25th International Geological Congress

ABSTRACTS

VOLUME 1

5

THE INFLUENCE OF GRAIN SIZE ON THE RHEOLOGICAL PROPERTIES OF CALCITE ROCKS

S.M. Schmid, *Research School of Earth Sciences, Australian National University, Canberra, A.C.T. Australia*

Not much attention has been paid so far to the role of the grain size as an important parameter determining the flow behaviour of rocks. Grain size dependence in flow properties has been described in the metallurgical literature in the case of:

1. The dependence of the lower yield stress on grain size described by the Hall-Petch relationship (1951, Proc. Phys. Soc. B64, p. 747.) of the form $\sigma_y = \sigma_o + K\, d^{-1/2}$ where σ_y is the lower yield stress, d the grain size, σ_o and K are constants. This relationship is known to hold at moderate temperatures where dislocation glide is operative.
2. At higher temperatures this hardening effect through small grain sizes gets weaker and a temperature is reached at which there is no systematic grain size dependence of flow stresses. Constitutive equations describing the stress dependence of strain rate in the "disclocation creep field" (Stocker and Ashby, 1973, Review of Geophys and Space Phys. II P. 391.) such as the power law relationship of the form $\dot{\epsilon} \propto \sigma^n$ $(3 < n < 8)$ do not include grain size as an independent parameter.
3. At still higher temperatures and lower stress levels where diffusional creep and/or grain boundary sliding become important (including superplastic behaviour) the grain size dependence gets very marked again, this time in the sense that small grain sizes have a weakening effect at a given strain rate. Relationships such as $\dot{\epsilon} \propto \sigma/d^2$ (Nabarro-Herring creep) or $\dot{\epsilon} \propto \sigma^2/d$ (superplastic materials) have been found, where d is the grain size.

In the case of calcite rocks it has recently been demonstrated (Olsson, 1974 J. of Geoph. Res. 79132,4859.) that the Hall-Petch relationship adequately describes the yield stress of marbles at room temperature.

Recent rheological investigations on finegrained (4.2 μm) Solenhofen limestone at 600° to 900° revealed a transition from power law creep with n = 4.5 into superplastic behaviour (n < 3) at conditions under which coarse grained Yule marble (Heard and Raleigh 1972. BGS. Amer 83, p. 835) (400 μm) shows no such transition. As seen in Fig. 1 this transition results in a rapid weakening of Solenhofen limestone towards low strain rates relative to Yule marble. The superplastic behaviour (generally believed to involved grain boundary sliding) meets the criteria accepted for superplasticity in metals and alloys which are:

1. Low n-values (1<n<3) in the power law relationship mentioned above. In Solenhofen limestone n drops from 4.5 to 2 at a transition stress that falls from 1050 bars at 600°C to 300 bars at 900°C.
2. Stable grain size of <10 μm, the grains remaining equiaxed up to high strains.
3. Low dislocation density and destruction of preferred orientation. The geological implications of this grain size dependence of flow stress in calcite rocks are manyfold. Extrapolation to geological strain rates in Fig. 1 shows that the field of superplastic behaviour in finegrained calcite rocks covers a wide range of stresses, temperatures and strain rates typical for upper crustal conditions.

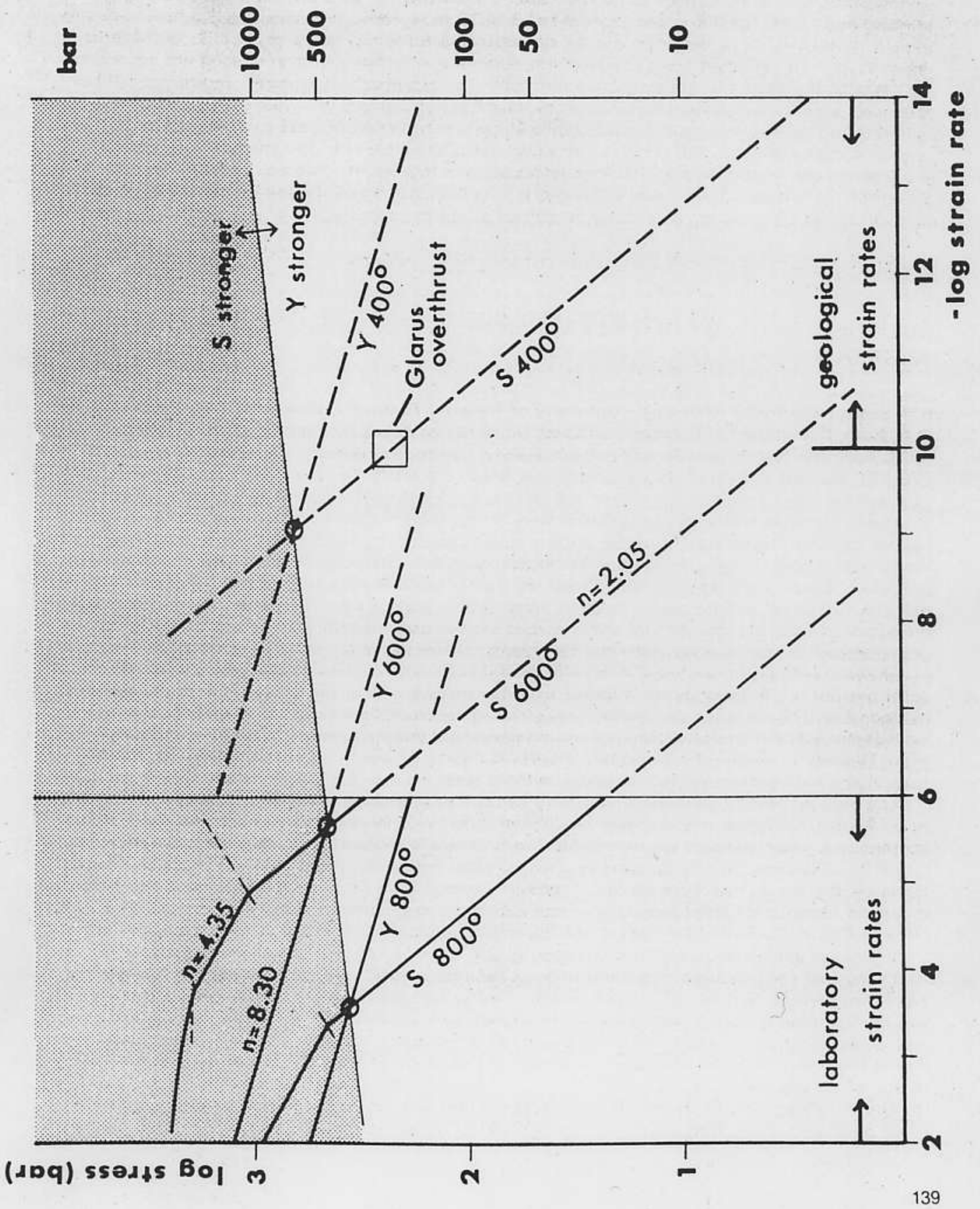
A few applications to particular problems are now briefly mentioned:

1. In a monomineralic calcite rock suite of varying grain size, competence contrasts may build up (reflecting differences in flow resistance) between layers of different grain size. The resulting inhomogeneities in the flow pattern could be used to establish whether a small grain size results in higher or lower flow resistance. This in turn would give important hints on the deformation mechanisms and the order of magnitude of stresses operative in the particular geological environment.
2. Ooids in oolitic limestones are often used as strain markers with the assumption that they deform homogeneously with their matrix. Deformation experiments on an oolitic limestone with finegrained ooids in a coarse grained (sparitic) matrix show that the strain in the ooids significantly exceeds the bulk strain in the rock once the ooids deform superplastically.
3. Very small grain sizes are characteristic of mylonitic zones. A reduction in grain size is achieved syntectonically by cataclasis or, more often, by recrystallization without subsequent grain growth. By their very nature mylonitic zones accumulate large amounts of strain suggesting that with increasing strain and grain size reduction a stable zone of weakness within the coarser grained country rock is produced (White, 1975, A. Roy Soc Lond). This suggests that in many mylonites diffusional creep and/or grain boundary sliding (including superplasticity) must have been at least partly operative.

An example of a finegrained calcite mylonite at the base of the Glarus overthrust has recently been described (Schmid, 1975, Eclogae geol Helv. 68, 251). In this case an estimate of strain rate

(10^{-10} sec $^{-1}$) and temperature (400°C) could be made. Using Solenhofen limestone as a model material for this equally finegrained mylonite a mechanically realistic basal shear stress of ~125 bars results from extrapolations according to Fig. 1. If the rheological properties observed above the transition stress into the superplastic field are extrapolated, unrealistically high stresses (Scmid, 1975, Eclogae geol Helu. 68, 251) are obtained, suggesting that this mylonite deformed superplastically.

Fig. 1: Composite stress/strain rate diagram for Solenhofen limestone and Yule marble for the 400°, 600° and 800° isotherms.



The values of A, H and n used in the constitutive equation of the form $\dot{\epsilon} = A \exp\left(\frac{-H}{RT}\right)\sigma^n$ are:

	log A (sec^{-1} bar^{-n})	H (kcal $mole^{-1}$)	n
Solenhofen, high stress regime	- 0.88	68.4	4.35
Solenhofen, superplastic regime	1.55	50.4	2.05
Yule marble 1 foliation*	−12.25	62.0	8.30

*Data from Heard and Raleigh, Bull Soc. Amer. 83 p. 835.