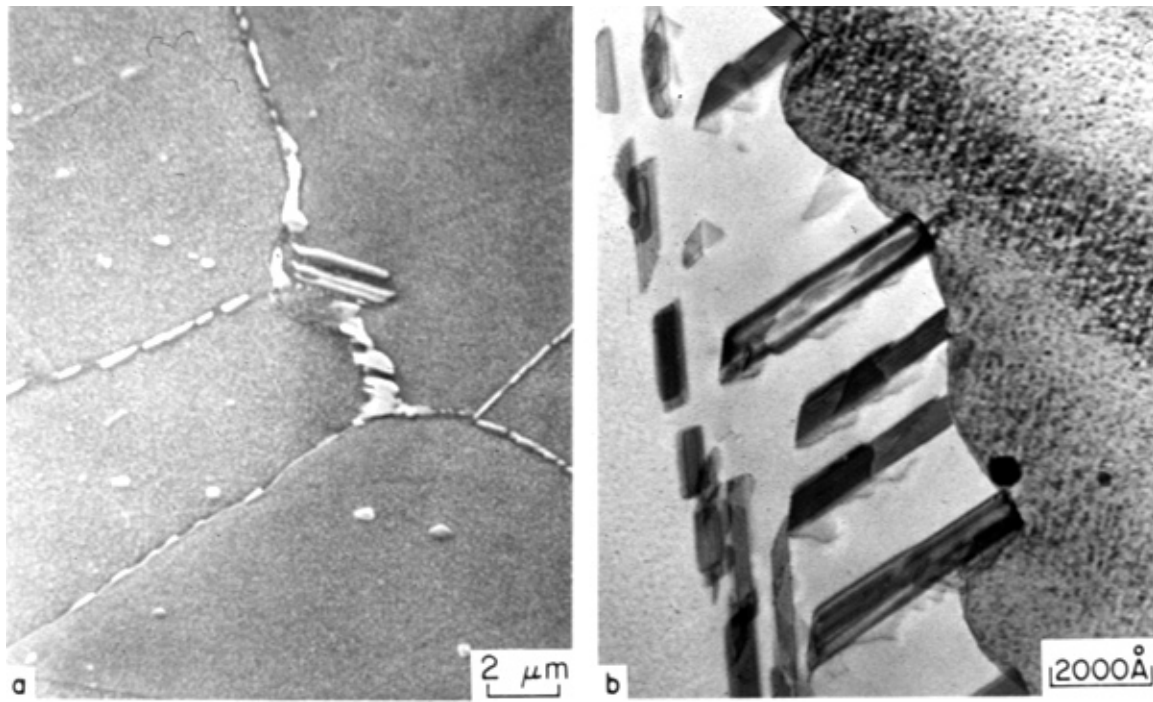


**a) As-quenched**

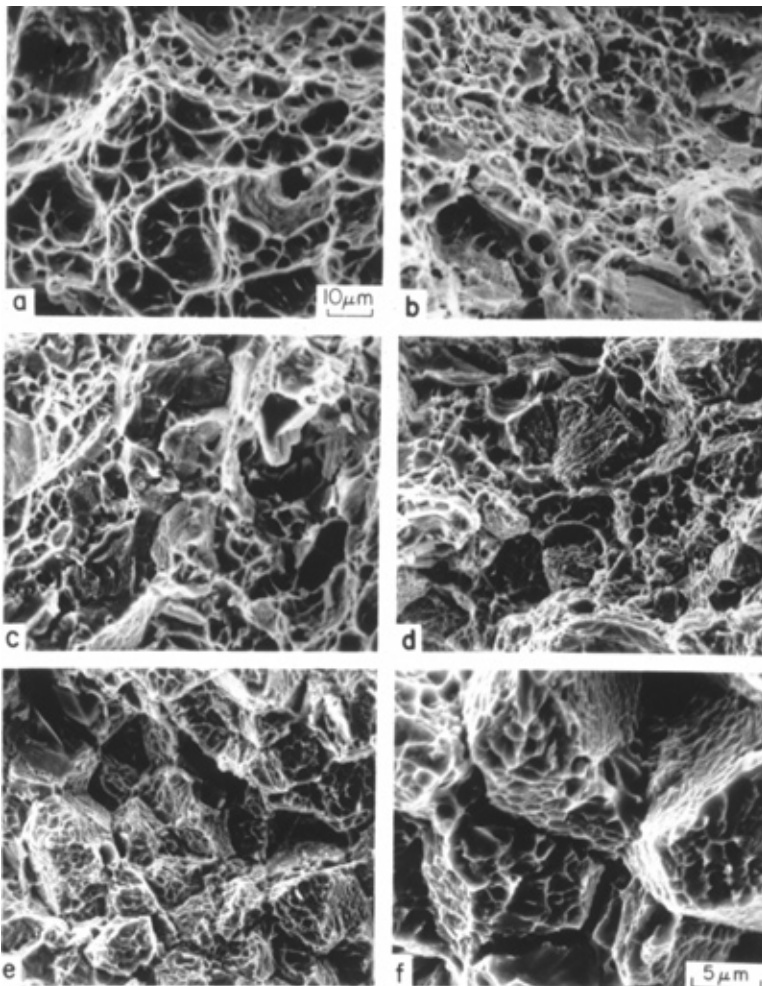


**b) 325°C**

Quenched & tempered low-alloy steel. In (a), the untempered martensite makes grain interiors very strong, and near-intergranular fracture path is observed, although fracture is locally somewhat ductile. In (b), tempering to produce temper embrittlement causes a shift to smooth, brittle intergranular fracture facets, though total ductility is not reduced much below that of the structure in (a).



At long aging times, an intermetallic phase,  $\text{Ni}_3\text{Ti}$ , called  $\eta$ , forms at grain boundaries in A-286 precipitation-strengthening stainless steel (Fe-25% Ni-15% Cr-2% Ti). As seen in a TEM view (b), the  $\eta$  particles are surrounded by a soft, precipitate-free region which encourages near-IG fracture paths. If aging progresses further, the  $\eta$  phase becomes almost continuous at the grain boundaries (a).

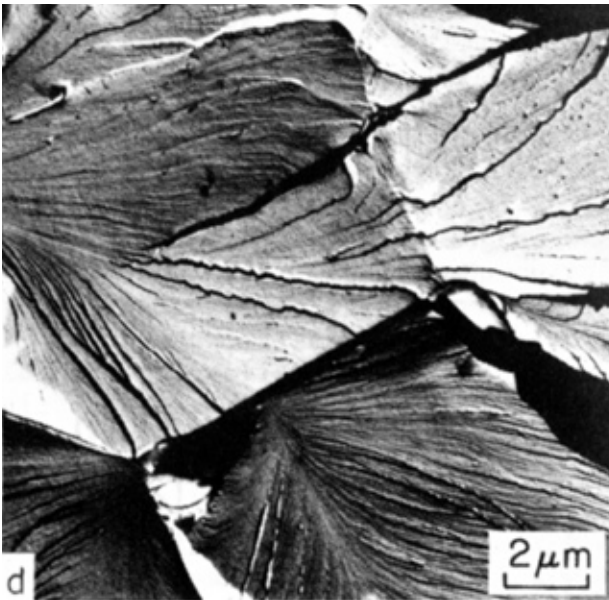


Fracture surfaces of A-286 with varying aging conditions, all at same magnification except (f). Photos (a, b), solution treated and unaged; (c, d), aged 16 hours at 993 K to peak strength; (e) 450 hours aged at 993 K; (f) aged 150 hours, shown at higher magnification. Note that fracture path progressively becomes more nearly intergranular but remains entirely a MVC process.

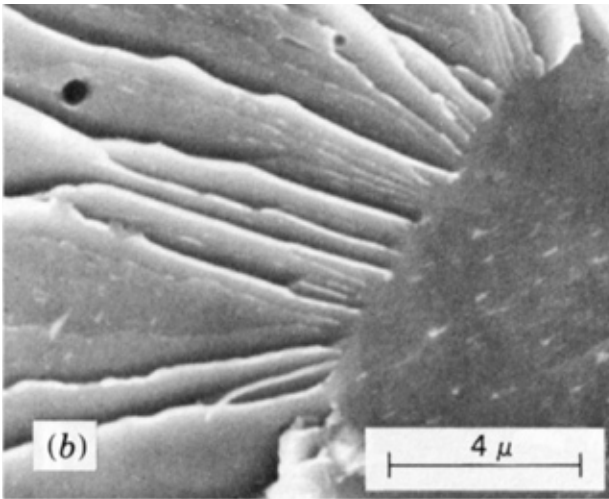
both figures, J.A. Brooks and A.W. Thompson, *Met. Trans. A*, vol. 24A, pp. 1983–1991 (1993).

## Cleavage Fracture

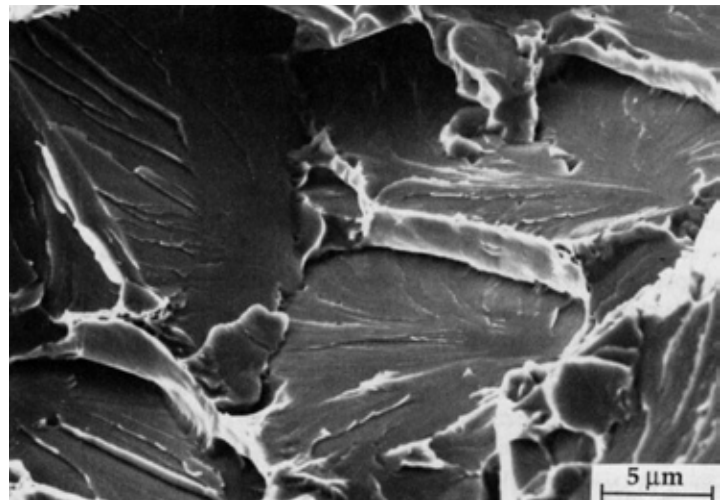
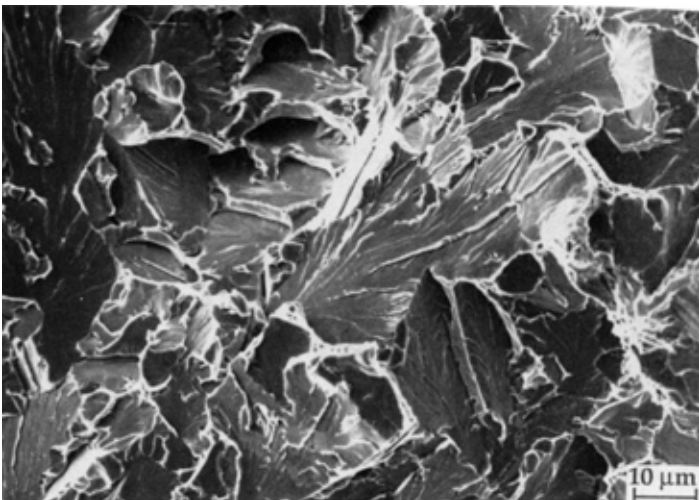
Cleavage fracture by definition occurs along crystallographic planes in each grain fractured.



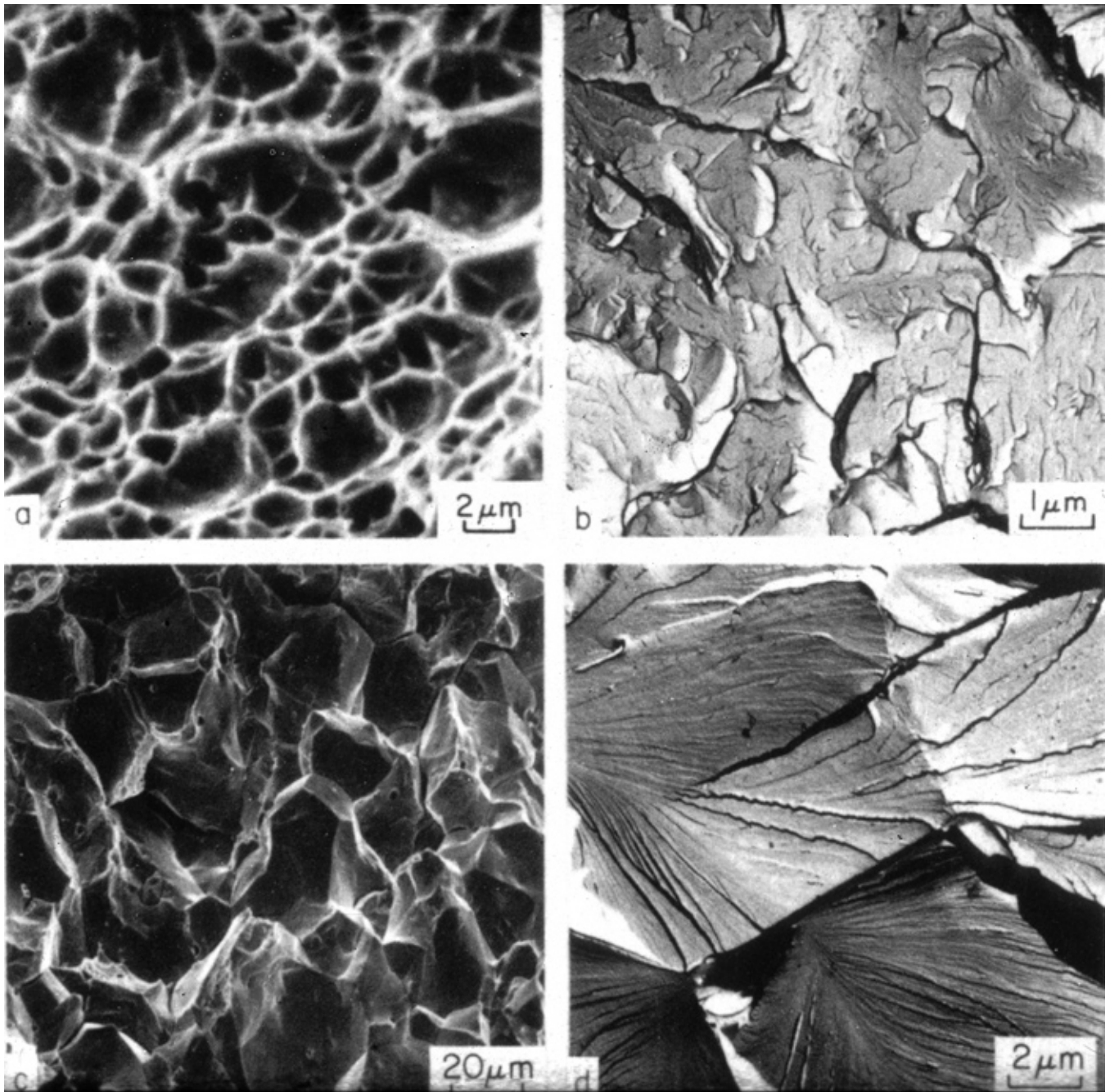
Above, niobium alloy, M. Mahoney, 1977  
Below, low-carbon steel, Hertzberg



“River Lines” identify separate origins on parallel but slightly offset planes. They may be traced back toward the general origin; they normally show a radiating pattern away from the point of origin, both within grains and globally.

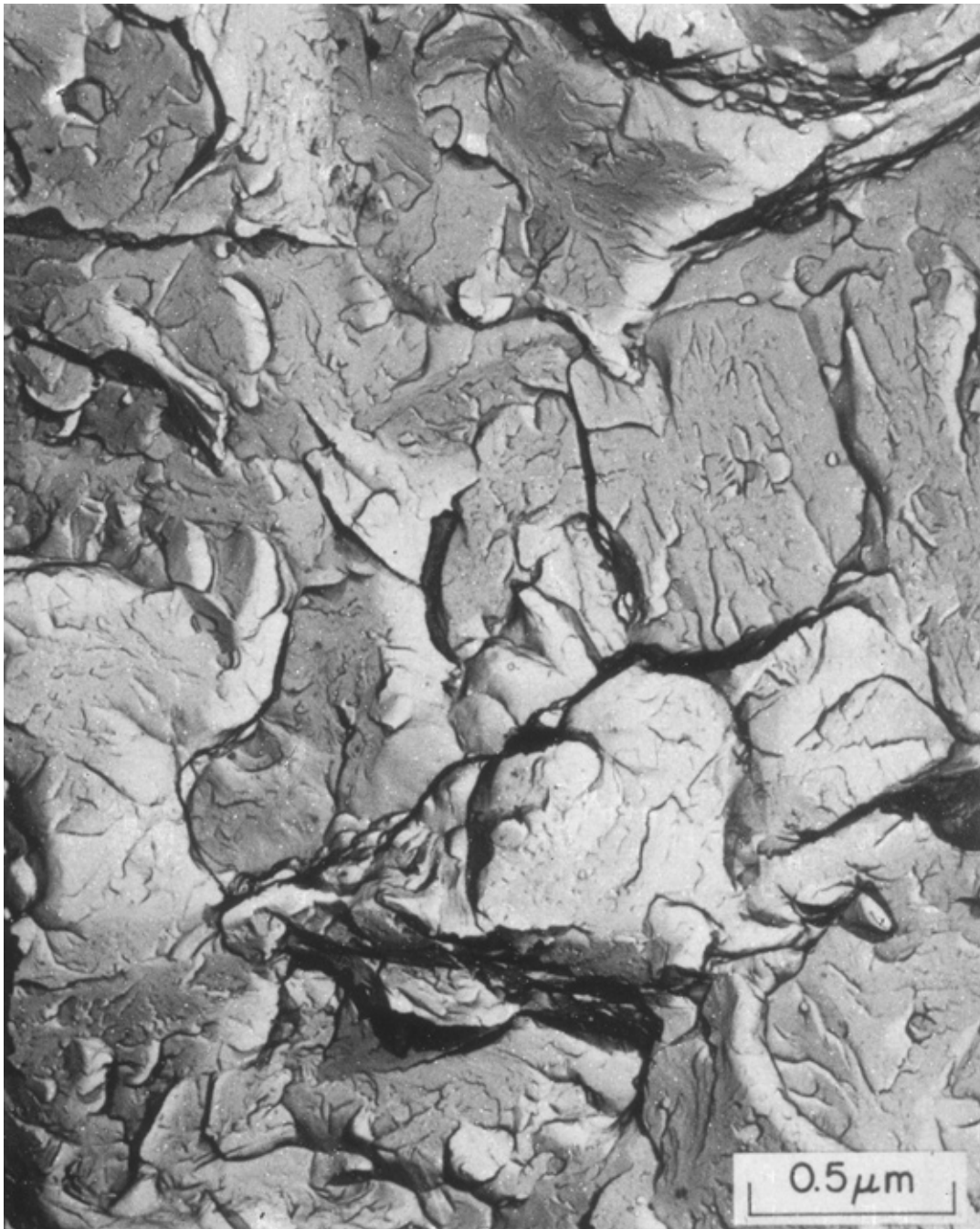


low-alloy steel: T.L. Anderson, *Fracture Mechanics* (3rd ed.), p. 235



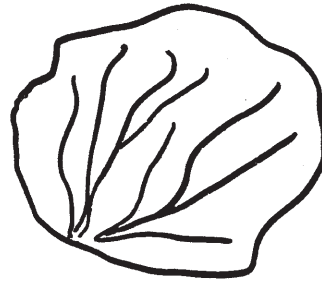
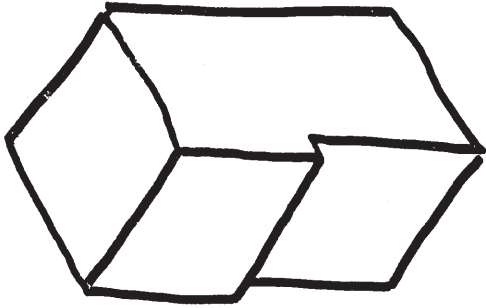
The four classical modes of fracture: (a) microvoid coalescence or MVC, (b) quasi-cleavage or QC, (c) intergranular fracture or IG, (d) cleavage.

## Quasi-Cleavage Fracture



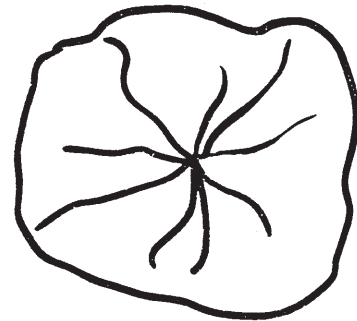
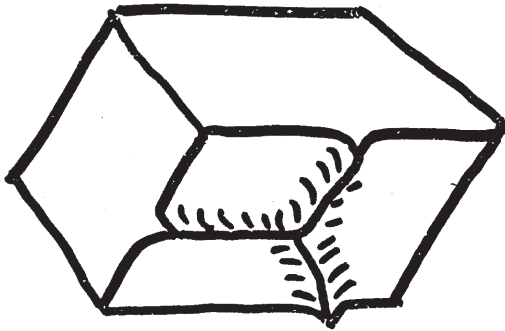
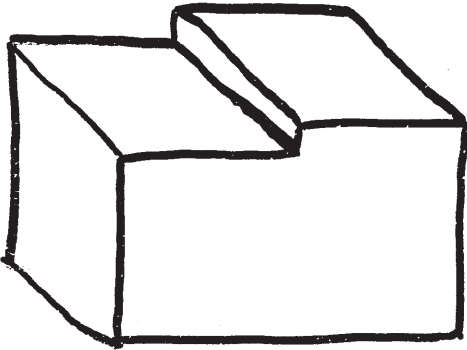
AISI 410 stainless steel, fractured at low temperature; photograph is from a carbon replica of the fracture surface, thus appears somewhat “flatter” and less three-dimensional than would the same specimen in the SEM.

Note radiating and poorly directional lines; most “facets” are grains. These locally radiating, rather than connecting toward an origin, river lines are among the diagnostic features of QC fracture. Facets may or may not be crystallographic. Most importantly, lines are ridges, not steps.



CLEAVAGE

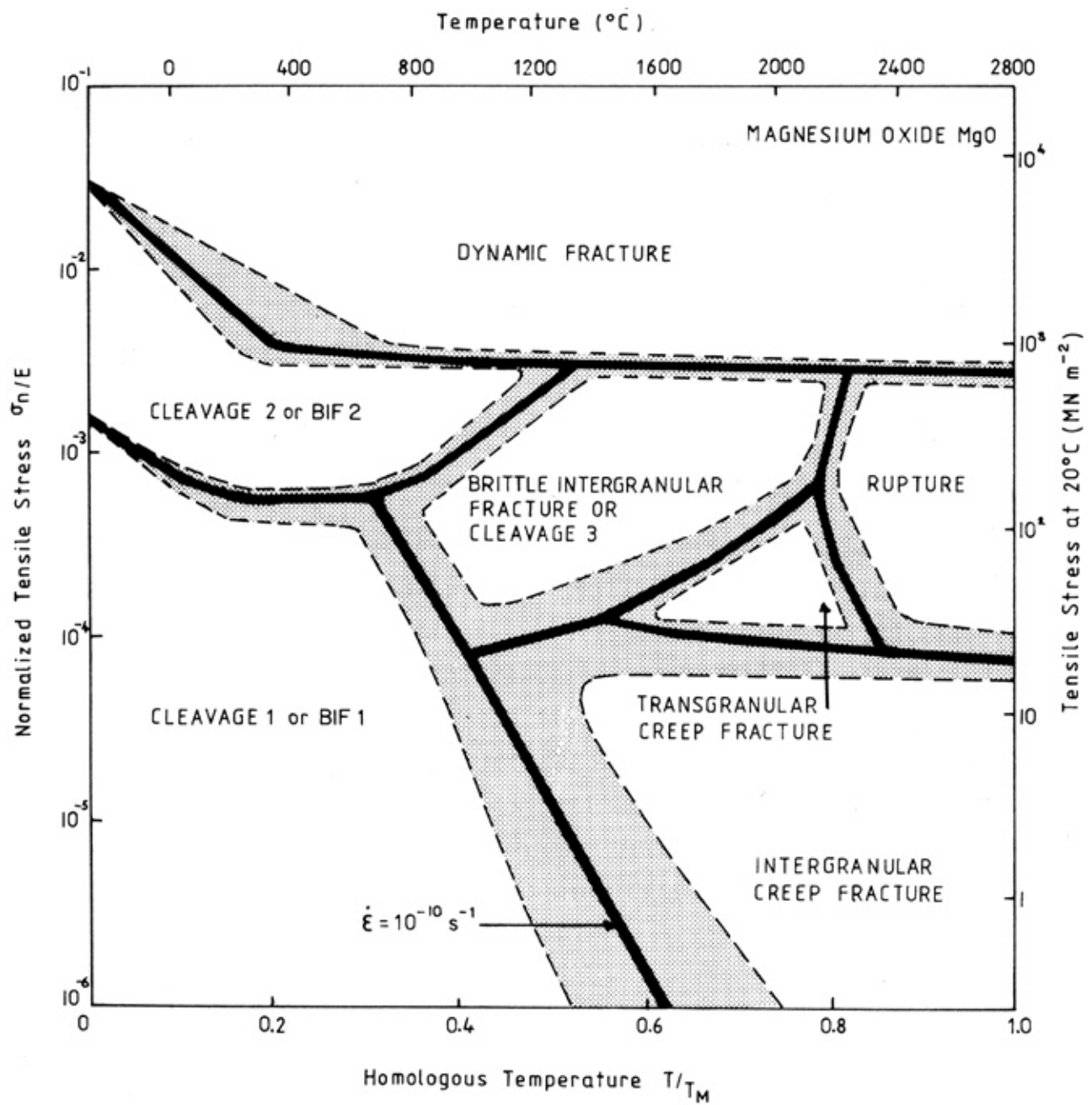
(LOW-INDEX  
CRYSTALLOGRAPHIC)



QUASI-CLEAVAGE

(MAY BE LOW-INDEX  
CRYSTALLOGRAPHIC)

Determination of step matching in cleavage, vs. ridge matching in quasi-cleavage, on two halves of a fracture surface.



M.F. Ashby, *Prog. Mater. Sci.*, 1981

By analogy with deformation mechanism maps, fracture maps can also be devised, though with the complication of dealing with strain rates, stress states, and minor metallurgical variables which can dramatically affect fracture processes.