New lattice preferred orientation(LPO) of amphibole experimentally found in simple shear

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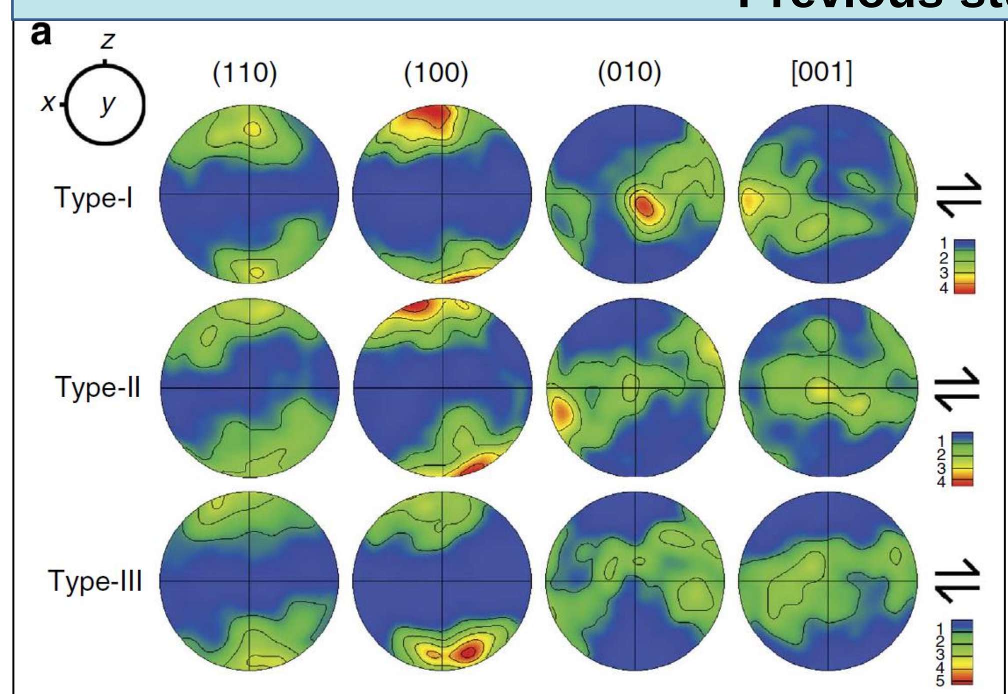
Introduction

In order to understand seismic anisotropy, it is necessary to study the CPO of the minerals in the rocks. Amphibolite is a major constituent rock of the middle to lower crust. Amphibole which is a major constituent mineral of amphibolite is elastically anisotropic and has a great effect on seismic anisotropy in the crust. However, there is very little experimental research on what CPO appears in amphibole at certain temperature and pressures. In this study we performed shear deformation of amphibolite under the pressure of 0.5GPa and temperatures of 500-700℃.

Previous studies



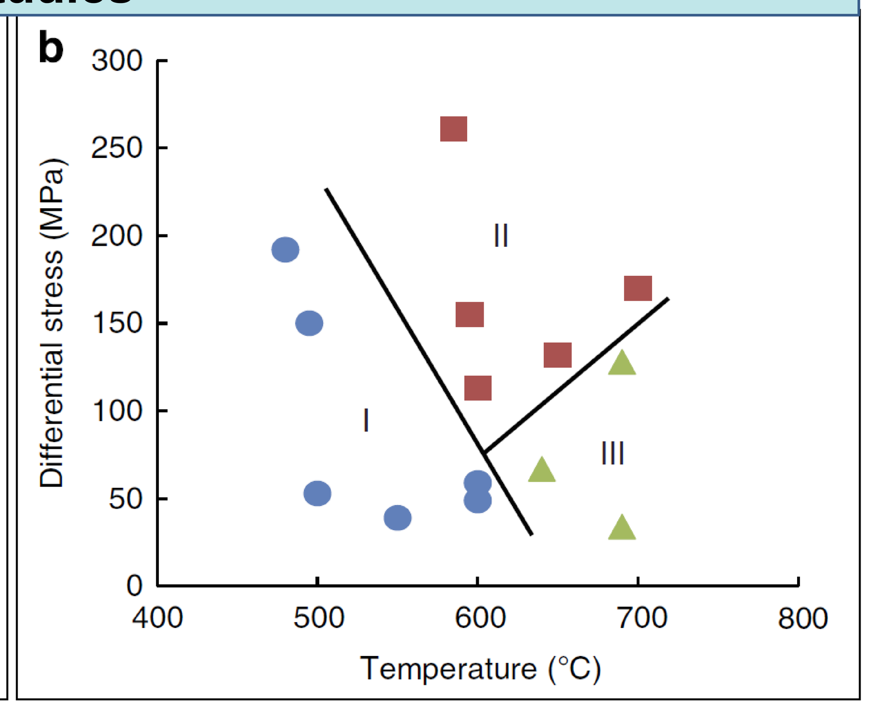


Fig. 1. (a) Pole figures of three CPO types of amphibole deformed at the pressure of 1GPa. (b) Amphibole CPO type diagram at the pressure of 1GPa (Ko and Jung, 2015).

In a recent experimental study, CPO of hornblende was classified into four types and three types (Type – I, II, III) were identified to be formed by temperature and differential stress at the pressure of 1GPa.

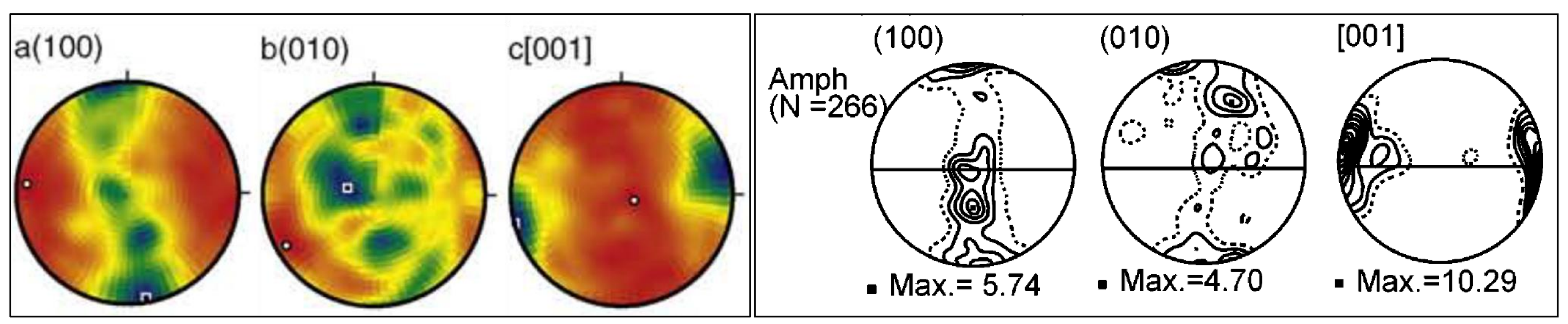
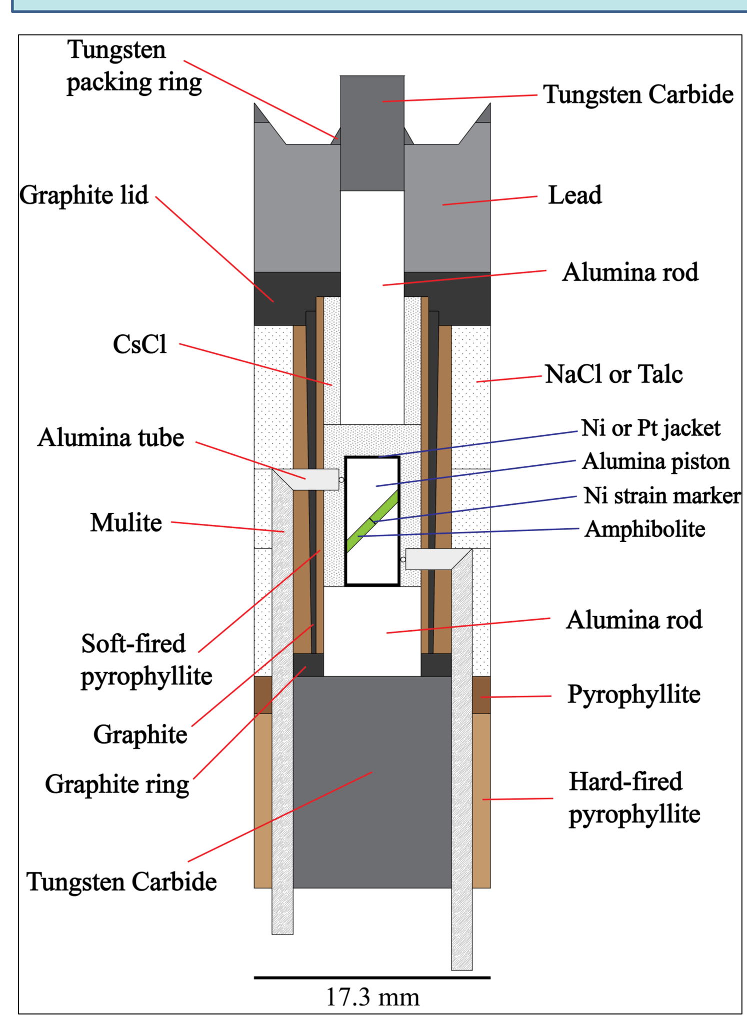


Fig. 2. Type – IV CPO of amphibole found in natural rock (Tatham et al., 2008; Kitamura, K., 2006).

But type – IV CPO, which is characterized as both [100] axes form a girdle subnormal to lineation were relatively common in nature and were not found in experiments at the pressure of 1GPa.

Methods



The experimetal conditions were temperature 500 – 700℃ and pressure 0.5 GPa. The used apaaratus is modified Griggs apparatus in Seoul national university. For shear strain measurements, thin nickel foil was inserted between samples perpendicular to shear plane. Confining pressure was raised for over 14hours. After reaching pressure of 0.5GPa, sample was annealed at leaest 1 hour to remove possible defects generated during pressurization. Temperature was raised for about 1 hour. After reaching target temperature, sample was deformed by moving down alumina piston with constant speed. After deformation, confining pressure was depressurized for over 14 hours.

CPOs of amphibole were determined by using electron backscattered diffraction (EBSD) attached on FE-SEM (JEOL JSM-7100F) with HKL system with channel 5 software in SNU. Seismic velocity and anisotropy were calculated by solving Christoffel equation using FORTRAN program (Mainprice, 1990) with CPO data and the elastic constants of hornblende (Aleksandrov and Ryzhova, 1961).

Fig. 3. A schematic figure of sample assembly for shear deformation experiment

CPOs of amphibole

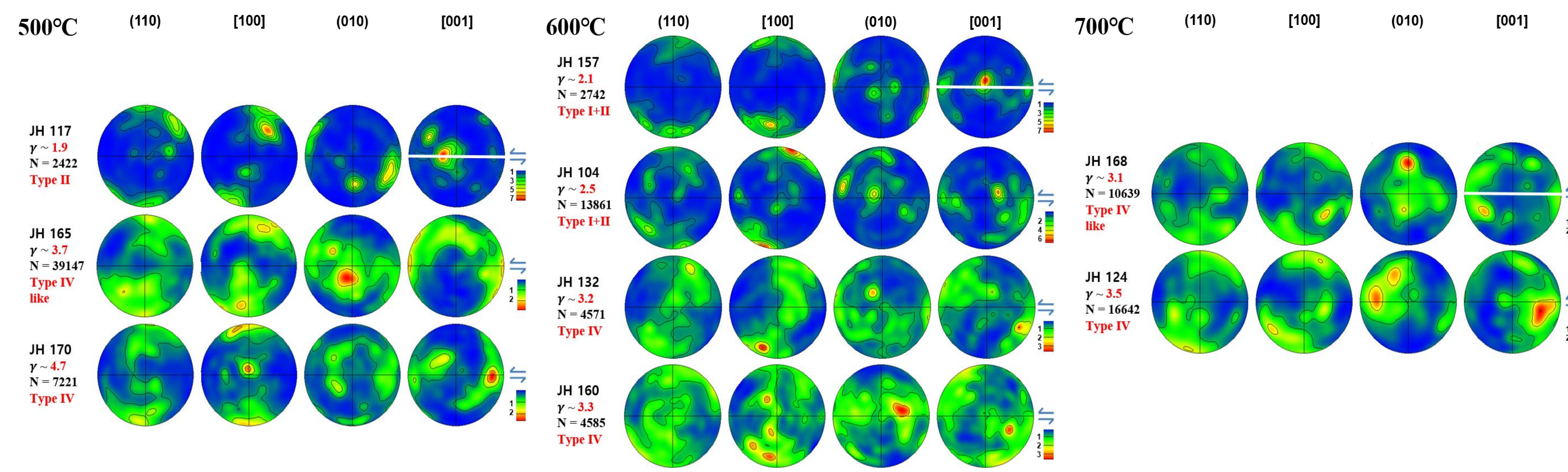
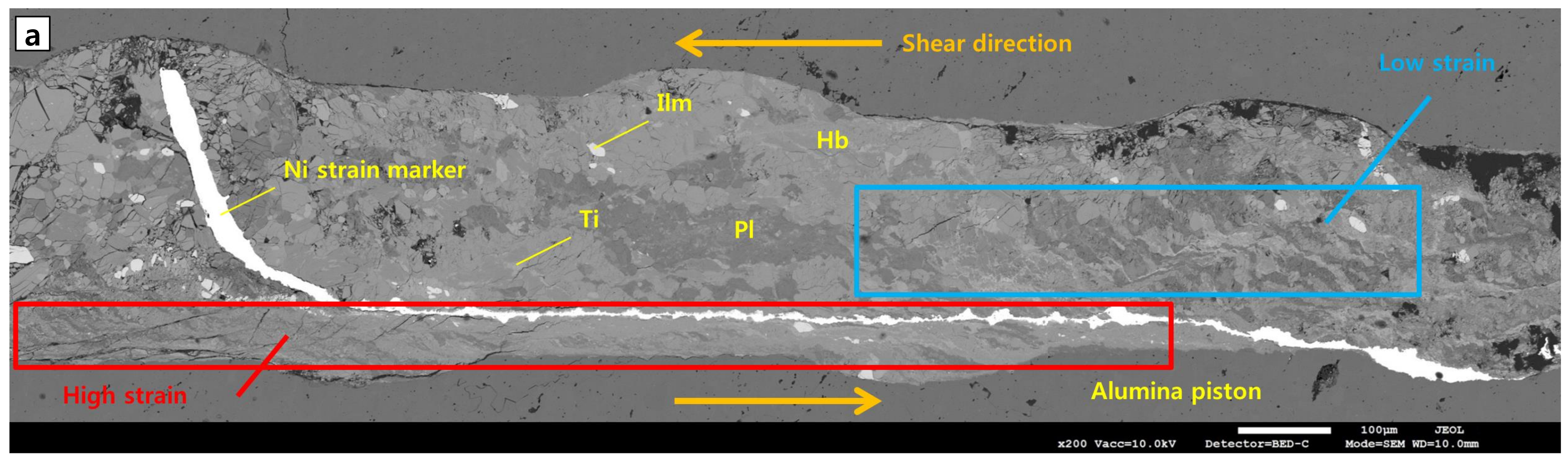


Fig. 4. Pole figures of amphibole which are projected in the lower hemisphere. A half-scatter width of 15°was used. The X direction represents shear direction and the Z direction which is top and bottom side of projection represents normal to shear plane. N = Number of grains γ = Average shear strain.

The CPO of amphibole in starting material is very weak. But he CPOs of amphibole after deformation are relatively strong and CPOs can be divided into four types. Two samples deformed in the temperature 700℃ (JH124, JH168) showed type – I CPO of amphibole. JH 117 deformed in 500℃ by low strain showed type – II and low strain samples deformed in 600℃ (JH 104 and JH157L) showed type – III CPO of amphibole. Type – IV fabrics were found in the relatively low temperature (500, 600℃) and high strain (maximum strain > 3).

Discussion



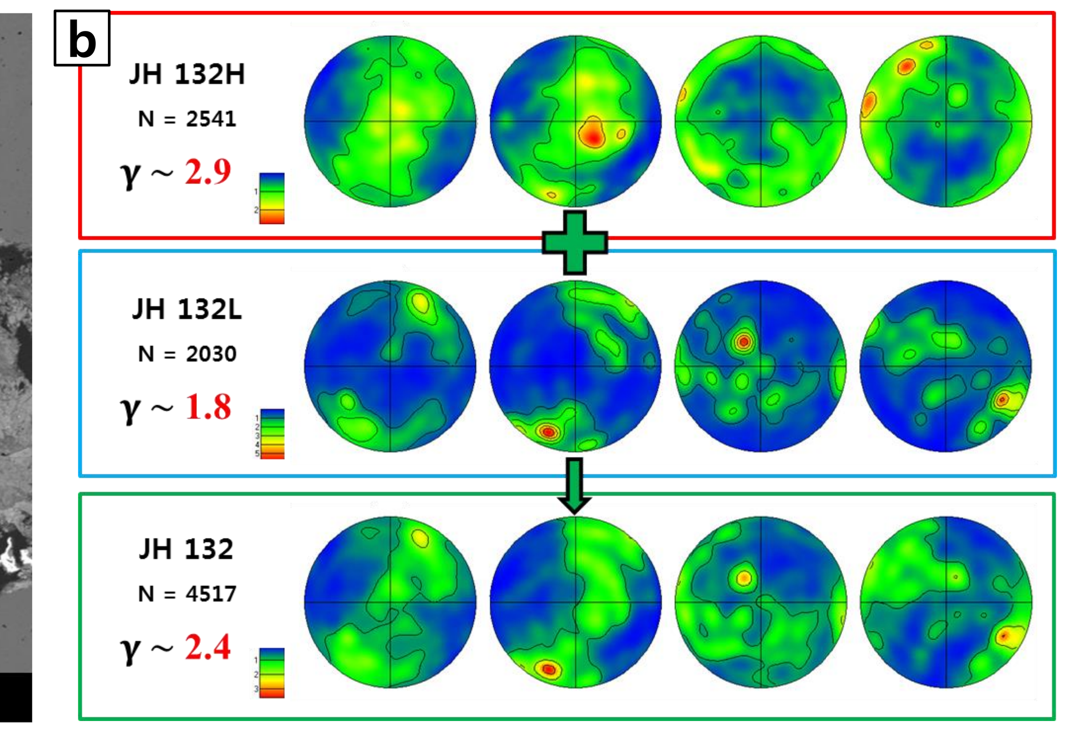
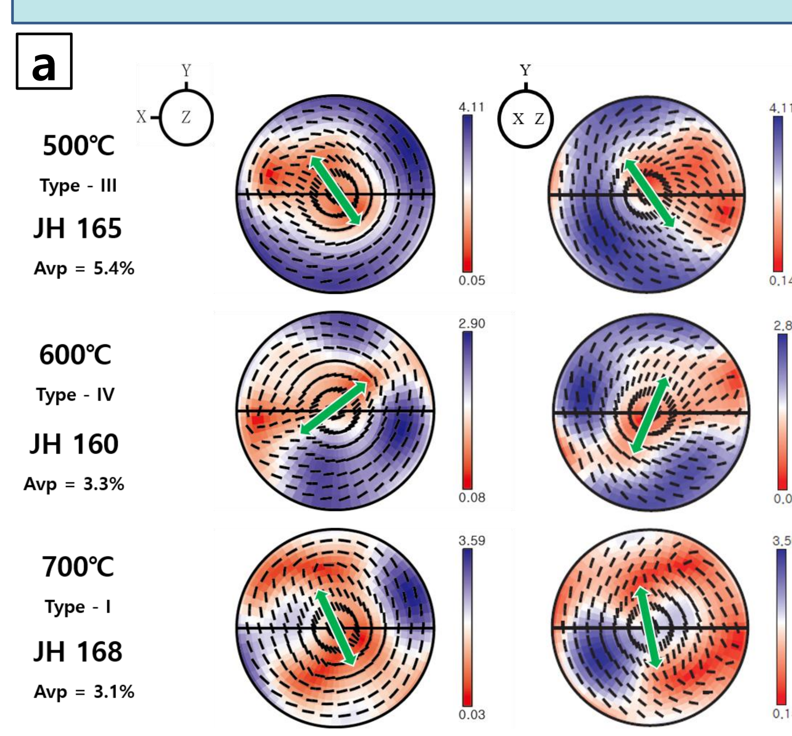


Fig. 5. (a) Backscattered electron image of deformed amphibolite in 600℃ (JH 132). This sample shows strong strain localization and it shows two different strain zones. Ni : Nickel, Ti : Titanite, Ilm : Ilmenite, Pl : Plagioclase, Hb : Hornblende **(b)** Pole figures of amphibole in sample JH 132 high strain zone (red box in figure a; JH132H) and low strain zone (blue box in figure a; JH132L) and whole sample (JH132).

Sample JH132 was deformed at 600℃ and its high strain zone and low strain zone are clearly distinguished. The low strain zone has a relatively high proportiton of amphibole porphyroclasts with relatively coarse grain sizes, while the high strain zone has very small grain sizes. As a result of EBSD mapping of each zone, Type – III CPO of amphibole was observed in low strain zone(γ ~1.8) and there is a previously undetected CPO in which [100] axes were aligned in a direction perpendicular to the shear direction on shear plane in high strain zone (γ ~2.9). Unlike JH132, in general high strain samples, fine-grained amphibole by high strain and coarse-grained amphibole by low strain are mixed. Thus, the fine-grained amphibole in which [100] axes are aligned parallel to y-axis and the coarse-grained amphibole in which [100] axes are aligned parallel to z-axis are mixed. As a result the type – IV CPO appears in which [100] axes are aligned as a girdle normal to shear direction.

Fast-shear wave polarization direction



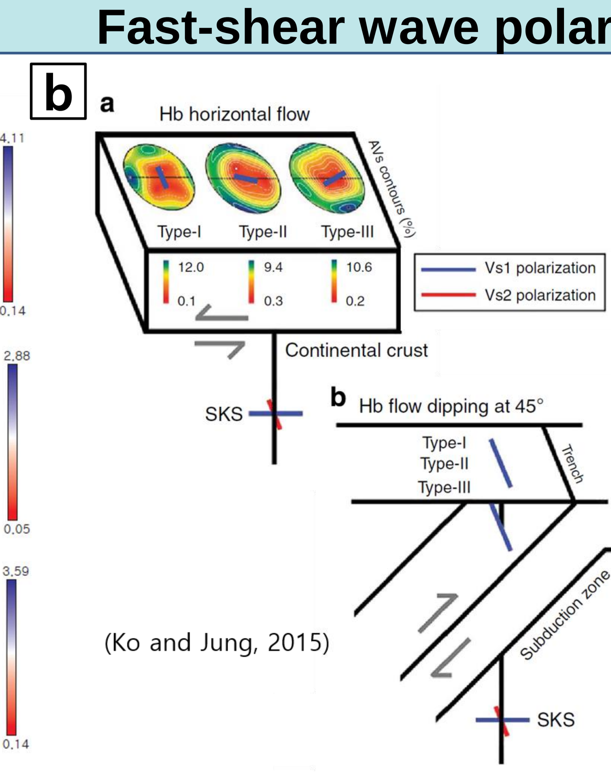


Fig. 6. (a) The polarization direction of fast shear wave for amphibole at the pressure of 0.5GPa. Left row shows polarization direction for horizontal flow and right row shows polarization direction for flow dipping at 45°. **(b)** The polarization direction of fast shear wave of amphibole deformed at the pressure of 1GPa for horizontal flow and flow dipping at 45° (Ko and Jung, 2015).

For horizontal flow, the fast-shear wave polarization direction of type – I and III CPO types of amphibole show subnormal to shear direction. But the polarization direction of type – IV CPO of amphibole show 45°angle with shear direction. For the flow dipping angle of 45°, all three types of CPO of amphibole show the polarization directions subnormal to shear direction. The polarization direction arranged in subnormal direction of shear direction are consistent with the previous experimental results at 1GPa. This suggests that the amphibole show a trench-parallel polarization direction regardless of depth and CPO types in the subduction zone.

Summary

In this study, we deformed amphibole by simple shear at the pressure 0.5GPa. We found four CPO types of amphibole. In particular, type – IV CPO of amphibole was first observed by experiment. The type – IV CPO of amphibole appeared at low temperature and high strain. The cause of type – IV CPO appears to be the mixing of fine-grained amphibole due to high strain and coarse grained amphibole due to low strain. The fast shear wave polarization directions were subnormal to shear direction on the flow dipping angle at 45°. This result is same result as at 1GPa and can explain the trench-parallel fast shear wave polarization direction in the subduction zones.