A new flow law for bischofite

Universiteit Utrecht

N. Muhammad, C.J. Spiers, C.J. Peach & J.H.P. De Bresser

HPT Laboratory, Department of Earth Sciences, Faculty of Geosciences, Utrecht University, the Netherlands.

European Geosciences Union General Assembly 2014
Vienna | Austria | 27 April – 02 May 2014
EGU.eu

1. Problem and Aims:

- Bischofite is normally extracted from the subsurface by solution mining in underground caverns.
- Abandonment of the caverns causes the wall rock to creep towards the inside due to overburden stress, which in turn results in subsidence at the surface.
- Aim: Flow law that allows reliable extrapolation from lab to strain rate ~ 10^{-9} s^{-1}, to be used in modelling.

2. Material and experiments:

- Polycrystalline cylindrical samples with average length = 80 mm and diameter = 35 mm (Figure 1)
- From as received cores (Figure 2)
- Jacketed and undried
- Triaxial deformation apparatus at HPT Lab (Figure 3)
- Triaxial tests at real *in-situ* conditions: $T = 70^oC$, $P_c = 40$ MPa. Additional tests at $P_c = 70$ MPa.
- Strain rate stepping experiments with stress relaxation after every constant deformation step

Figure 1. Bischofite sample with piston assembly

Figure 2. As received 100 cm long pure bischofite core

Figure 3. Triaxial apparatus (Shuttle vessel)

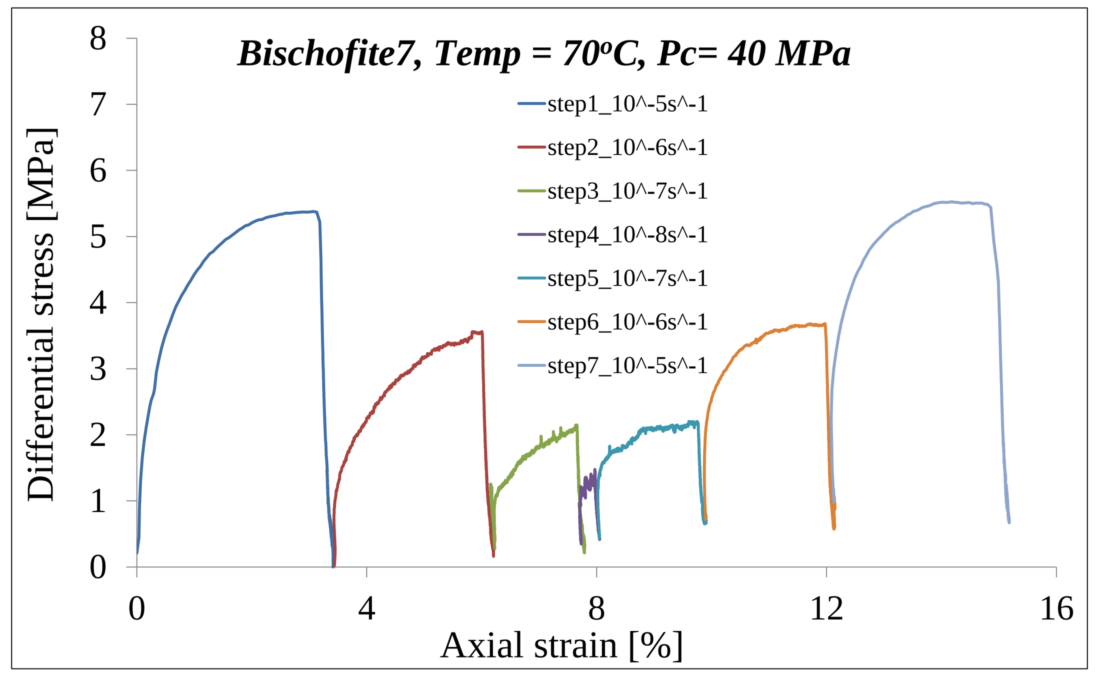

Figure 4. Strain rate sensitivity of flow stress at 40 MPa

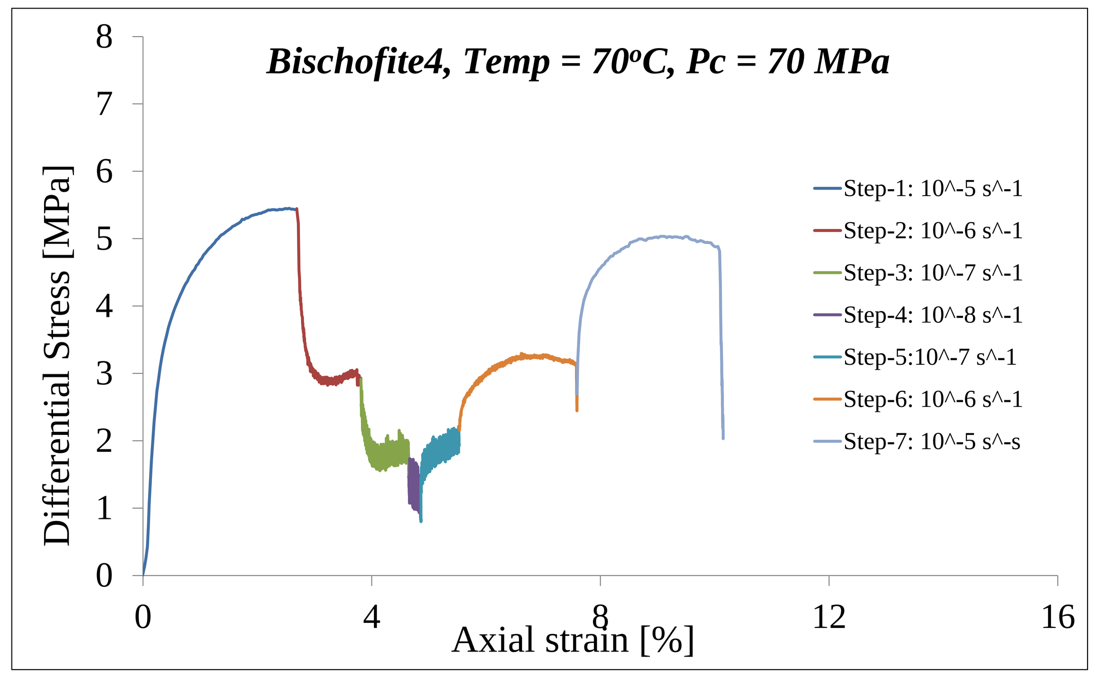

Figure 5. Strain rate sensitivity of flow stress at 70 MPa

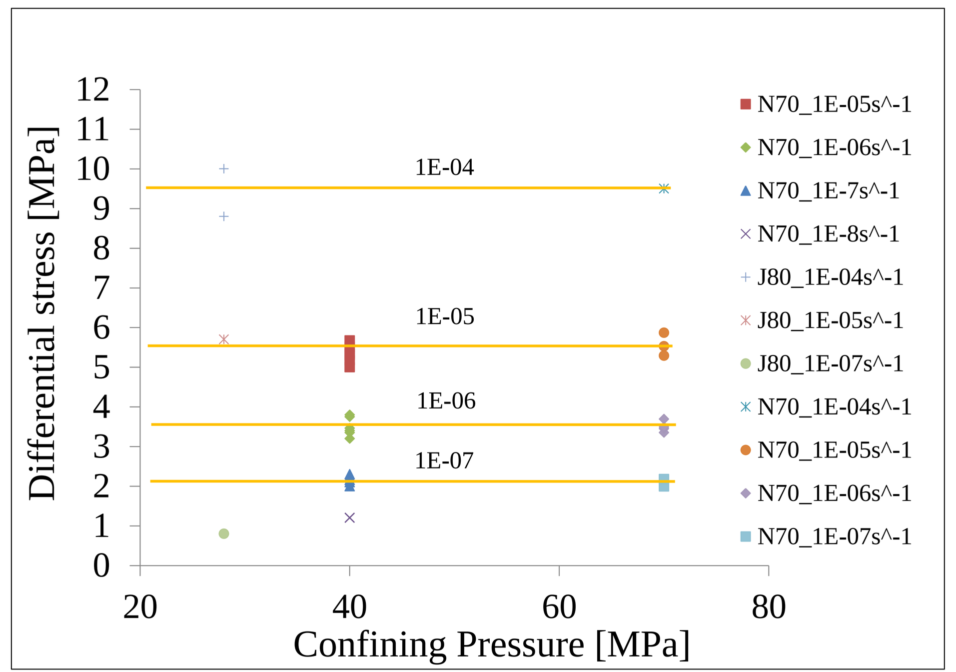

Figure 6. No Effect of confining pressure

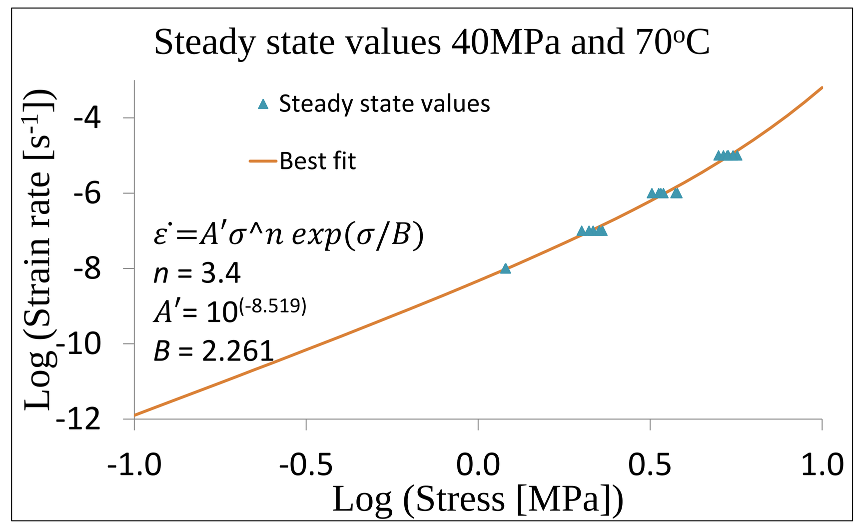

Figure 7. Non-linear trend of steady state points

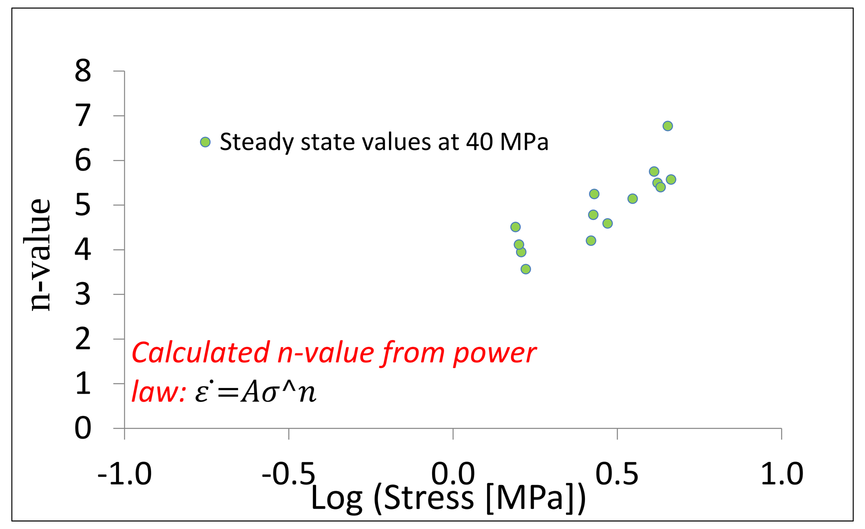

Figure 8. n-value vs. log of steady state stress

3. Mechanical behaviour:

- Bischofite is strain rate sensitive.
- Steady state stress values are reasonably well reproducible
- Steady state stress values do not follow linear trend on log σ - log $\dot{\varepsilon}$ plot, so conventional power law cannot be used.
- No pressure sensitivity of strength at tested conditions.
- Bischofite is weaker during relaxation than during deformation at constant strain rate, at the same stress.

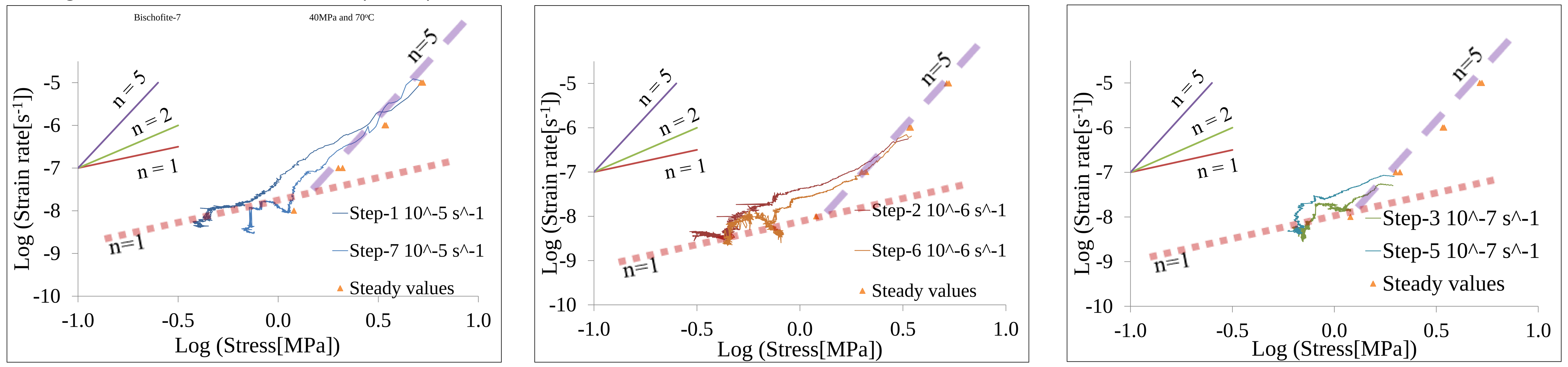

Figure 9. Stress relaxation curves with steady state differential stress values. Similar strain rate steps are combined to see the reproducibility.

4. Flow laws used in analyses (at constant Temperature):

$\dot{\varepsilon} = A\sigma^n$	(Grain Size Insensitive (GSI) Power law)
$\dot{\varepsilon} = A'\sigma^n exp\left(\frac{\sigma}{B}\right)$	(GSI Exponential law)
$\dot{\varepsilon} = C\sigma d^{-p}$	(Grain Size Sensitive)

5. Role of grain size:

- *From previous work (Van Eekelen et al (1984): Bishofite shows dynamic recrystallization.*
- *Grain sizes at steady state stresses (our experiments) from piezometric relation Figure 10.*

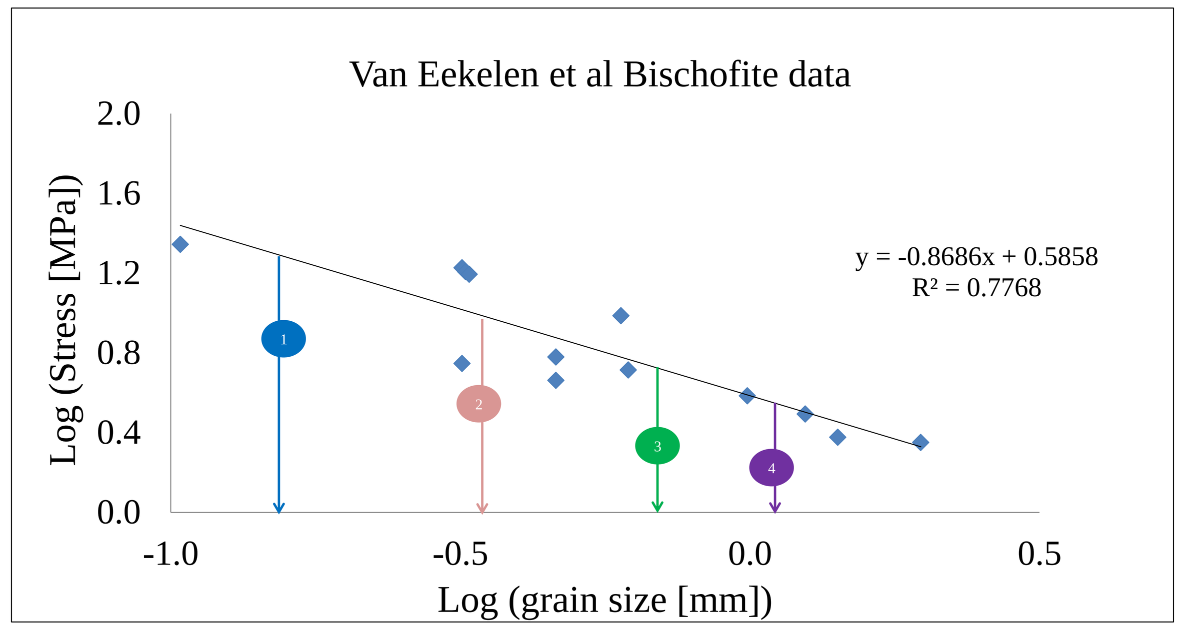

Figure 10. Flow stress vs. mean grain size at 60°C

- *Relaxation trend towards n = 1, suggests role of GSS*
- *So description by composite flow law (GSI+GSS) ?* $\dot{\varepsilon} = A\sigma^n exp\left(\frac{\sigma}{B}\right) + C\sigma d^{-p}$,
- *Evaluation of 'p' based on assumption of constant microstructure (constant grain size) during relaxation.*
- *Result: p = 2-0.6: No conclusion yet on mechanism*

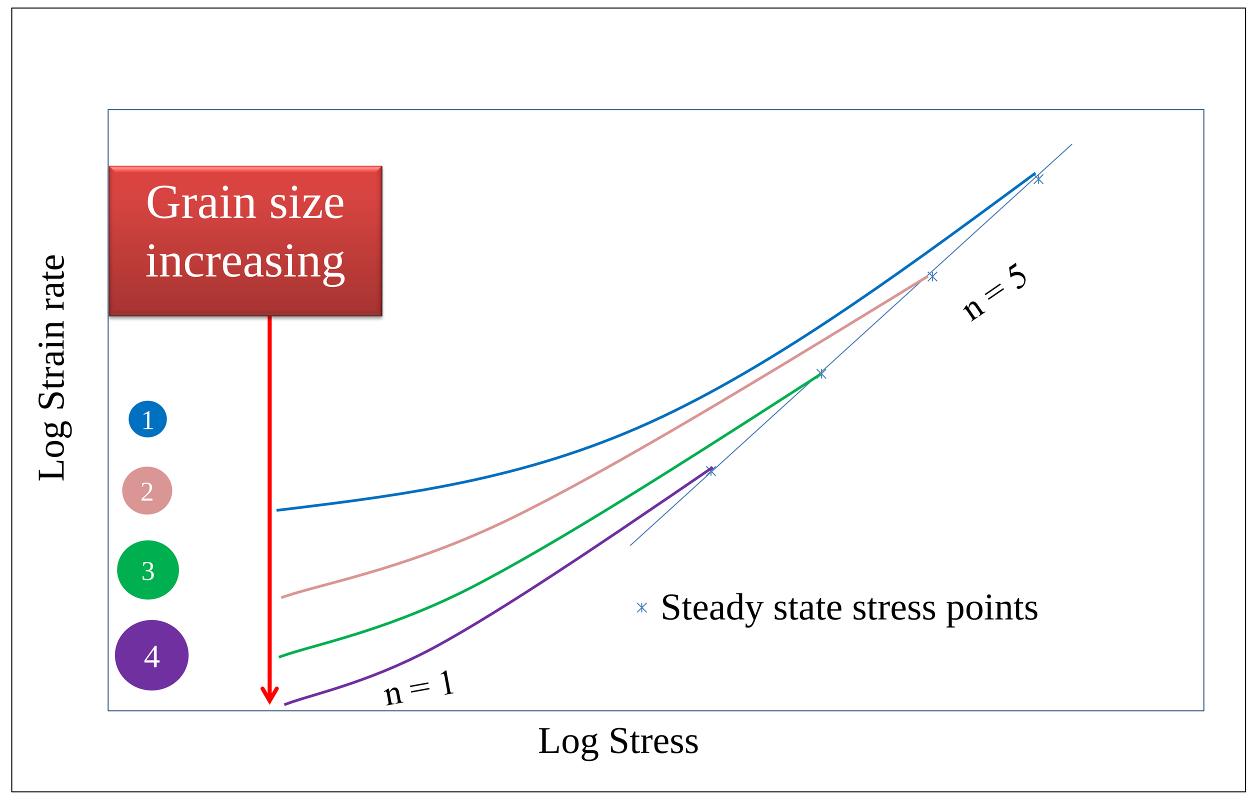

Figure 11. Schematic diagram: Changing n-value during relaxation

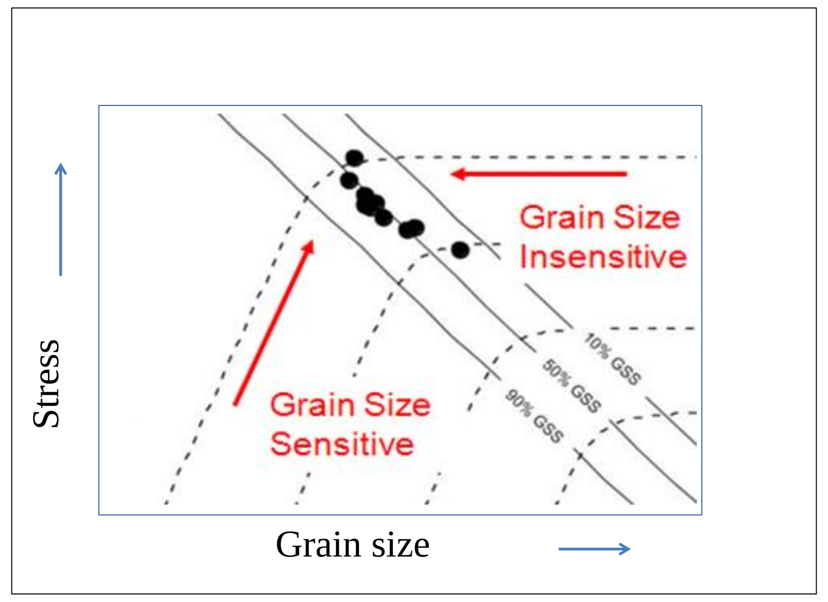

Figure 12. Boundary hypothesis

6. Conclusions:

- Observed behaviour differs between constant strain rate steps and relaxation periods.
- Trend to n = 1, in relaxation not seen at constant strain rate.
- Implies effective microstructural modification
- So balance between GSI and GSS? of "boundary hypothesis"
- $\dot{\varepsilon}_{total} = \dot{\varepsilon}_{GSI} + \dot{\varepsilon}_{GSS}$ and $\dot{\varepsilon}_{GSI} \approx \dot{\varepsilon}_{GSS}$:$\dot{\varepsilon}_{total} = 2\dot{\varepsilon}_{GSI}$
- We propose that a flow law of the type $\dot{\varepsilon} = A'\sigma^n exp\left(\frac{\sigma}{B}\right)$ should be applied at 70°C and 40 MPa. Best fit analysis resulted in values $n = 3.4$, $A' = 10^{(-8.519)}$ and $B = 2.261$.

References:

1. De Bresser, J. H. P. "On the mechanism of dislocation creep of calcite at high temperature " *Journal of geophysical research* (2002).
2. Muhammad, N., Spiers, C.J., Peach, C.J. and de Bresser, J.H.P. "Effect of confining pressure on plastic flow of salt at 125°C" *Saltmech-VII* (2012).
3. Rutter, E. H., and D. H. Mainprice. "The effect of water on stress relaxation of faulted and unfaulted sandstone" *pure and applied geophysics* (1978).
4. Ter Heege, J.; Bresser, J. D. & Spiers, Dynamic recrystallization of wet synthetic polycrystalline halite: *Tectonophysics , (*2005).
5. Urai, Janos L. "Water assisted dynamic recrystallization and weakening in polycrystalline bischofite." *Tectonophysics* (1983).
6. van Eekelen, Hans A., Ton Hulsebos, and Janos L. Urai. "Creep of bischofite. *Saltmech-I (*1984).

Acknowledgements:

This work was supported through a scholarship for Nawaz Muhammad awarded by the Higher Education Commission of Pakistan and through additional sponsorship provided independently by Nedmag Industries. The authors thank Gert Kastelein, Peter van Krieken and Eimert de Graaff for technical support.