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Interactive comment on "High temperature indentation creep tests on anhydrite – a promising first look" *by* D. Dorner et al.

J.-P. Gratier (Referee)

jean-pierre.gratier@ujf-grenoble.fr

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Review of "High temperature indentation creep tests on anhydrite – a promising first look" by Dorner, Roeller and Stoeckhert

By Jean-Pierre Gratier (Jean-Pierre.Gratier@ujf-grenoble.fr)

General comments: The submitted manuscript emphasizes the potential of indentation creep testing in order to understand the mechanisms of deformation on the example of polycrystalline anhydrite. The experimental method is well described and the data are interesting. However the conditions of the deformation, at very high temperatures and in dry conditions, render the application to natural deformation processes rather limited. The potential for geological applications must be discussed in more details.

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The introduction presents the two objectives of the work: (i) explore whether indentation creep testing can be used to investigate the mechanical behaviour of rock-forming minerals and (ii) investigate the mechanical behaviour of such rocks in natural deformation. The problem, which is not clearly discussed in the manuscript, is the conditions of the natural deformations that the authors want to study. Experiments are run at atmospheric pressure, relatively fast strain rates (10-5 to 10-9/s), in dry conditions and very high temperatures (700 to 920°C with homologous temperatures T/Tm ranging from 0.57 to 0.69). What is the geological context that is aimed to be discussed? One could guess that such a context corresponds to a metamorphic context with very high temperature and pressure? Is it right? If yes the main problems and the questions about anhydrite behaviour in such a metamorphic context must be raised here.

However the statement in the discussion of "the obvious weakness of the anhydrite horizon inferred from the natural structure" raises the question of another possible range of application, which is the behaviour of weak decollement horizons? In this last case the conditions of the deformation are rather different from the ones of the experiments. It should be wet conditions at low temperature and pressure. This clarification about the geological context that the authors want to study is needed in the introduction in order to help the reader to follow the discussion.

The part on the presentation of the rock (anhydrite) does not answer the question raised above. It leaves open a large range of applications, which are not limited to very high temperatures. The geological applications that are cited in this part correspond to the conditions of use of the properties of low porosity and low permeability of anhydrite with the application to the study of cap rocks for technical storage and nuclear waste. In this case it is difficult to avoid discussing the effect of water on the anhydrite behaviour and anyway the conditions of pressure and temperature are rather low (some kilometres of depth), much lower than the ones used in the experiment. The other proposed application is, from a tectonic point of view, the mechanical weakness of anhydrite invoked to be responsible for localization of deformation with the cited example of Triassic evaporitic formations that control the Jura deformation. In this case, as in the preceding one, the deformation occurs at relatively low depth (some kilometres of depth in the Jura, Burkhard & Sommaruga, Geol. Soc Spec. Pub. 1998) and consequently at low temperature and pressure and likely in the presence of water.

The experimental procedure is well described from a technical point of view. The scientific approach and the applied method are pertinent. It must be noted that the samples had already a foliation before the experiment. One can guess that it was to best distinguish between this initial foliation and a possible induced experimental foliation that the direction of the indenting was chosen to be parallel to the foliation. This makes sense. However this choice needs a little more discussion. What could be the consequence of this choice on the results? What would have been the effect on the results of amplifying the original foliation? The stress field and the strain rate field are rather complex in the indentation creep technique as acknowledged by the authors and they use various previous studies including some modelling approaches in order to shift from the imposed stress and strain rate values on the indenter to the stress and strain rate conditions within the sample.

The results are interesting and well presented: stress exponent and activation energy are evaluated. Coupled to experimental measurements this leads to the building of creep laws. The microstructures are described in thin section under optical microscope. Zones of crystallographic preferred orientation are identified from such optical observations without more quantitative measurements. The data and the observations indicate some crystal plastic deformation with dynamic recrystallization and recovery during indentation. This part constitutes an original and substantial contribution.

An intriguing observation, which is not discussed in the manuscript, is the fact that the surfaces of the indented samples do not show a bulge shape around the indented hole as one would have expected if the deformation were done at constant volume. On the contrary, a moat is observed around the indenter. This does not seem to be compatible with a deformation at constant volume? Is there a volume change? Is there a porosity change of the material during the indentation process?

The discussion on the various paths of deformation and on their complexity in the various zones of the deformed sample is interesting. The discussion of the deformation regime is also convincing. Data as the high stress exponent (3.9) and the high activation energy values (388 kJ/mole) and the observation of various zones with crystallographic preferred orientation attest of deformation in the regime of dislocation creep controlled by recovery and recrystallization as stated in the manuscript.

The discussion of the extrapolation to natural deformation is less convincing mainly because it is not clear which type of deformation context is discussed. If the authors want to discuss the behaviour of anhydrite in metamorphic context at high temperature and pressure and dry conditions the use of the creep law with the modification of the strain rate could be acceptable if it was demonstrated that the natural deformation occurs in such conditions. However as said above such specific metamorphic context must be discussed in the introduction.

Alternatively if the authors want to discuss the geological context described in the part devoted to the presentation of anhydrite, the conditions of the deformation are low temperature and low pressure (some kilometres depth) in presence of water. In such a case the extrapolation of the experimental creep law obtained in dry condition at 700 to 920°C to low temperature (100 – 200°C) and wet conditions needs careful discussions. Other mechanisms of deformation might be at work at low temperature controlled by friction or diffusive mass transfer. The authors argue that crystallographic preferred orientation has been described in anhydrite. It would be interesting to give the geological context. The comparison with quartz behaviour contradicts the statement that anhydrite is associated with weak horizons, so what is the geological context that is aimed here?

Even in the context of low temperature and pressure, the observation of crystallographic preferred orientation is not necessarily a marker of dislocation creep law: as discussed in the manuscript, it could be linked to anisotropic growth during pressure solution creep. It could also be restricted to the rocks with large grain size. Pressure solution is a major mechanism of creep in the earth's upper crust, where the proposed geological applications are focused, for soluble minerals under stress as quartz, calcite, feldspar, halite, anhydrite-gypsum. . . This creep mechanism has been proposed to play a key role in active creeping fault (Rutter & Mainprice, Pure & Appl. Geoph. 1978) more or less mixed with frictional processes (Bos & Spiers, JGR, 2002). Moreover, in a decollement context as in active creeping fault the strain values are incredibly large: displacement of one kilometre that is accommodated within a shear zone of 10 meters of thickness would imply a shear strain value of 100. According to Ramsay (Fold. & Fract. of Rocks, 1967) this would be associated with shortening (l2/l0) of 0,01 and extension (l1/l0) of 100. Can dislocation creep mechanisms accommodate such large strain values? Is it possible to calculate, from the crystallographic preferred orientation measured in nature, such associated large shear strain values? Is it possible to evaluate a partition between the mechanisms of deformation depending on the lithology and the microstructure (grains size)?

Alternatively, diffusion-accommodated grain sliding as superplastic flow proposed by Ashby & Verral (Acta Metal. 1973) are more likely to accommodates the large strain values required in active creep zones as along decollement or aseismic fault. Such mechanism of creep has been proposed to occur in natural shear zones at relatively high temperature if diffusion occurs along grain boundary (Boullier & Gueguen, Contrib. Min. Petro. 1975). Alternatively the diffusion process could be accelerated by the presence of a fluid phase trapped around the grains. In this case diffusion-accommodated grain sliding by pressure solution could controlled the active fault creep process within the earth's upper crust (Gratier et al. Tectonoph. 2013).

Finally, the discussion of the potential of the high temperature indentation tests is interesting however the applications to natural deformation are limited. Other indenting techniques have been developed these last 30 years at lower temperature and in pres-

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ence of the mineral solution in order to study pressure solution creep and compaction, fracturing and healing that are well representative of the deformation within the earth' upper crust where the proposed geological applications are focused. Such experiments could be mentioned here.

In conclusion, the high temperature indentation tests are interesting however the discussion of their possible applications to the natural deformations needs some developments.

Interactive comment on Solid Earth Discuss., 5, 2081, 2013.