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# Accounting for elastic anisotropy in crystal plasticity within the context of olivine dynamic recrystallization using a level-set framework

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## ► To cite this version:

Jean Furstoss, David Ruiz Sarrazola, Marc Bernacki, Carole Petit, Clément Ganino, et al.. Accounting for elastic anisotropy in crystal plasticity within the context of olivine dynamic recrystallization using a level-set framework. AGU Fall Meeting 2019, Dec 2019, San Francisco, United States. hal-02440169

**HAL Id: hal-02440169**

**<https://hal.science/hal-02440169>**

Submitted on 15 Jan 2020

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## Abstract :

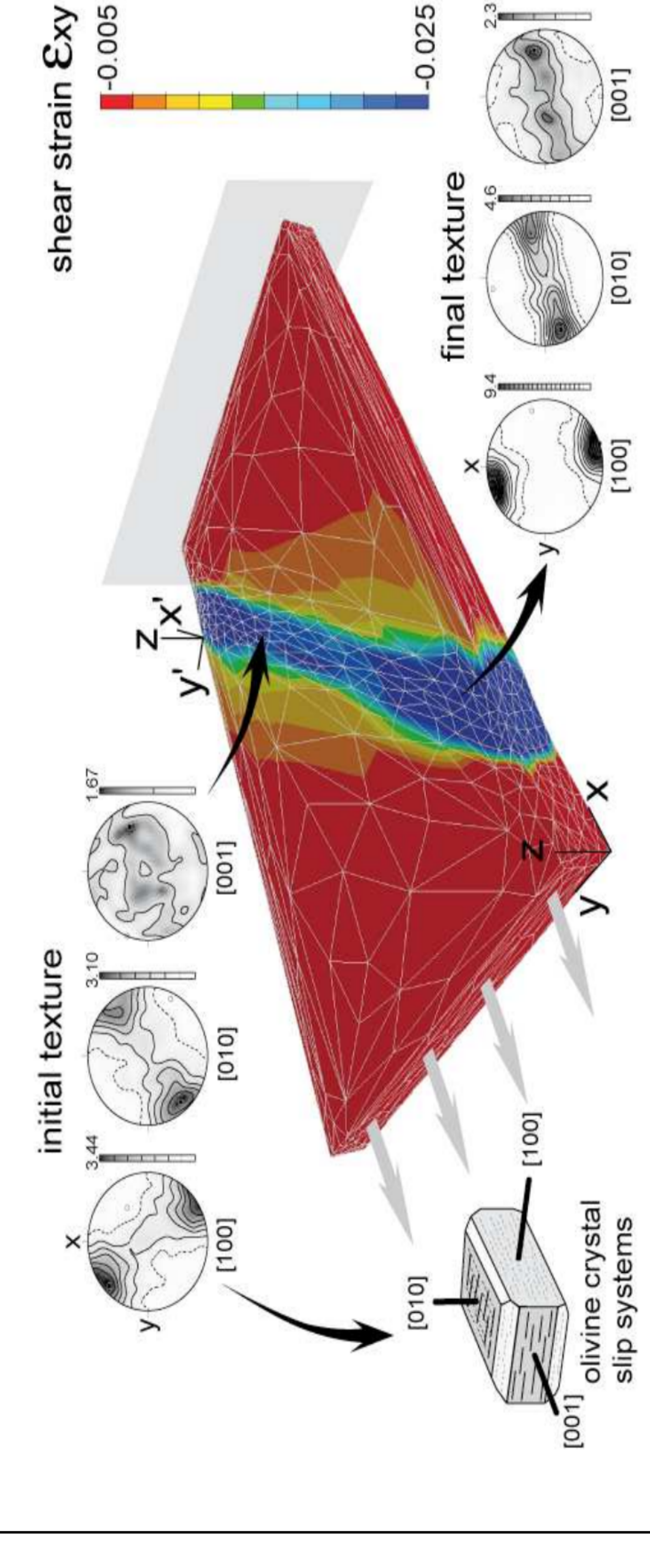
Because olivine is the major constituent of upper mantle rocks, its mechanical properties and microstructural evolutions play an important role in the lithosphere rheology. In this study, we investigate the deformation of olivine polycrystals through a numerical framework coupling the crystal plasticity and the finite element method (CPFEM). The rheology of the olivine aggregate is described through a crystal plasticity model that we have developed and that takes into account the elastic anisotropy of the olivine crystal, based on published experimental data. The mixed velocity/pressure finite element formulation has also been modified in order to take into account the informations coming from crystal plasticity computation. In addition to predicting polycrystal mechanical behaviour, this methodology also permits to track the development of lattice preferred orientation (LPO) during deformation. These important features are predicted using the proposed approach during the deformation of olivine aggregate with and without accounting for elastic anisotropy. Our results suggest that the elastic anisotropy exerts a weak influence on the subsequent plastic deformation and thus on polycrystal mechanical behaviour, LPO development and local pressure and stress.

## Context :

Most rocks exhibit a mechanical behaviour strongly anisotropic

This is mainly due to lack of independent slip systems accommodating strain during plastic deformation

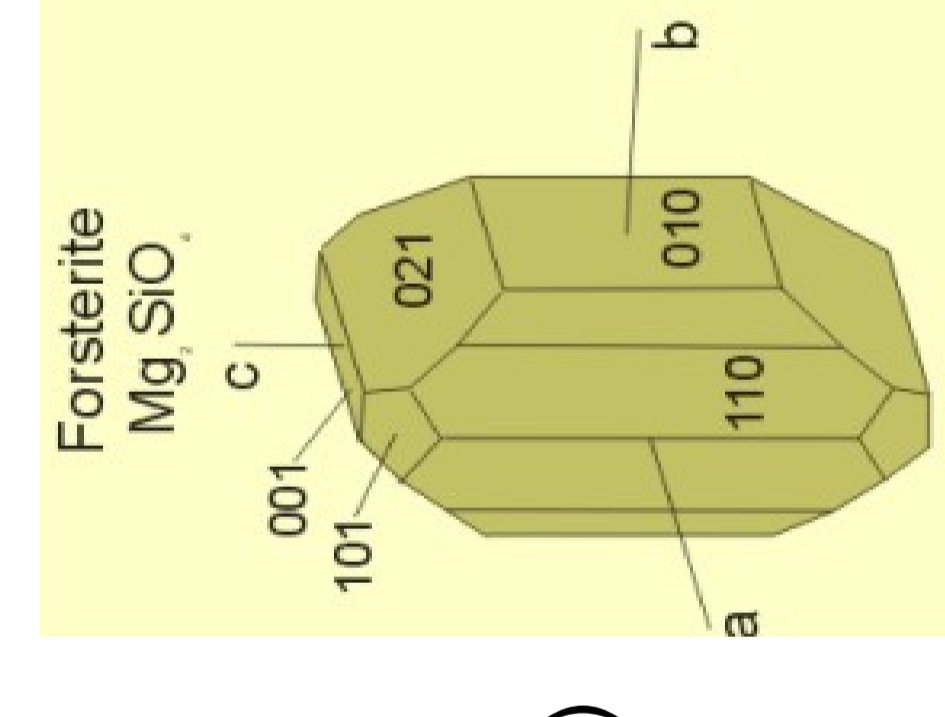
Consequently, plastic deformation of rocks often leads to the development of marked lattice preferred orientation (LPO)



Numerical simulation of a shear zone creation and activation with the corresponding LPO development from Tommasi et al. 2009

$$C^e (MPa) = \begin{pmatrix} 192 & 66 & 60 & 0 & 0 & 0 \\ 66 & 160 & 56 & 0 & 0 & 0 \\ 60 & 56 & 272 & 0 & 0 & 0 \\ 0 & 0 & 0 & 60 & 0 & 0 \\ 0 & 0 & 0 & 0 & 62 & 0 \\ 0 & 0 & 0 & 0 & 0 & 49 \end{pmatrix}$$

Forsterite elastic constants from Isaak et al. 1989



Orthorhombic crystallographic structure of forsterite (Mg rich end member of olivine)

Does the elastic anisotropy have an influence on the mechanical behaviour and LPO development during plastic deformation, in the case of olivine ?

## Numerical implementation :

### Crystal plasticity formulation

The formulation is based on a set of 3 equations describing the equilibrium of strain, the rotation of the lattice and the evolution of the strength.

A set of constitutive laws has to define :

**A list of slip system :**

| Case             | Burgers vector | Glide plane | Characteristics |
|------------------|----------------|-------------|-----------------|
| Low temperature  | [001]          | (100)       | (100)           |
|                  | [100]          | (010)       | (110)           |
|                  |                | (110)       | (011)           |
| High temperature | [001]          | (021)       | (110)           |
|                  | [101]          | (011)       | (111)           |
|                  |                | (111)       | (011)           |

The elastic behaviour :  $\sigma_{ij} = C_{ijkl}^e \epsilon_{kl}$

The flow rule :  $\dot{\gamma}^\alpha = \dot{\gamma}_0 \left| \frac{\tau^\alpha}{\tau_c^\alpha} \right|^m \text{sign}(\tau^\alpha)$

The hardening behaviour :  $\tau_c^\alpha = \tau_{c0}^\alpha + \Psi \mu b^\alpha \sqrt{\rho t^{\text{tot}}}$

With initial CRSS ( $\tau_{c0}^\alpha$ ) discriminating slip systems with [100] and [001] Burgers vector from dislocation dynamics simulation (Durinck et al. 2007)

Dislocation density evolution :  $\frac{d\rho^\alpha}{dt} = \frac{K_1 - K_2 \rho^\alpha}{M} |\dot{\gamma}^\alpha|$

where K1 and K2 are taken to best fit monocystal deformation experiments (Phackey 1989)

**CP calculation provides : - deviatoric stress**  $S_{ij}$

- tangent matrix  $C_{ijkl}^e = \frac{\partial S_{ij}}{\partial \epsilon_{kl}}$

All tensors are expressed within the appropriate Kelvin base ( $K_{ij}^N, K_{kl}^N$ ) which accounts for crystal type (Mehrabadi et al. 1990) :

$C_{ijkl}^e K_{kl}^N = \lambda^N K_{ij}^N$  the 6 tensors of the base are the eigentensors of the elastic constant matrix

Stress and strain become : and the Hooke's law is reduced to :  $\sigma^N = \sigma_{ij} K_{ij}^N, \epsilon^N = \epsilon_{ij} K_{ij}^N, \sigma^N = \lambda^N \epsilon^N$

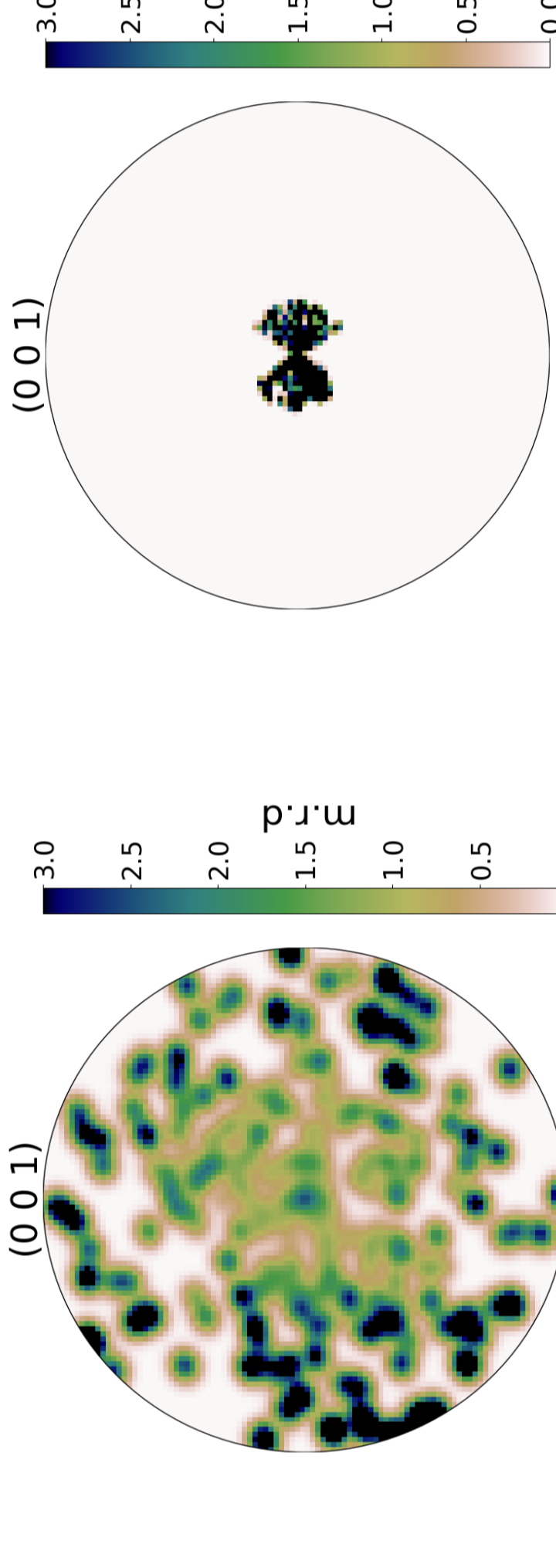
## Results for initially textured and non textured polycrystal

Without elastic anisotropy

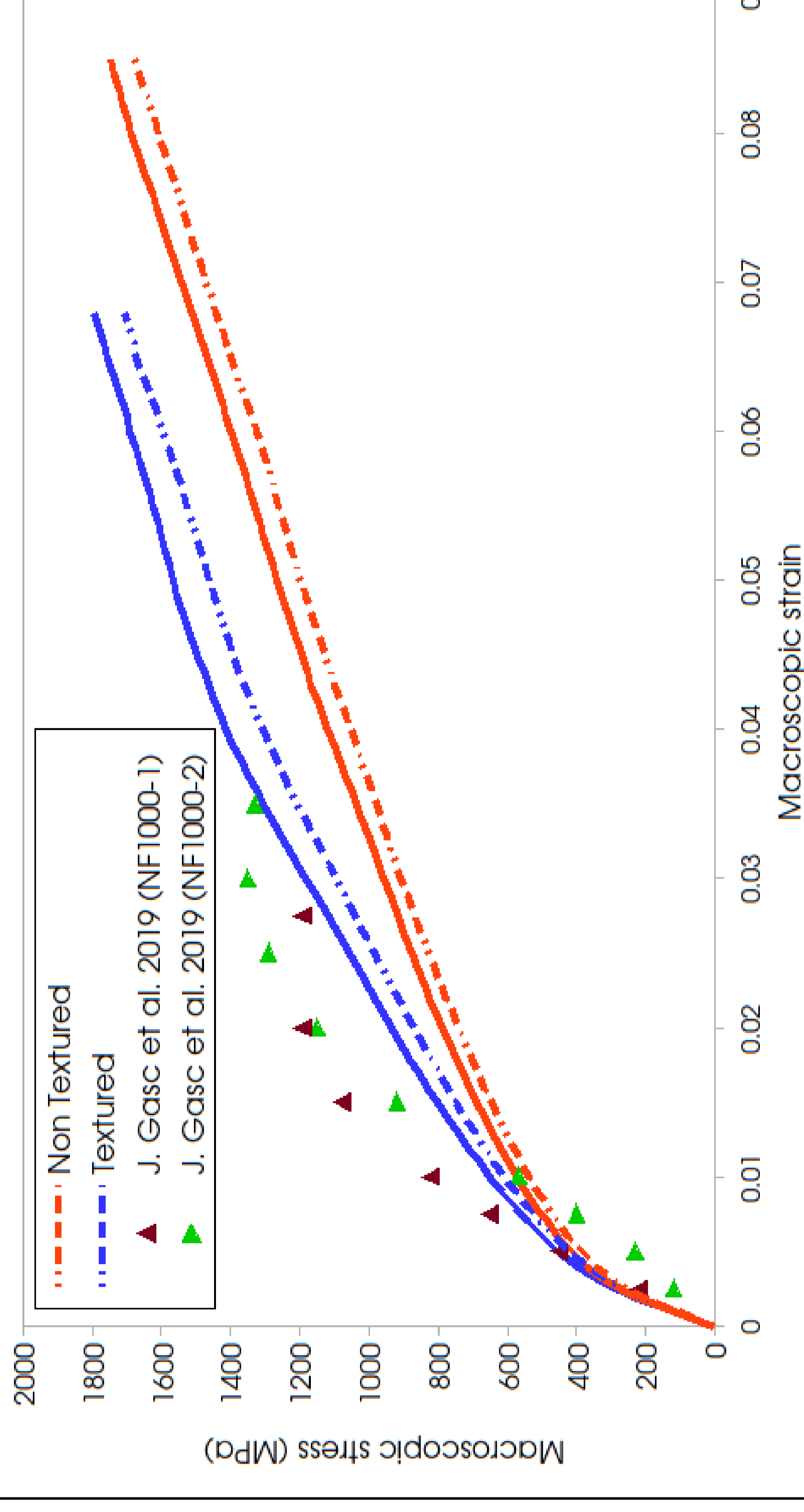
With elastic anisotropy

Cube (2mm aside) compression  
 Isotropic mesh (1 million element) remeshed every 1% of macroscopic strain  
 300 grains of 0.18mm mean grain size  
 Initial total dislocation density  $10^5 \text{ mm}^{-2}$   
 Macroscopic strain rate  $10^{-3} \text{ s}^{-1}$  and increment of 0.1% at every step

Initial pole figures

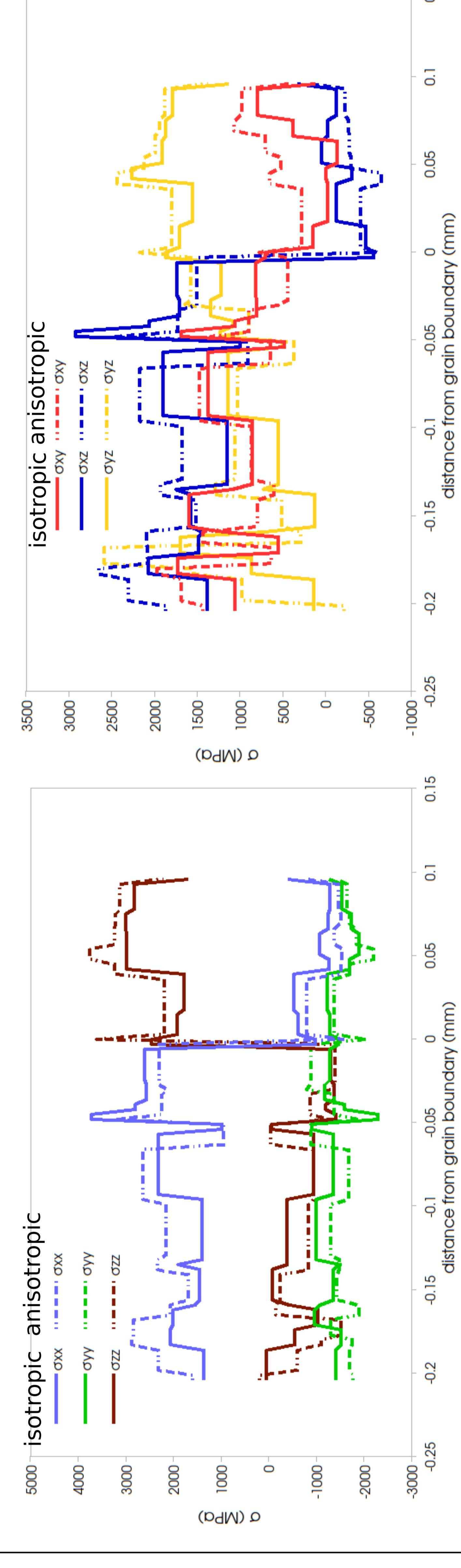


Macroscopic mechanical behaviour (full line with anisotropy, dashed line without anisotropy)

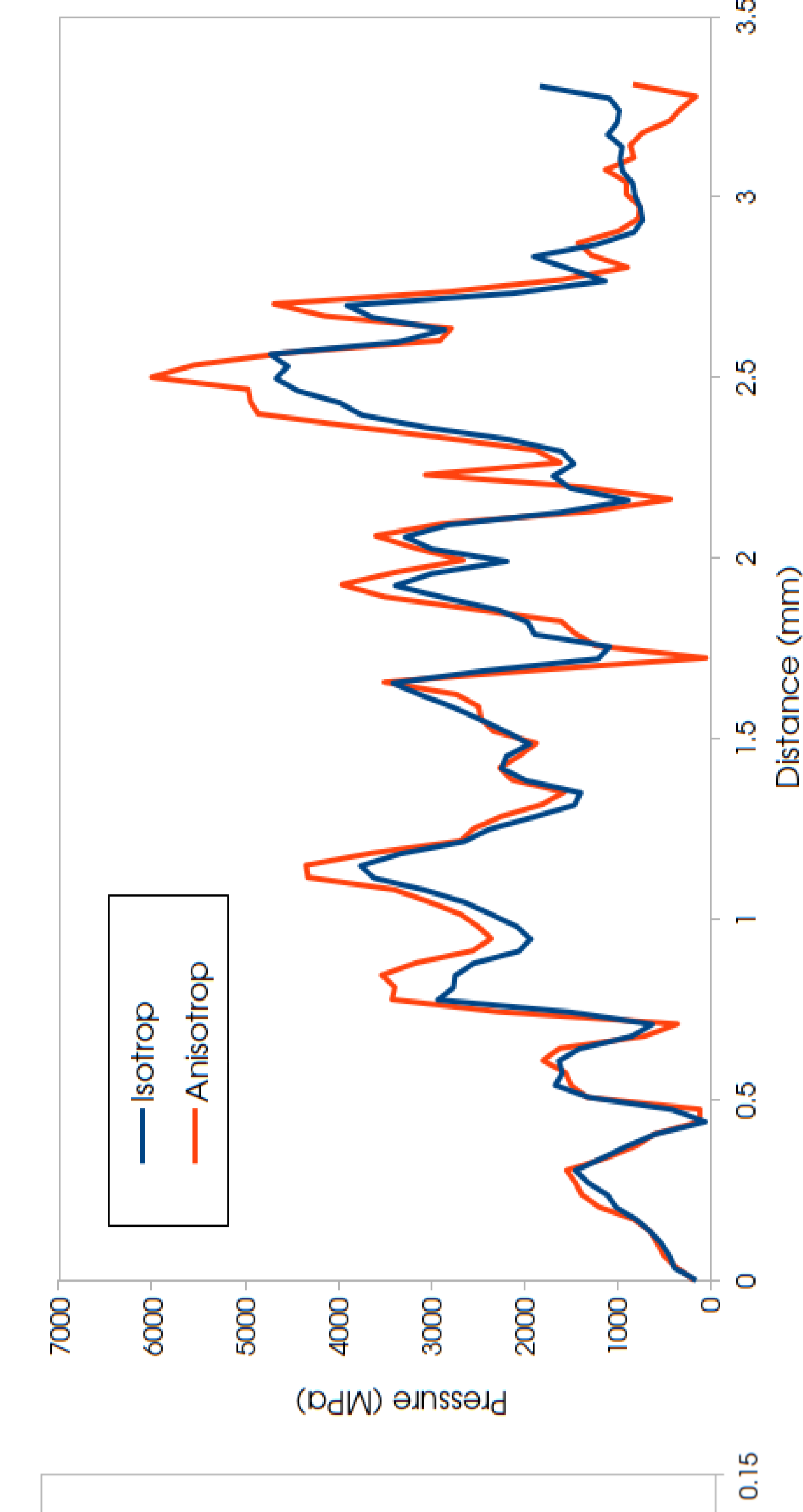


## Results at local scale

Deviatoric stress components along a line passing through a grain boundary



Pressure evolution between two opposite edges



## Discussion/Conclusion :

No strong influence is observed between models accounting or not for anisotropic elasticity :

- neither on macroscopic mechanical behaviour,
- nor on texture development,
- nor on local total dislocation density, and this for initially textured or not material

Same trends with local differences about few tens of percent on :

- local pressure
- local stresses

At this point, there is no clear evidence for the influence of anisotropic elasticity on plastic deformation

## Perspectives :

The influence of elastic anisotropy has to be tested within dynamic recrystallization simulations  
 Nucleation criterium based on local disorientation or local stress may imply some changes

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## Acknowledgments :

This work was supported by CNRS INSU 2018-programme Tellus-SYSTER. The supports of the French Agence Nationale de la Recherche (ANR), ArcelorMittal, Areva, ASCOMETAL, AUBERT&DUVAL, CEA, SAFRAN through the DIGIMU Industrial Chair and consortium are gratefully acknowledged.