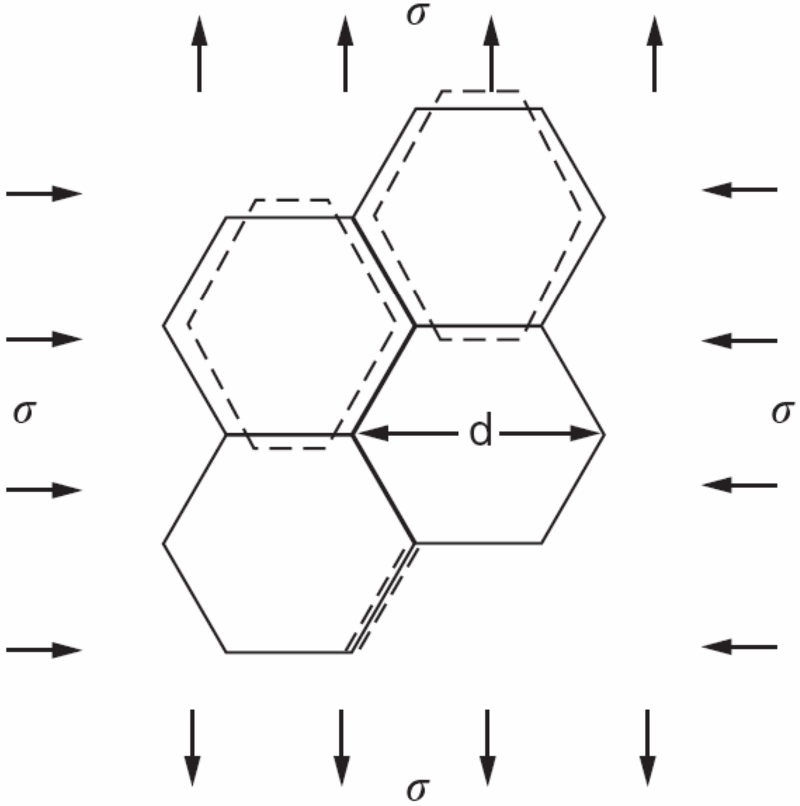
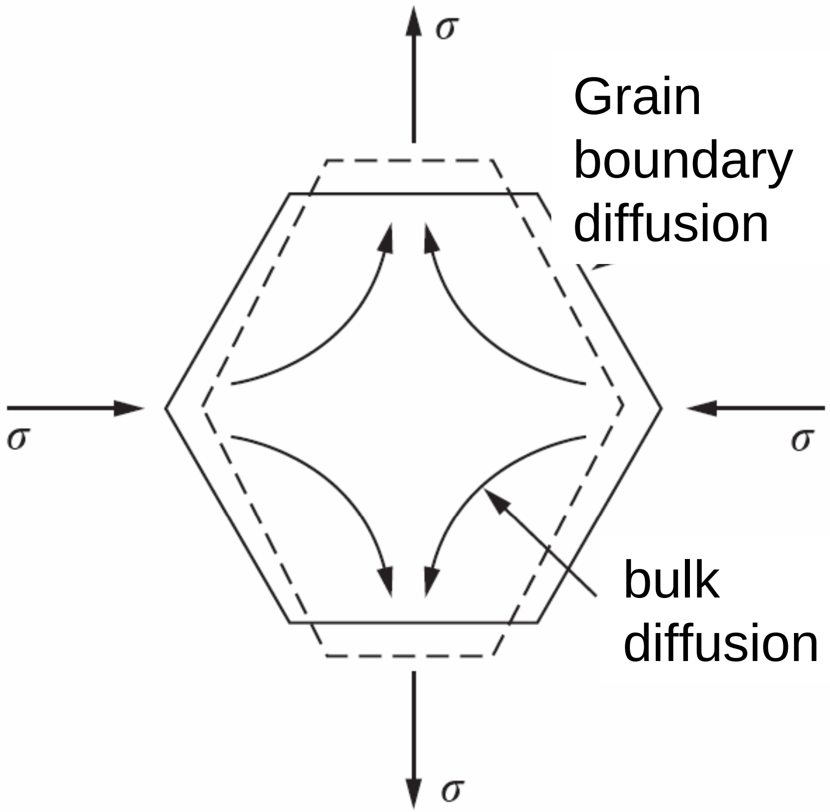
Diffusion creep (linear-viscous creep)

As the stress is reduced, the rate of power-law creep falls rapidly. But creep does not stop; instead, an alternate mechanism takes over.

A polycrystal can extend in response to the applied stress by grain elongation; here, the stress acts again as a mechanical driving force but this time atoms diffuse from one set of the grain faces to the other, and dislocations are not involved.





(Source: M.F. Ashby, D.R.H. Jones, Engineering Materials I, 3rd Ed, Butterworth-Heinemann, 2005, p. 295).

At high temperatures, diffusion takes place through the crystal itself, by bulk diffusion. Creep rate varies with grain size, and is given by

$$\dot{\epsilon}_s = \frac{K_3 \sigma^n \exp\left(-Q_c / RT\right)}{d^2}$$

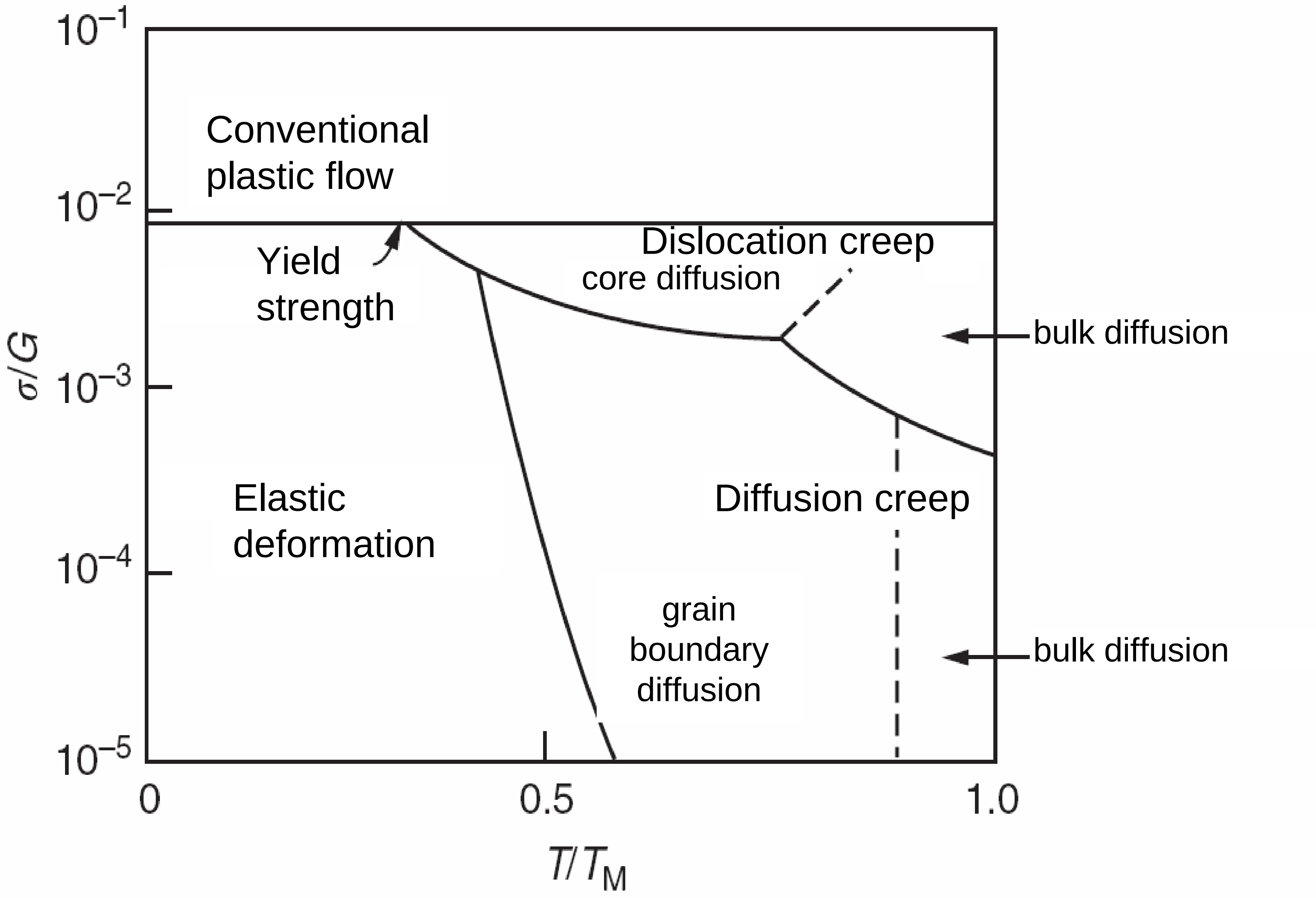
(Nabarro-Herring Creep).

At lower temperatures bulk diffusion is slow, and grain boundary diffusion takes over. TIn order that holes do not open up between the grains, grain boundary sliding is required as an accessory to this process (Coble creep).

$$\dot{\epsilon}_s = \frac{K_4 \sigma^n \exp\left(-Q_c / RT\right)}{d^3}$$

(Sources: W.F. Hosford, Mechanical Behavior of Materials, Cambridge, 2005, p. 265.
M.F. Ashby, D.R.H. Jones, Engineering Materials I, 3rd Ed, Butterworth-Heinemann, 2005, p. 304).

Creep Mechanism Maps



(Source: M.F. Ashby, D.R.H. Jones, Engineering Materials I, 3rd Ed, Butterworth-Heinemann, 2005, p. 304).

Creep Mechanisms: Summary

- Creep
  - High σ — Dislocation (Power-law) creep, $n = 3-8$
    - High T $\rightarrow$ Bulk diffusion
    - Low T $\rightarrow$ Core diffusion
  - Low σ — Diffusion (linear-viscous) creep, $n = 1$
    - High T $\rightarrow$ Bulk diffusion (N-H creep) $\propto \dfrac{1}{d^2}$
    - Low T $\rightarrow$ GB diffusion (Coble creep) $\propto \dfrac{1}{d^3}$

Data Extrapolation Methods

The need often arises for engineering creep data that are impractical to collect from normal laboratory tests. This is especially true for prolonged exposures (on the order of years).

A commonly used extrapolation procedure employs the **Larson-Miller parameter**, defined as:

$$T\left(C + \log t_r\right)$$

where

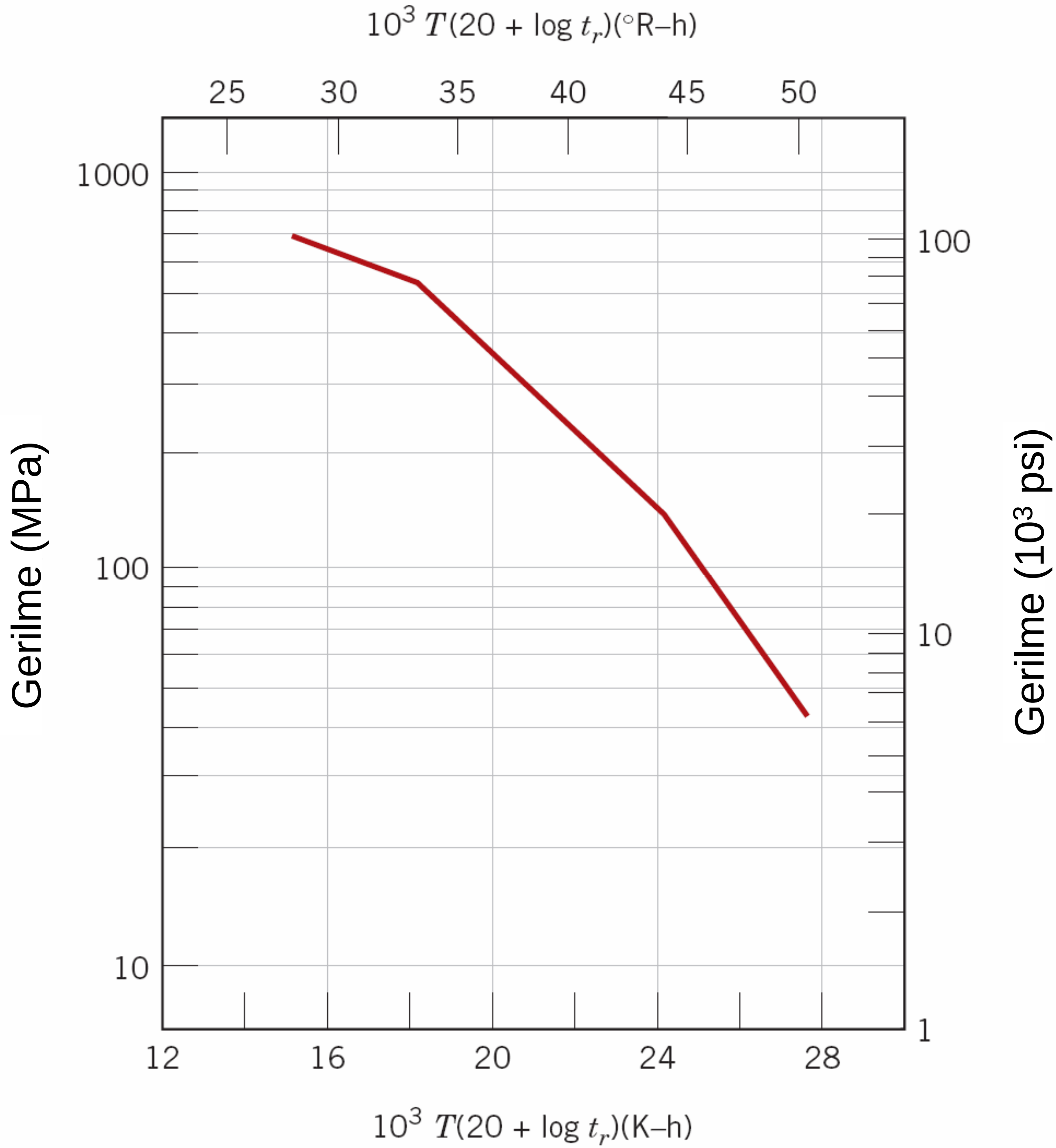
C is a constant

T is in Kelvin, and

t_r is the rupture lifetime.

The rupture lifetime at a specific stress level varies with temperature such that this parameter remains constant.

Or, the data may be plotted as a logarithm of stress versus the Larson-Miller parameter:



Design Example 1

Rupture Lifetime Prediction
Using the LArsonMiller adat for the S-590 alloy shown in the figure, predict the time to rupture for a component that is subjected to a stress of 140 MPa at 800°C.

Solution:

The Larson-Miller parameter at 140 MPa is 24.0×10^3'tür, for T in K, t_r in h. Therefore,

$$24.0\times10^3 = T\left(20+\log t_r\right) = 1073\left(20+\log t_r\right)$$

Solving for time,

$$22.37 = 20+\log t_r \qquad t_r = 233\,\mathrm{h}\,\left(9.7\,\mathrm{days}\right)$$

Alloys for High-Temperature Use

Several factors affect the creep chaarcteristics of metals. These include melting temperature, elastic modulus, and grain size.

In general, the higher the melting temperature, the greater the elastic modulus, and the larger the grain size, the higher the creep resistance.

Relative to grain size, smaller grains permit more grain boundary sliding, which results in higher creep rates. This effect may be contrasted to the influence of grain size on the mechanical behavior at low temperatures.