Petrofabric and Seismic properties of exhumed subducted oceanic crust from Naga Hills Ophiolite, North-East India

Saquib Abdullah[1], Santanu Misra[1], R Sarvesha[1], and Biswajit Ghosh[2]

[1]Indian Institute of Technology Kanpur
[2]University of Calcutta

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Abstract

The microstructures, textures and seismic anisotropy of a foliated blueschist-eclogite rock from Naga Hills Ophiolite (NHO) complex, North-East India has been investigated to understand the fabric relationship and deformation mechanism prevailed during the metamorphism and subduction of the Neo-Tethys oceanic crust. The Naga Hills blueschist-eclogite rock essentially contains omphacite, phengite, glaucophane, and garnet, representing an oceanic crust that experienced P-T stability field of blueschist and further eclogite metamorphism before it resurfaced accreting in the Naga Hills. Omphacite and glaucophane show weak shape preferred orientation (SPO), while phengite displays a strong SPO. The Crystallographic Preferred Orientations (CPO) of omphacite is characterized by the [001]-axes gridles within the foliation, and the (010)-poles concentrated sub-perpendicular to the foliation. For glaucophanes, the [001] axis aligns parallel to lineation and the [100] axis and (110) pole plunge perpendicular to foliation. These CPOs correspond to SL-type fabrics, related to a deformation geometry within the plain strain field and they developed from plastic deformation through dislocation creep. The seismic anisotropies of the individual minerals, blueschist-eclogite domains and their contributions in the bulk rock anisotropy has been discussed. The calculated seismic anisotropies (AVP and AVS) of bulk rock are 12.8% and 8.1%, respectively. This strong seismic anisotropy is due to the presence of phengite and glaucophane and can contribute to the observed seismic anisotropy in the subduction zone. The average low P-wave velocity of whole rock from NHO compared to blueschist is probably due to the low P-wave velocity of phengite (avg VP: 6.2 kms-1). Therefore, the low seismic velocity in the upper layer and the strong seismic anisotropy of the subducting oceanic crust can be attributed to the presence of glaucophane and phengite.

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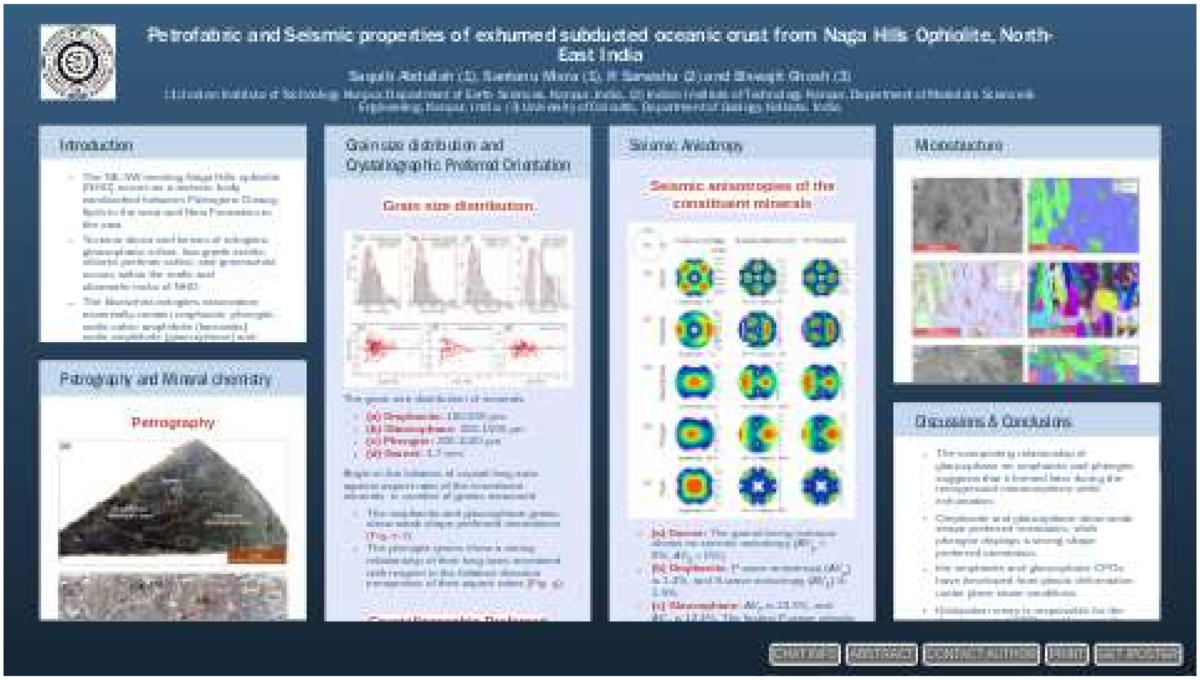

Saquib Abdullah (1), Santanu Misra (1), R Sarvesha (2) and Biswajit Ghosh (3)

(1) Indian Institute of Technology Kanpur, Department of Earth Sciences, Kanpur, India, (2) Indian Institute of Technology Kanpur, Department of Materials Science & Engineering, Kanpur, India, (3) University of Calcutta, Department of Geology, Kolkata, India

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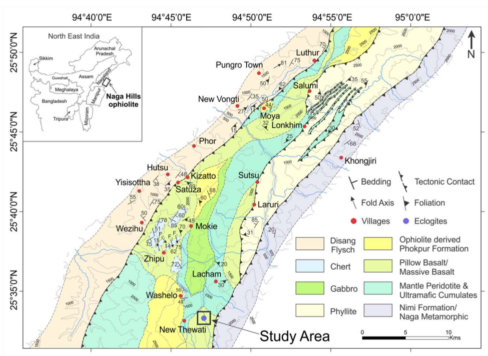
INTRODUCTION

- The NE-SW trending Naga Hills ophiolite (NHO) occurs as a tectonic body sandwiched between Paleogene Disang flysh to the west and Nimi Formation to the east.

- Tectonic slices and lenses of eclogites, glaucophane schist, low-grade zeolite, chlorite-prehnite schist, and greenschist occurs within the mafic and ultramafic rocks of NHO.

- The blueschist-eclogites association essentially contain omphacite, phengite, sodic-calcic amphibole (barroisite), sodic amphibole (glaucophane) and garnet with minor epidote and rutile.

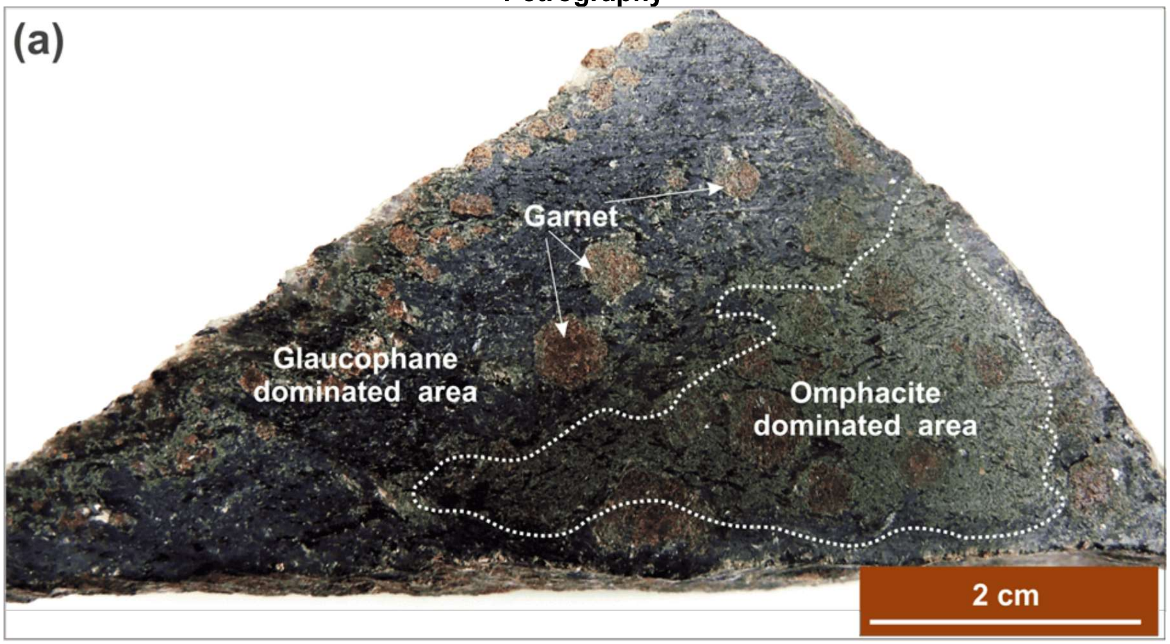
- The study aims to investigate the microstructure, texture, and seismic anisotropy of a foliated blueschist-eclogite rock in the NHO complex, North-East India to understand the deformation mechanism prevailing in the subducting oceanic crust.

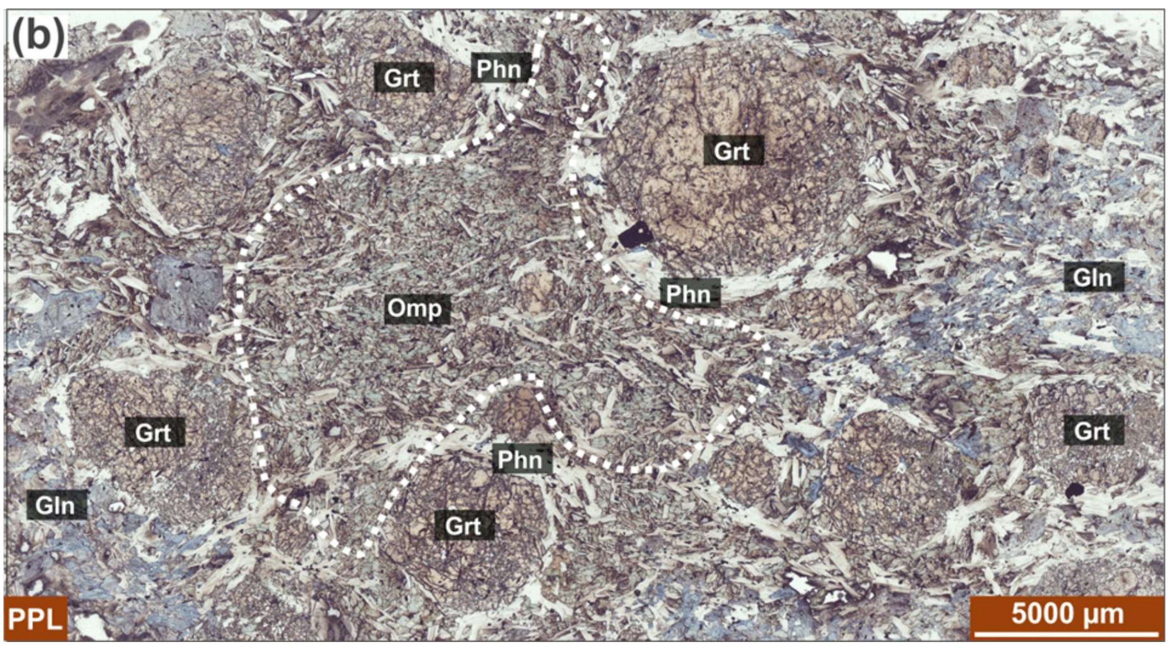


Geological map of Nagaland ophiolite complex and associated areas (modified after Mitra et al., 1986).

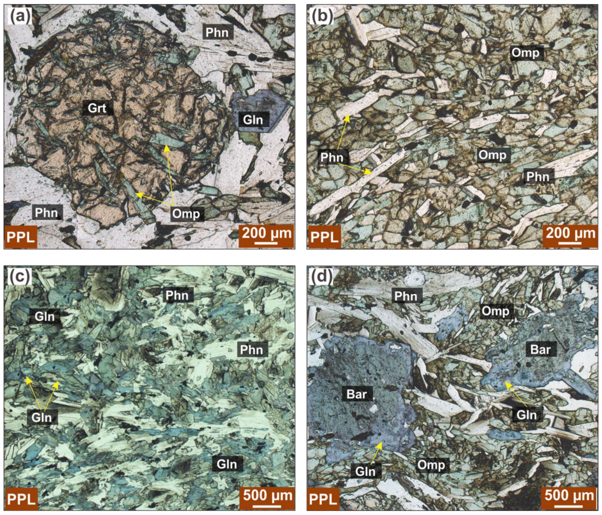
PETROGRAPHY AND MINERAL CHEMISTRY

Petrography



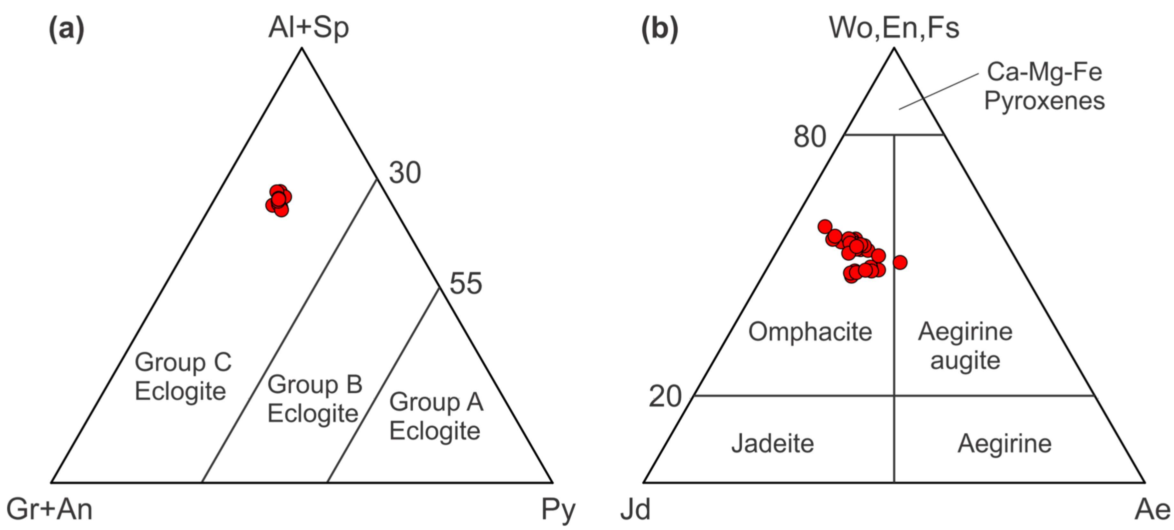


- **(a)** Hand specimen of the rock sample, showing eclogite and blueschist rich domains with no sharp boundary with the occurrence of large garnet grains.
- **(b)** Eclogitic domains are concentrated with omphacite with fewer occurrences of phengite, whereas the blueschist domains are dominated by glaucophane and phengite. Garnet is omnipresent. Grt: garnet, Gln: glaucophane, Omp: omphacite, Phn: phengite.



- **(a)** Garnets show poikiloblastic texture and contain omphacite crystals.
- **(b)** Omphacite and Phengite show granoblastic texture and shape preferred orientation.
- **(c)** Glaucophane that shows irregular grain boundaries.
- **(d)** Large glaucophane show an overprinting relationship with earlier formed minerals. Bar: barroisite Grt: garnet, Gln: glaucophane, Omp: omphacite, Phn: phengite.

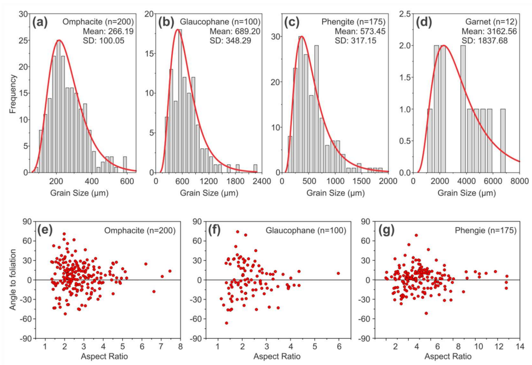
Mineral Chemistry



- **(a)** Garnet plots in the Group C of the eclogite field (Coleman et al., 1965) depicting that the parent rock belongs to tholeiitic basalt.
- **(b)** Clinopyroxene of the eclogite from NHO plots within the assigned omphacite field in the ternary diagram of Ca–Mg–Fe, and Na pyroxenes (Morimoto et al., 1988).

GRAIN SIZE DISTRIBUTION AND CRYSTALLOGRAPHIC PREFERRED ORIENTATION

Grain size distribution



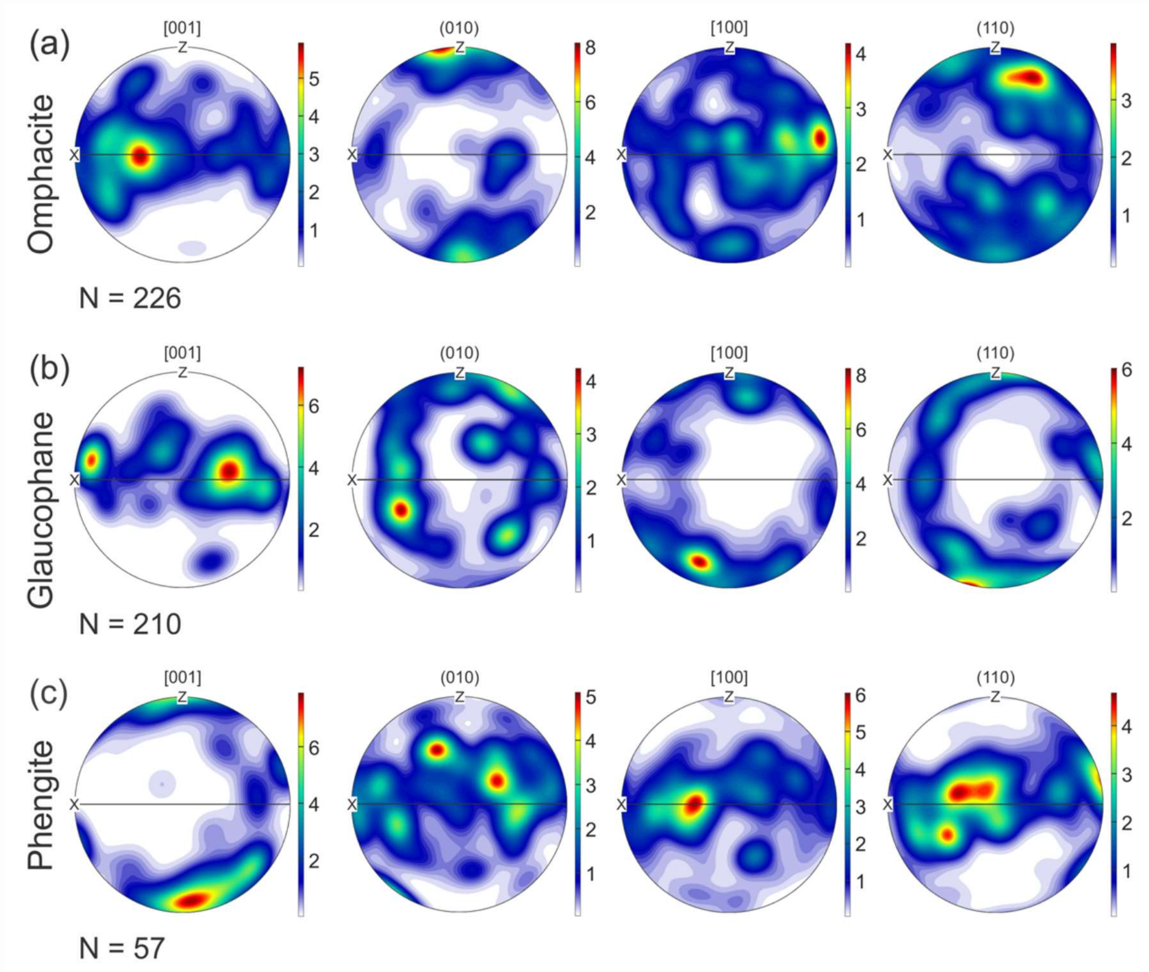
The grain size distribution of minerals

- **(a) Omphacite:** 100-600 μm
- **(b) Glaucophane:** 200-1500 μm
- **(c) Phengite:** 200-1500 μm
- **(d) Garnet:** 1-7 mm

Angle to the foliation of crystal long axes against aspect ratio of the constituent minerals. n: number of grains measured

- The omphacite and glaucophane grains show weak shape preferred orientations (Fig. e–f)
- The phengite grains show a strong relationship of their long axes orientated with respect to the foliation direction irrespective of their aspect ratios (Fig. g).

Crystallographic Preferred Orientation (CPO)

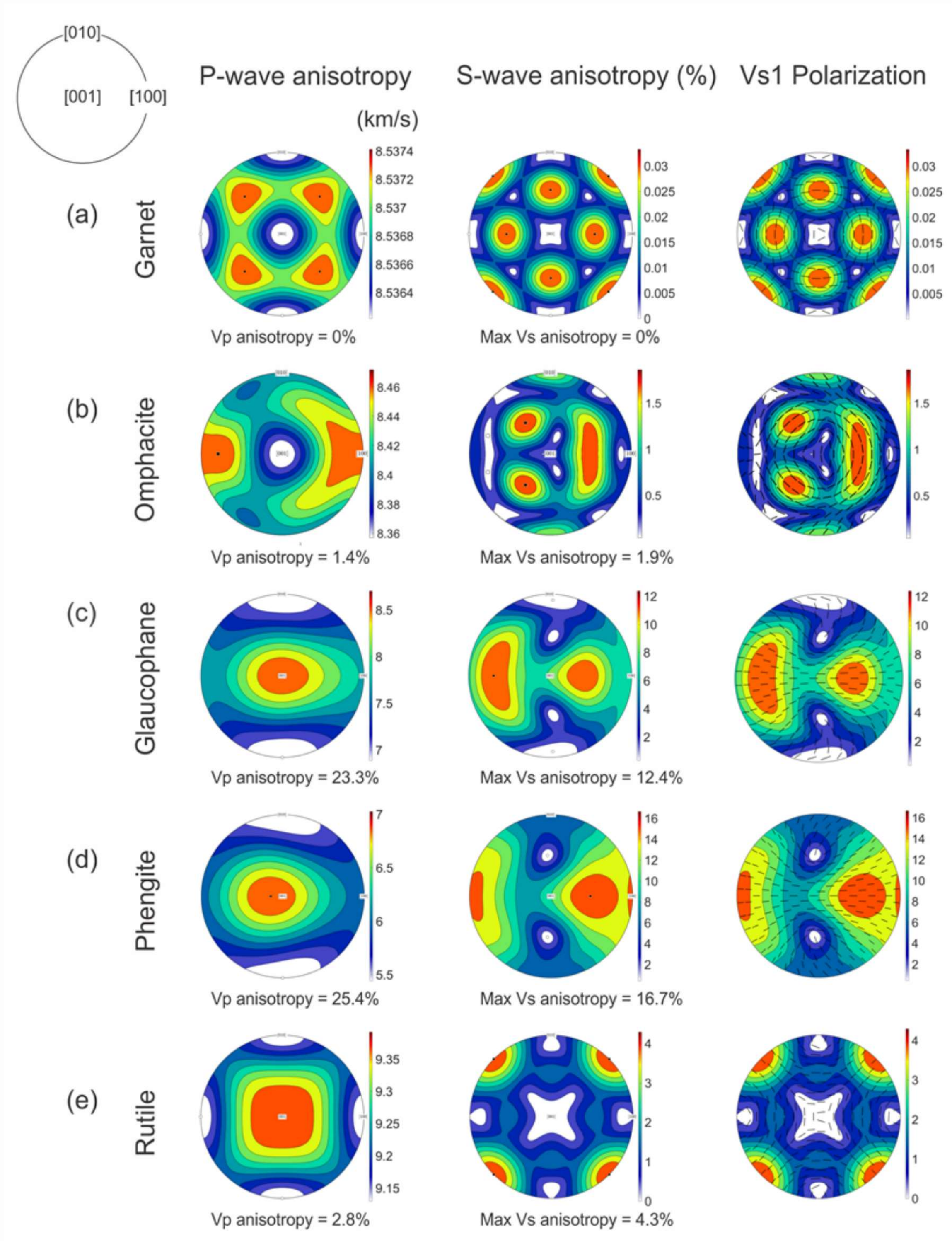


Pole figures of omphacite, glaucophane, and phengite.

- **(a) Omphacite:** [001]-axes girdle within the foliation plane and (010)-poles are point maximum perpendicular to foliation plane
- The CPO of omphacite corresponds to SL-type fabric related to deformation geometry within the plane strain field.
- **(b) Glaucophane:** [001]-axes aligning parallel to the lineation and [100]-axes are point maxima normal to the foliation plane
- The CPO of glaucophane also corresponds to SL-type fabric related to deformation geometry within the plane strain field.
- **(c) Phengite:** [001]-axes normal to the foliation with [100]-axes showing point maxima at an angle to the lineation within the foliation plane.
- The omphacite and glaucophane CPOs have developed from plastic deformation under plane strain conditions through dislocation creep.

SEISMIC ANISOTROPY

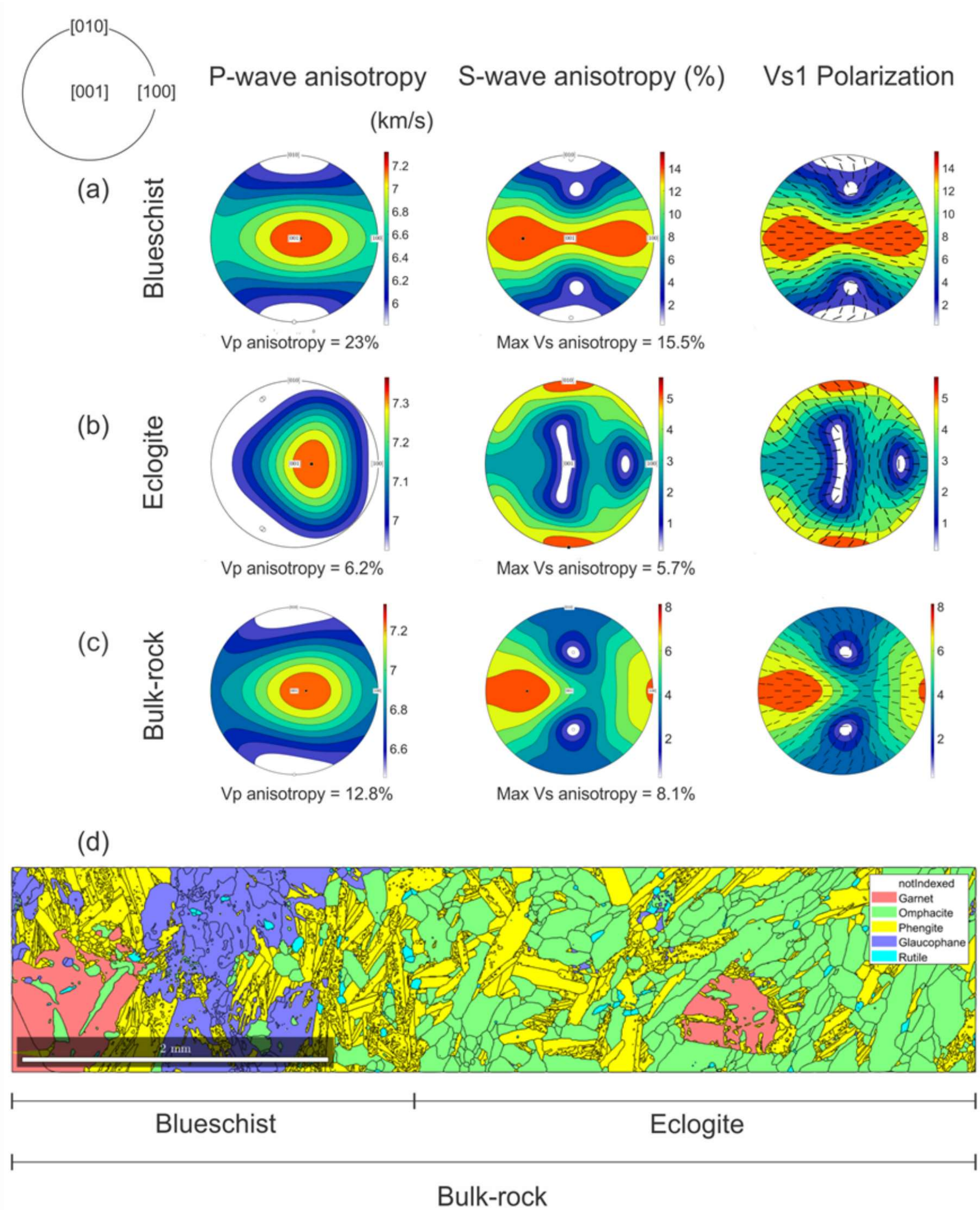
Seismic anisotropies of the constituent minerals



- **(a) Garnet:** The garnet being isotropic shows no seismic anisotropy (AV_P = 0%, AV_S = 0%).
- **(b) Omphacite:** P-wave anisotropy (AV_P) is 1.4%, and S-wave anisotropy (AV_S) is 1.9%.
- **(c) Glaucophane:** AV_P is 23.3%, and AV_S is 12.4%. The fastest P-wave velocity in glaucophane is parallel to the lineation direction.
- **(d) Phengite:** AV_P is 25.4%, and AV_S is 16.7%.

- **(e) Rutile:** AV_P is 2.8%, and AV_S is 4.3%.

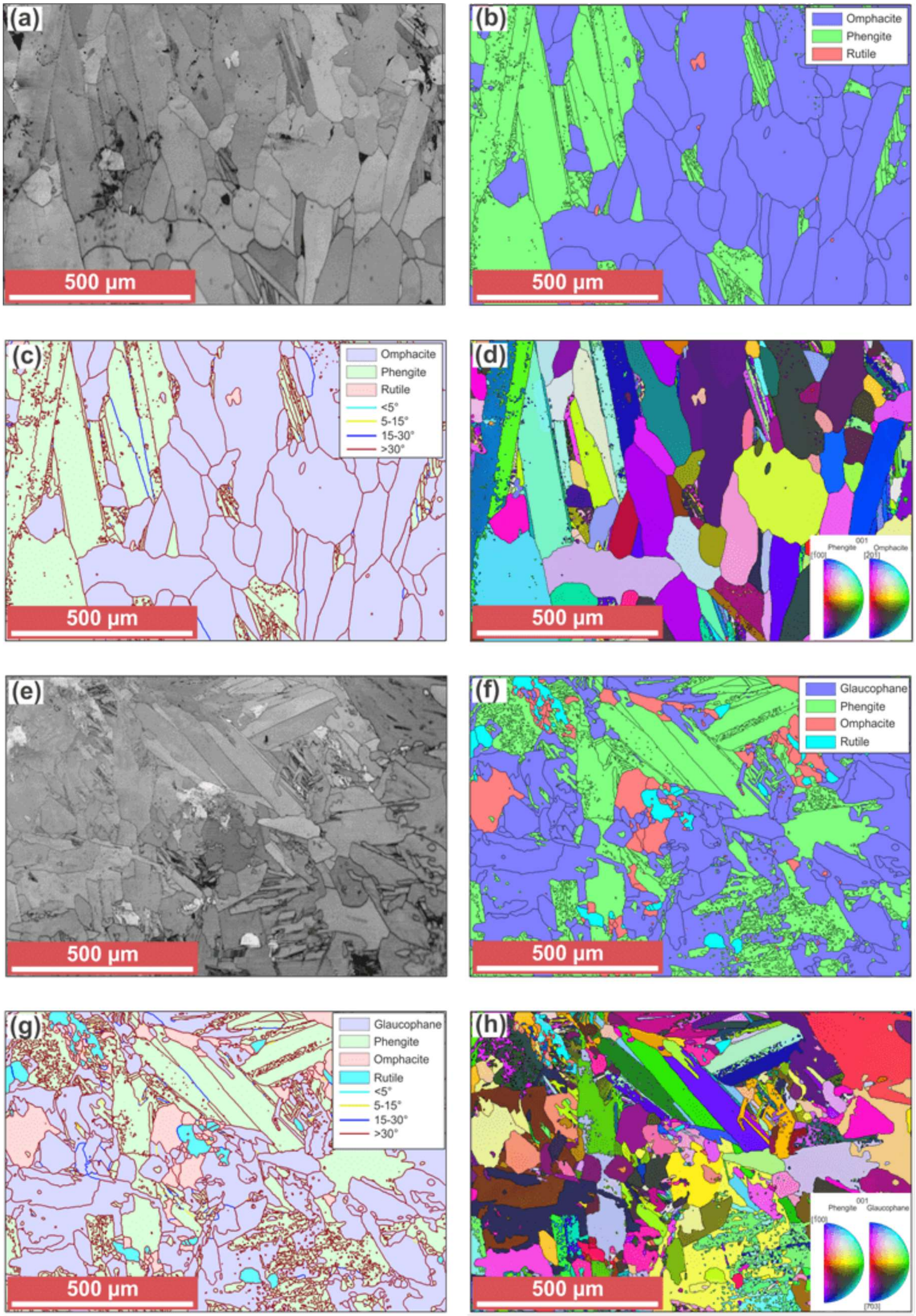
Seismic anisotropies of the blueschist and eclogite domains and bulk rock



- **(a) Blueschist:** AV_P is 23%, and AV_S is 15.5%.
- The P-wave velocity is maximum parallel to the lineation and minimum perpendicular to the foliation plane
- The strong seismic anisotropy of blueschist is attributed to the high modal abundance of glaucophane and phengite, both of which owe high seismic anisotropy values.
- **(b) Eclogite:** AV_P is 6.2%, and AV_S is 5.7%.
- The presence of phengite is the main reason for the high seismic anisotropy of eclogite.
- **(c) Bulk-rock:** AV_P is 12.8%, and AV_S is 8.1%.

- Glaucophane and phengite are the two minerals that contribute the highest to the bulk-rock seismic anisotropy.
- The bulk-rock seismic anisotropy in the present study depends on the contribution of each mineral constituting the rock, their volume proportion, and in turn the proportion of blueschist and eclogite in the rock.
- **(d) EBSD map** used for calculating the seismic anisotropies of the bulk-rock and blueschist-eclogite domains of the bulk-rock.

MICROSTRUCTURE



(a, e) Band contrast map, (b, f) Phase map, and (c, g) Grain boundary misorientation map showing high angle grain boundaries with the neighboring grains. (d, h) Inverse pole figure map showing the orientation of grains in 001 directions.

Omphacite (a-d)

- straight grain boundaries in a band contrast map and phase map indicate no evidence of grain boundary migration induced recrystallization (Fig. a, b).
- The omphacite grains show a high angle grain boundary with their neighboring grains (Fig. c).
- IPF map (Fig. d) shows that most of the grains are oriented.

Glaucophane (e-h)

- The irregular and curved grain boundaries of glaucophane (Fig. e and f) are due to the reactive texture that developed during the transition of eclogite to blueschist facies condition during retrogression.
- The grains show a high angle grain boundary with their neighboring grains (Fig. g) suggesting the absence of dynamic recrystallization.
- The grains are randomly oriented in the IPF map (Fig. h)

DISCUSSIONS & CONCLUSIONS

- The overprinting relationship of glaucophane on omphacite and phengite suggests that it formed later during the retrogressed metamorphism while exhumation.
- Omphacite and glaucophane show weak shape preferred orientation, while phengite displays a strong shape preferred orientation.
- the omphacite and glaucophane CPOs have developed from plastic deformation under plane strain conditions.
- Dislocation creep is responsible for the development of CPOs and hence is the primary deformation mechanism in the subducting oceanic crust.
- The strong seismic anisotropy of blueschist is attributed to the presence of a high-volume proportion of glaucophane and phengite with their high seismic anisotropy values.
- The presence of phengite with its significant high seismic anisotropy contributes greatest to the high seismic anisotropy in eclogite.
- The bulk-rock seismic anisotropies which represent the seismic anisotropy of subducted oceanic crust depend on the contribution of each mineral present in the rock, their volume proportions.
- The presence of oriented minerals with strong seismic anisotropies (glaucophane and phengite in this study) and their volume- proportions have a significant influence on the overall seismic anisotropy in the subducting oceanic crust.

ABSTRACT

The microstructures, textures and seismic anisotropy of a foliated blueschist-eclogite rock from Naga Hills Ophiolite (NHO) complex, North-East India has been investigated to understand the fabric relationship and deformation mechanism prevailed during the metamorphism and subduction of the Neo-Tethys oceanic crust. The Naga Hills blueschist-eclogite rock essentially contains omphacite, phengite, glaucophane, and garnet, representing an oceanic crust that experienced *P-T* stability field of blueschist and further eclogite metamorphism before it resurfaced accreting in the Naga Hills. Omphacite and glaucophane show weak shape preferred orientation (SPO), while phengite displays a strong SPO. The Crystallographic Preferred Orientations (CPO) of omphacite is characterized by the [001]-axes gridles within the foliation, and the (010)-poles concentrated sub-perpendicular to the foliation. For glaucophanes, the [001] axis aligns parallel to lineation and the [100] axis and (110) pole plunge perpendicular to foliation. These CPOs correspond to SL-type fabrics, related to a deformation geometry within the plain strain field and they developed from plastic deformation through dislocation creep. The seismic anisotropies of the individual minerals, blueschist-eclogite domains and their contributions in the bulk rock anisotropy has been discussed. The calculated seismic anisotropies (AV_P and AV_S) of bulk rock are 12.8% and 8.1%, respectively. This strong seismic anisotropy is due to the presence of phengite and glaucophane and can contribute to the observed seismic anisotropy in the subduction zone. The average low P-wave velocity of whole rock from NHO compared to blueschist is probably due to the low P-wave velocity of phengite (avg V_P: 6.2 kms^{-1}). Therefore, the low seismic velocity in the upper layer and the strong seismic anisotropy of the subducting oceanic crust can be attributed to the presence of glaucophane and phengite.