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Lattice preferred orientation and seismic anisotropy of chloritoid in subduction zone

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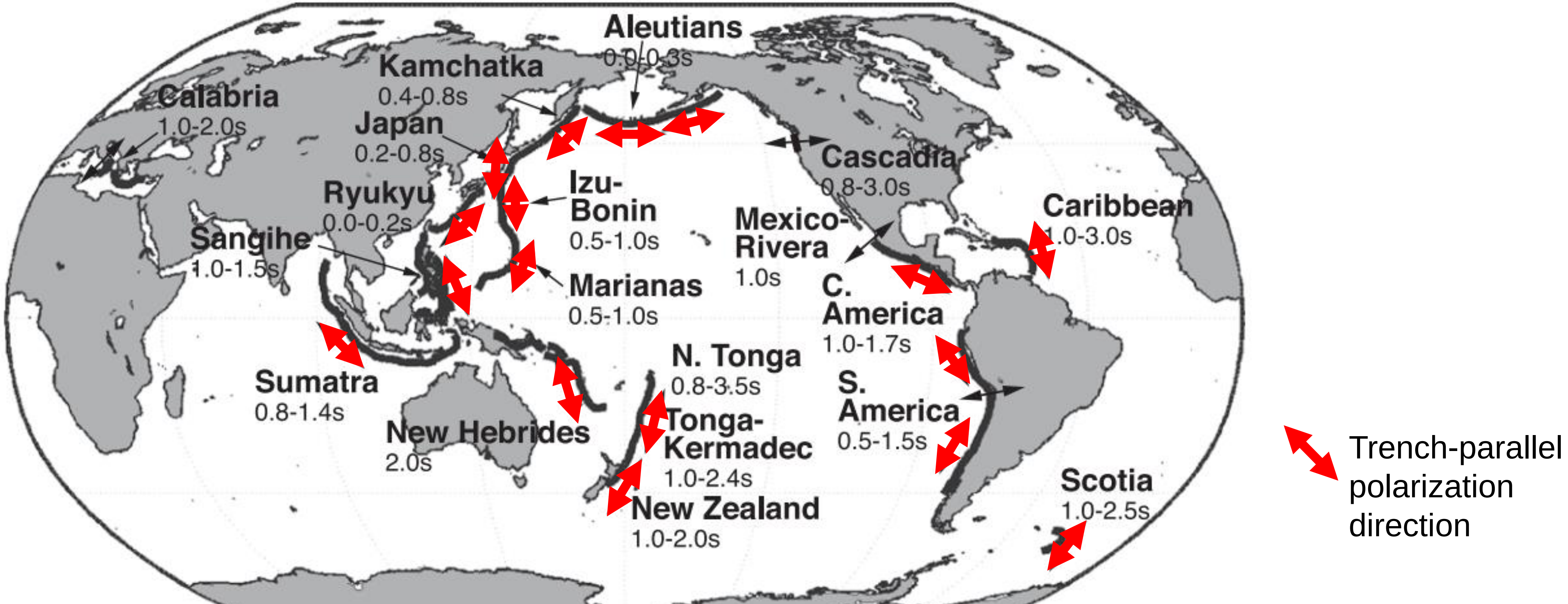
Introduction

» **Seismic anisotropy** which has been observed in worldwide subduction zone, may be caused by the **lattice preferred orientation (LPO)** of elastically anisotropic minerals (Karato, 2008; Mainprice and Ildefonse, 2009).



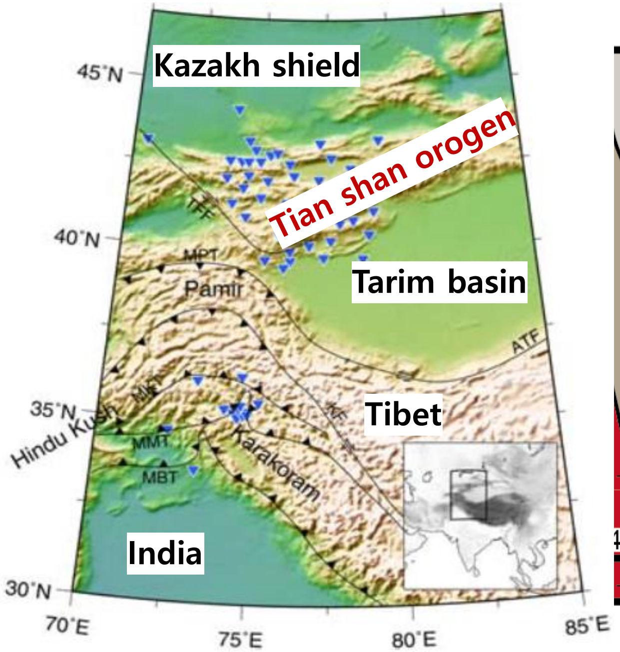
modified after Long (2013)

Introduction

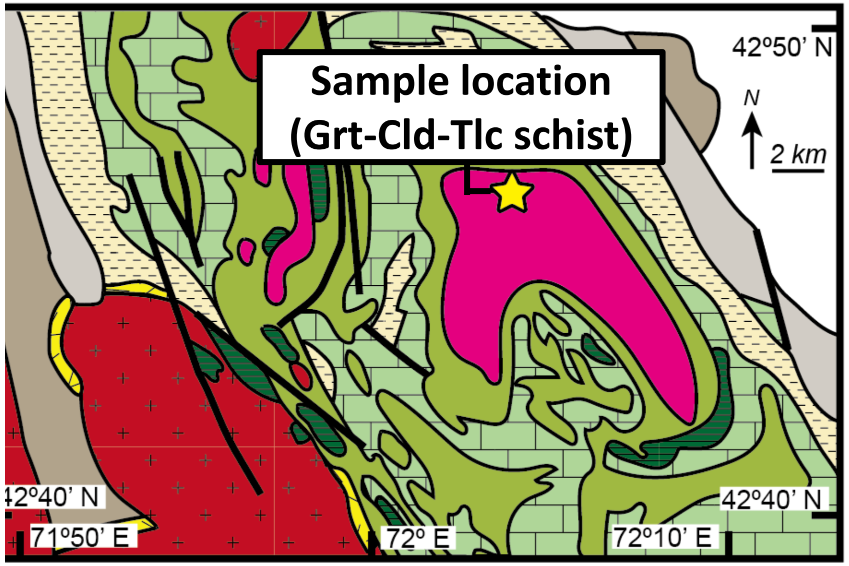
- Many **hydrous minerals** are known to be **elastically very anisotropic** (Mainprice and Ildefonse, 2009).
- The **LPO of hydrous mineral aggregates** may cause a significant **seismic anisotropy** in subduction zones (Jung, 2017; Lee et al., 2020).

- Chloritoid commonly occurs in greenschist- to eclogite-facies metamorphic rocks including the subducting oceanic crust and overlying metapelites, however both **the elasticity and the LPO of chloritoid have been unknown**.

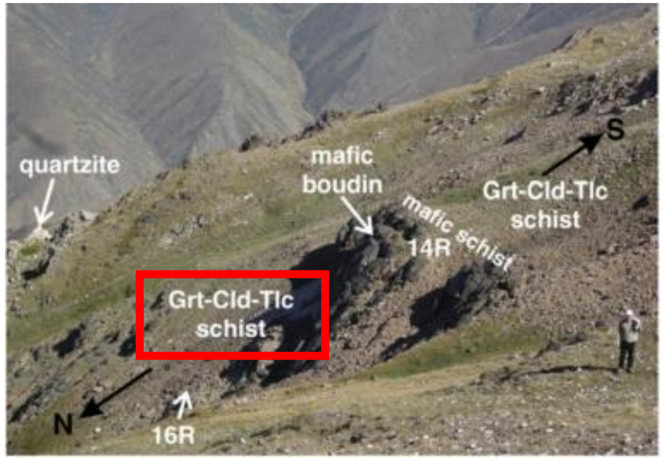
Geological background of samples

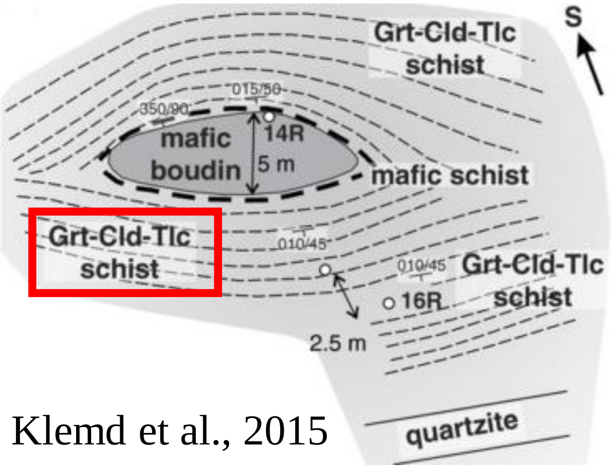


Kumar et al., 2005



modified after Orozbaev et al., 2015

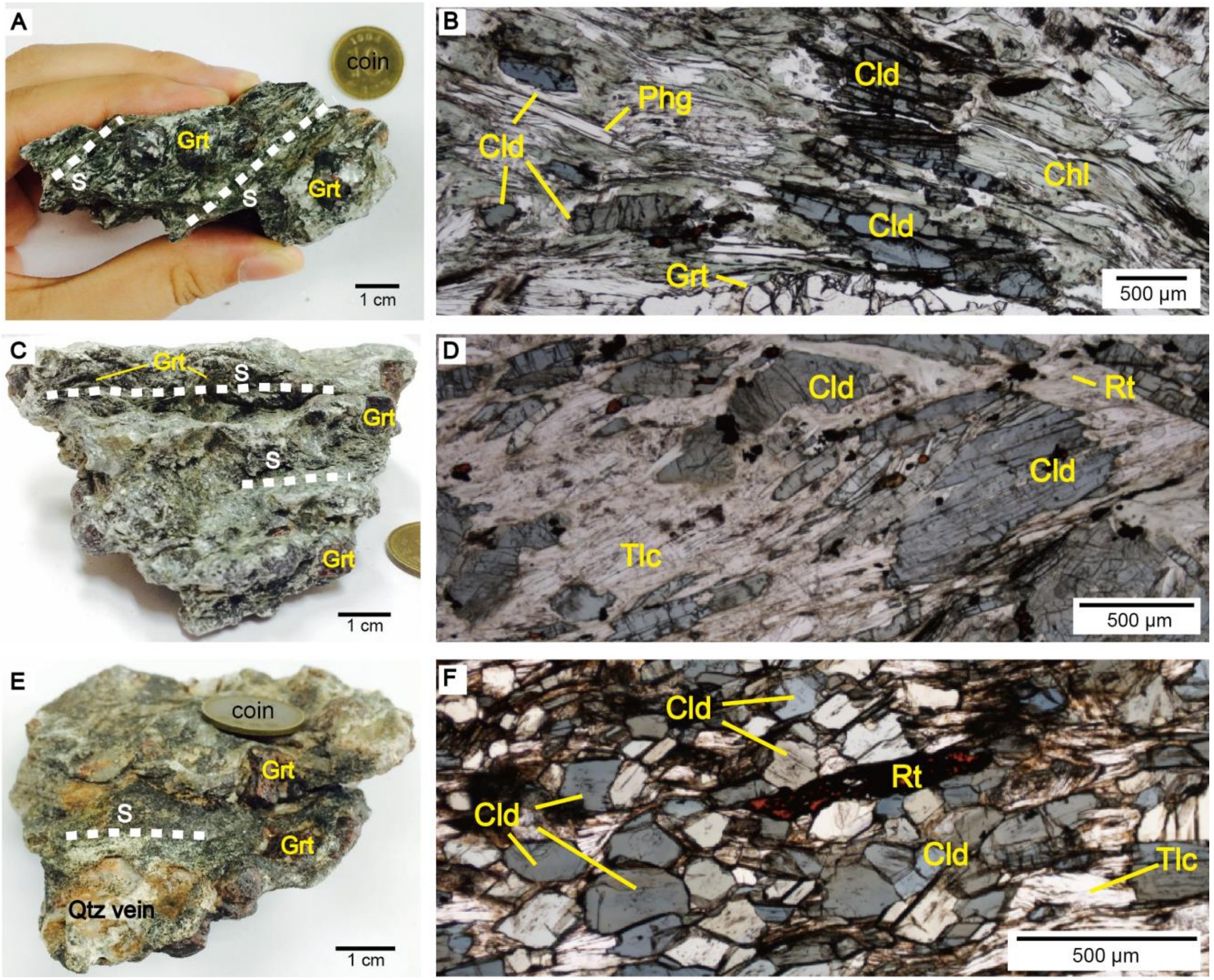




Klemd et al., 2015

- **Garnet-chloritoid-talc schists** from the central Makbal UHP complex in Tianshan (Kazakhstan-Kyrgyzstan).
- **UHP peak metamorphism** (2.9 GPa, 580 °C) at 480 Ma [Meyer et al., 2014; Togonbaeva et al., 2009].
- Prograde-to-peak path of subduction, bearing coesite [Orozbaev et al., 2015; Togonbaeva et al., 2009].

Materials and Method: sample description



» Grt-Cld-Tlc schists from Makbal Complex (samples #15R, #10-16, #12-52).

» Chloritoid 10 – 25 vol.%

» Elongation of grains parallel or subparallel to the lineation.

Methods

» **Measurement of the LPO** using electron backscattered diffraction **(EBSD)** attached to JSM-6380 SEM.

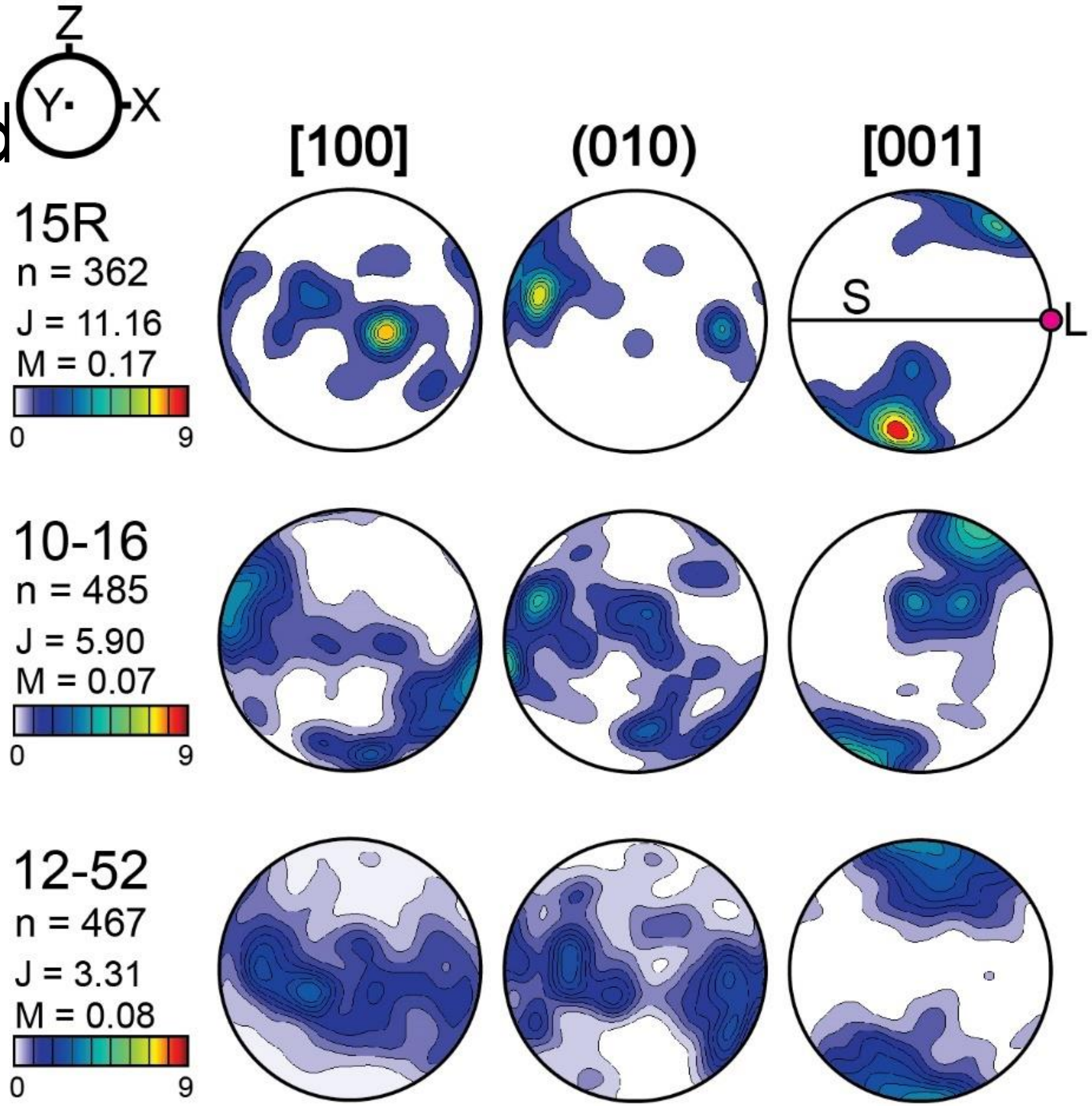
» **Plotting the LPO data and calculation of the LPO-induced seismic anisotropy** using the Matlab-based **MTEX** software (Mainprice et al., 2008).

JSM-6380 SEM with HKL EBSD system in SNU

Results: LPO of chloritoid

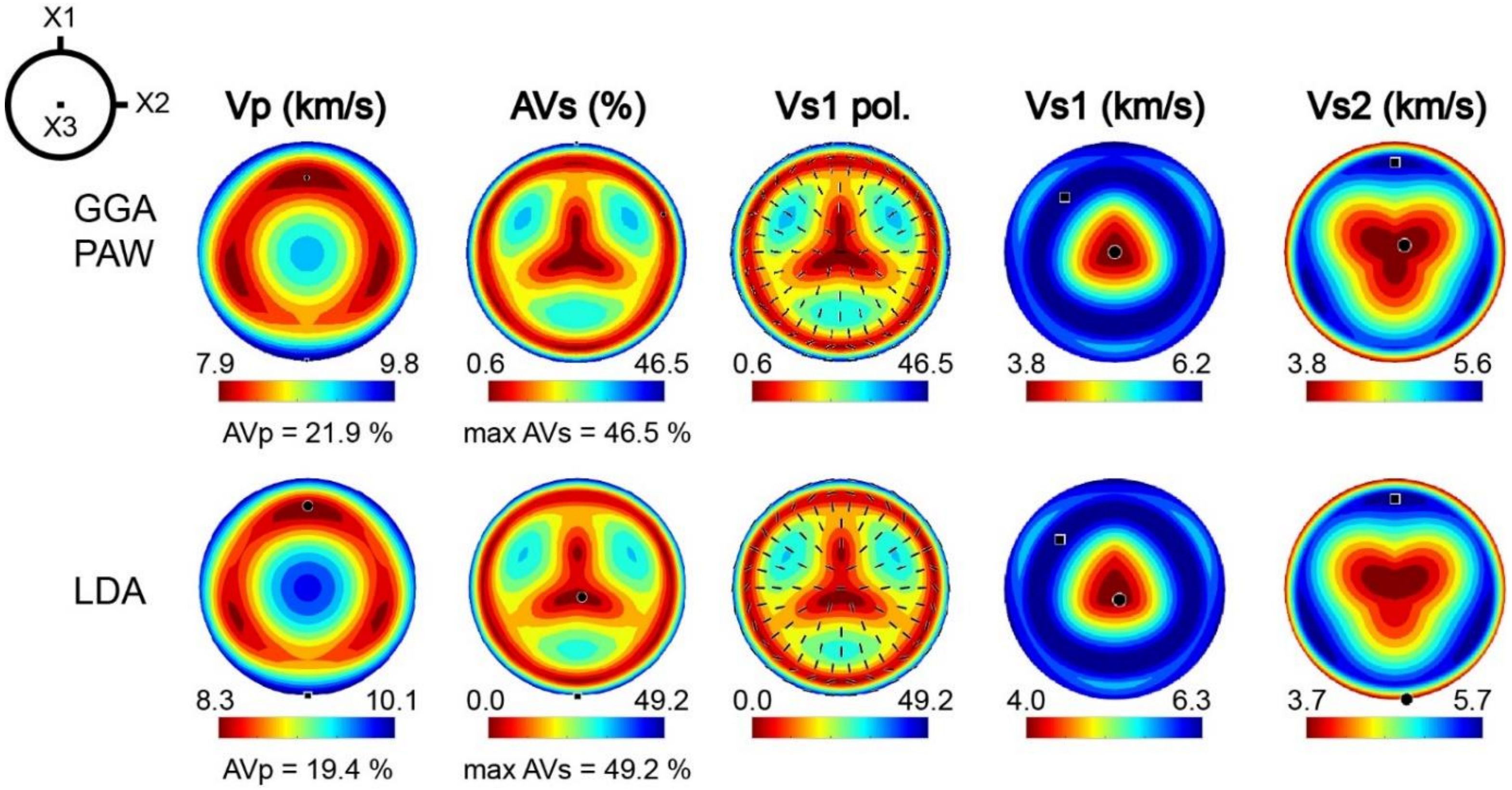
- Concentration of [001] axes subnormal to the foliation.

- Girdle distribution of [100] axes and (010) poles subparallel to the foliation.



Results: elastic anisotropy of single-crystal chloritoid (*new result in this study*)

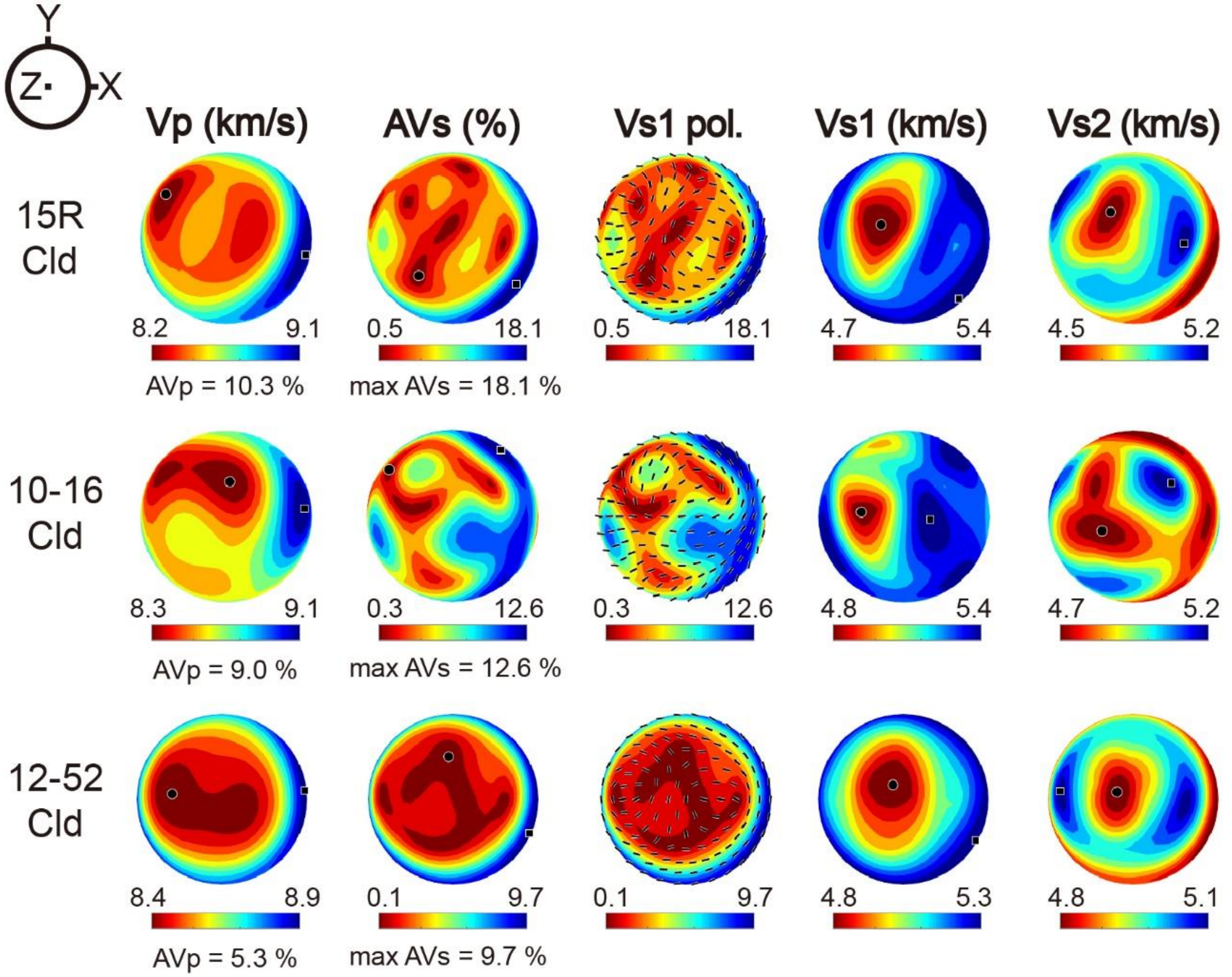
Formula : $\mathbf{Mg_2Al_4Si_2O_{10}(OH)_4}$
Monoclinic magnesiochloritoid



Single-crystal anisotropy of Cld

- AVp = 19 – 22 %
- Max AVs = 47 – 49 %

Results: seismic velocities and anisotropies of polycrystalline chloritoid



LPO-induced seismic anisotropy of Cld

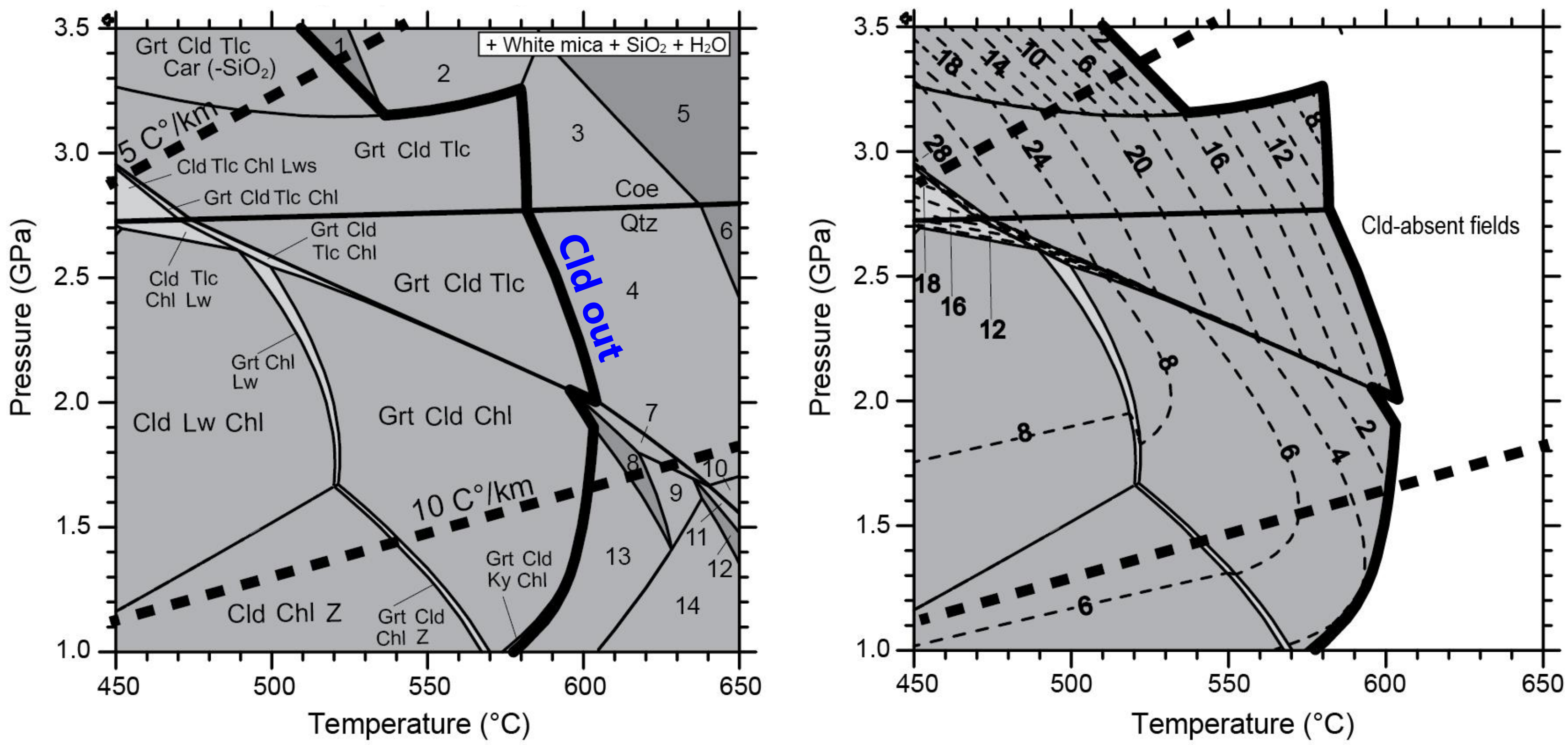
» AVp = 5 – 10 %

» Max AVs = 10 – 18 %

Results: stability and modal abundance of chloritoid

A Pseudosection of Grt-Cld-Tlc schist (sample #10-16)

B Volume % of chloritoid



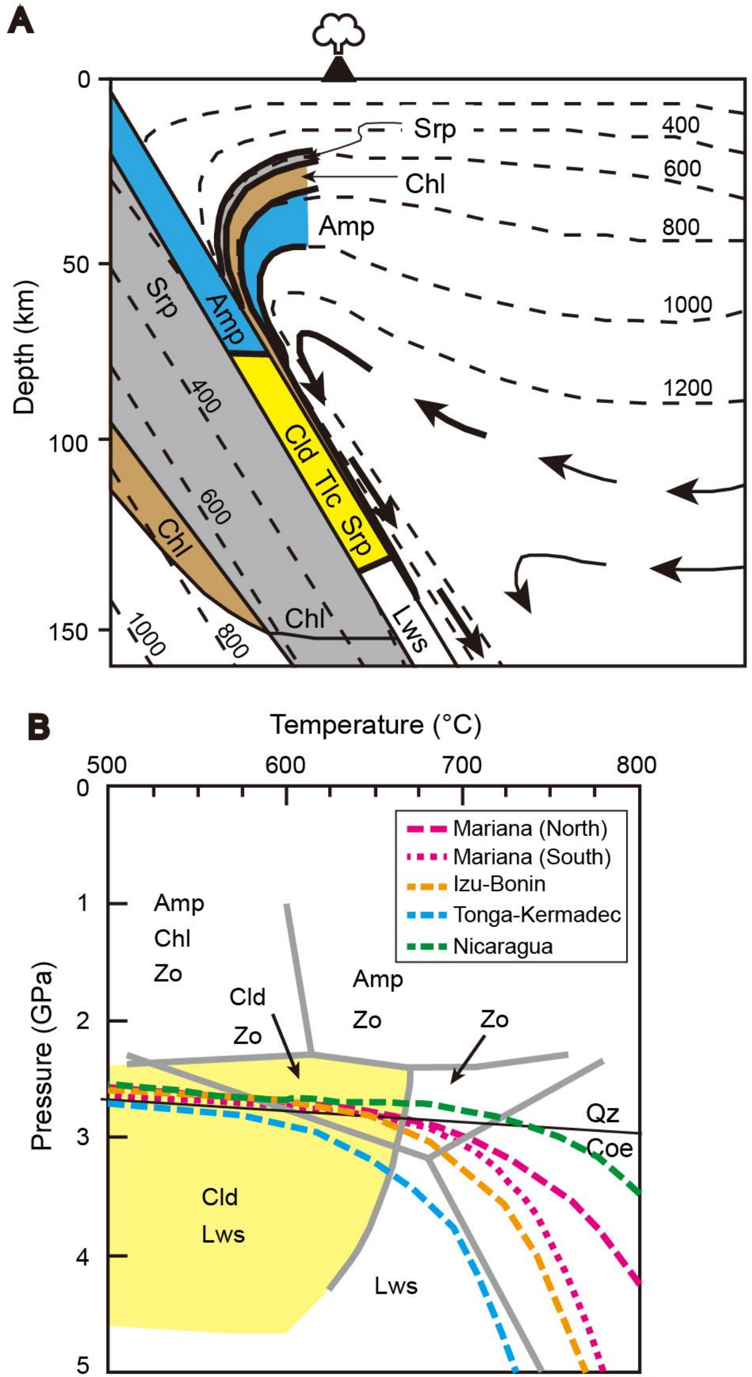
1: Grt + Tlc + Car (- SiO2)
2: Grt + Tlc + Car
3: Grt + Tlc + Ky (+ Coe)
4: Grt + Tlc + Ky (+ Qtz)
5: Grt + Tlc (+ Coe)
6: Grt + Tlc (+ Qtz)
7: Grt + Chl + Tlc
8: Grt + Chl
9: Grt + Chl + Bt
10: Grt + Tlc + Ky + Bt (- Wm)
11: Grt + Chl + Tlc + Bt (- Wm)
12: Grt + Chl + Bt (- Wm)
13: Grt + Chl + Ky
14: Grt + Chl + Ky + Bt (- Wm)

- Within the given P-T conditions, the highest amount of chloritoid was **28 vol.%**
- Good agreement with the observed amount of chloritoid in the samples.
- Along cold subduction geotherms (5–10 ^{0}C/km), the maximum chloritoid amount reaches 26 vol %.

Discussion: chloritoid stability and its implication for seismic anisotropy in subduction zones

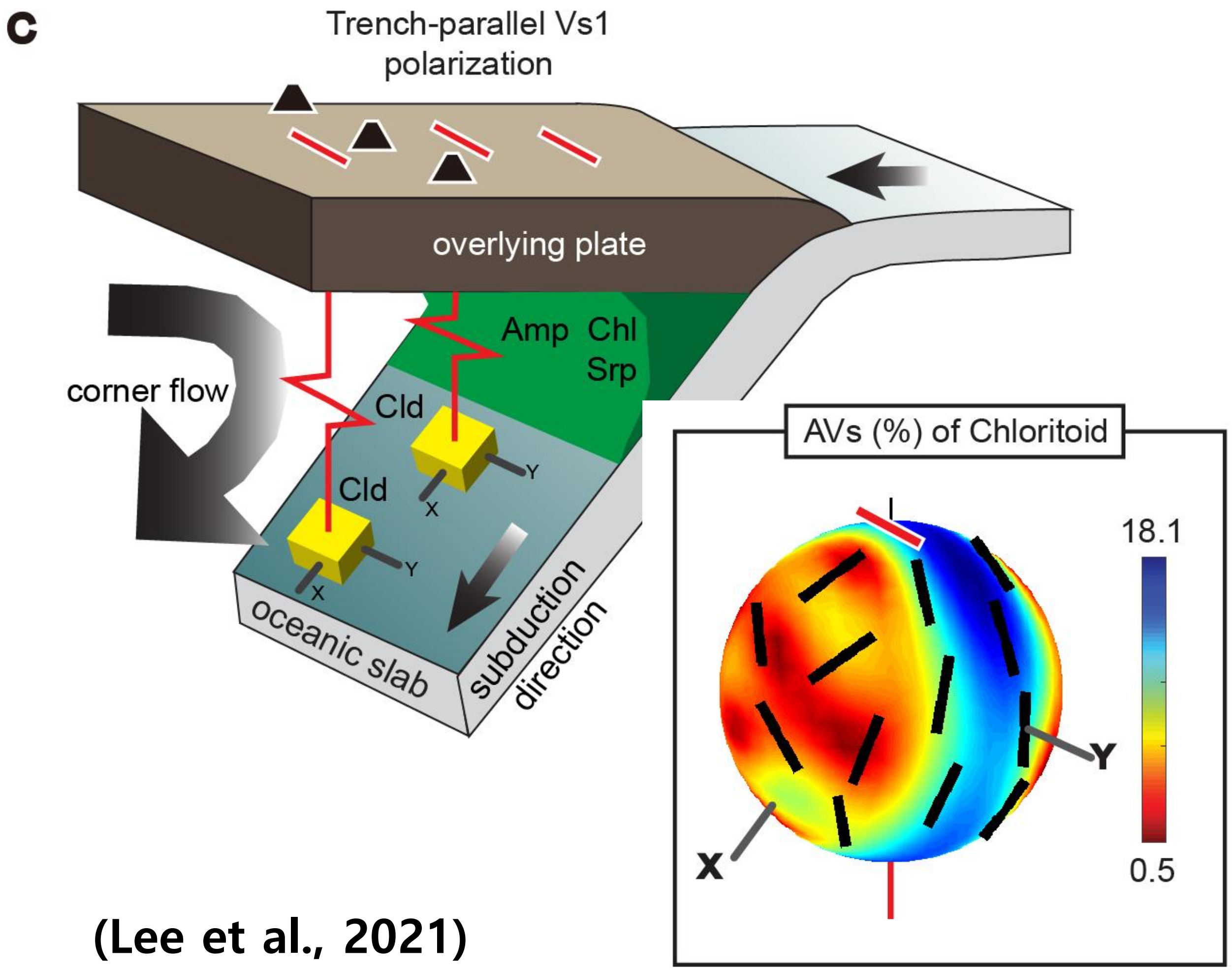
- Chloritoid was found to be stable under high-pressure conditions ranging from the **blueschist to the eclogite facies**.

- In steeply dipping subduction zones, chloritoid is likely to be stable along the slab-mantle at a depth range between 80 and 120 km.



Discussion: chloritoid stability and its implication for seismic anisotropy in subduction zones

» The effect of the chloritoid LPO on the **trench-parallel seismic anisotropy** would be important in **cold and high-angle** subduction zones.

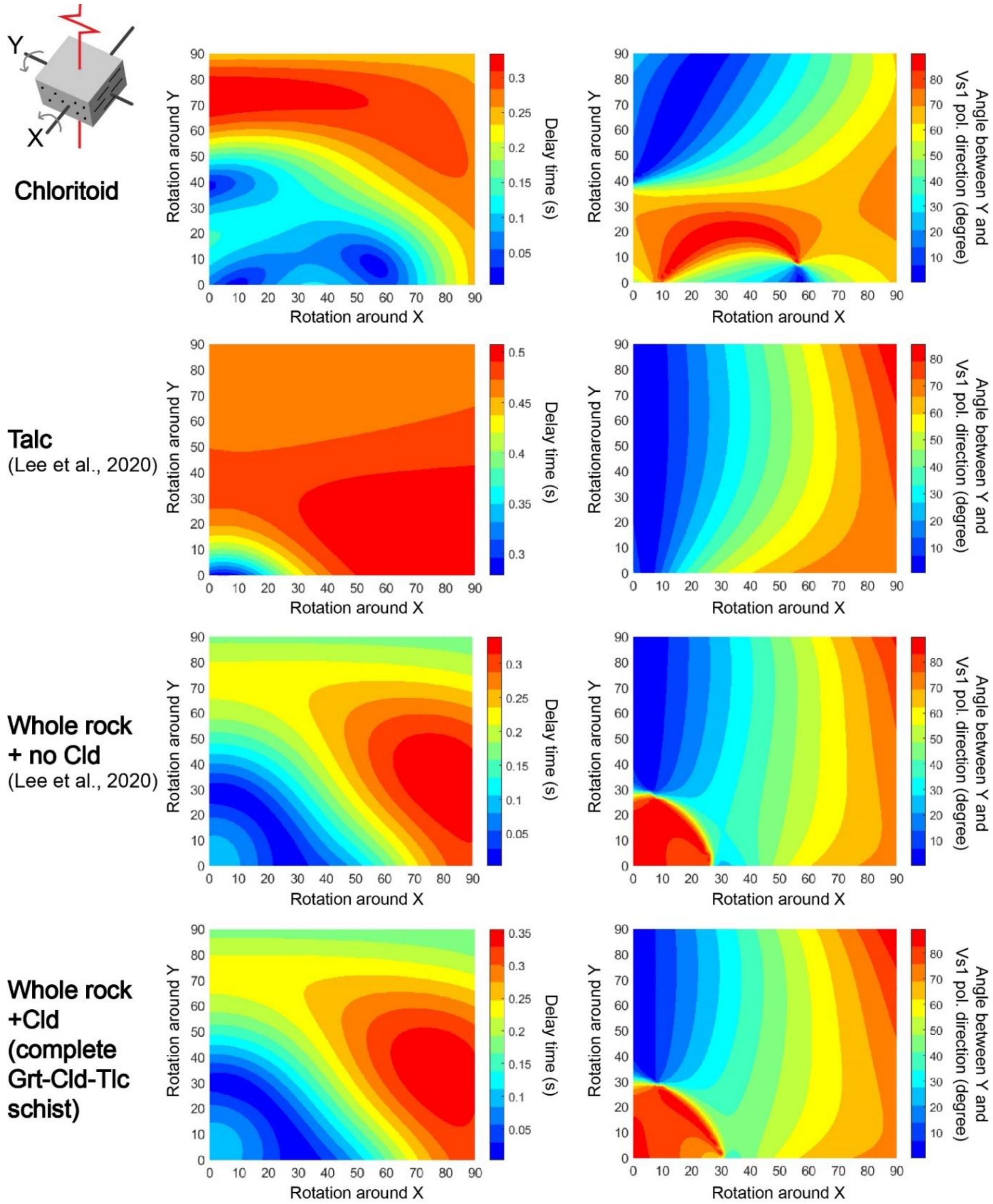


(Lee et al., 2021)

Discussion: effect of chloritoid LPO on seismic anisotropy of the Grt-Cld-Tlc schist

Delay time of S-wave

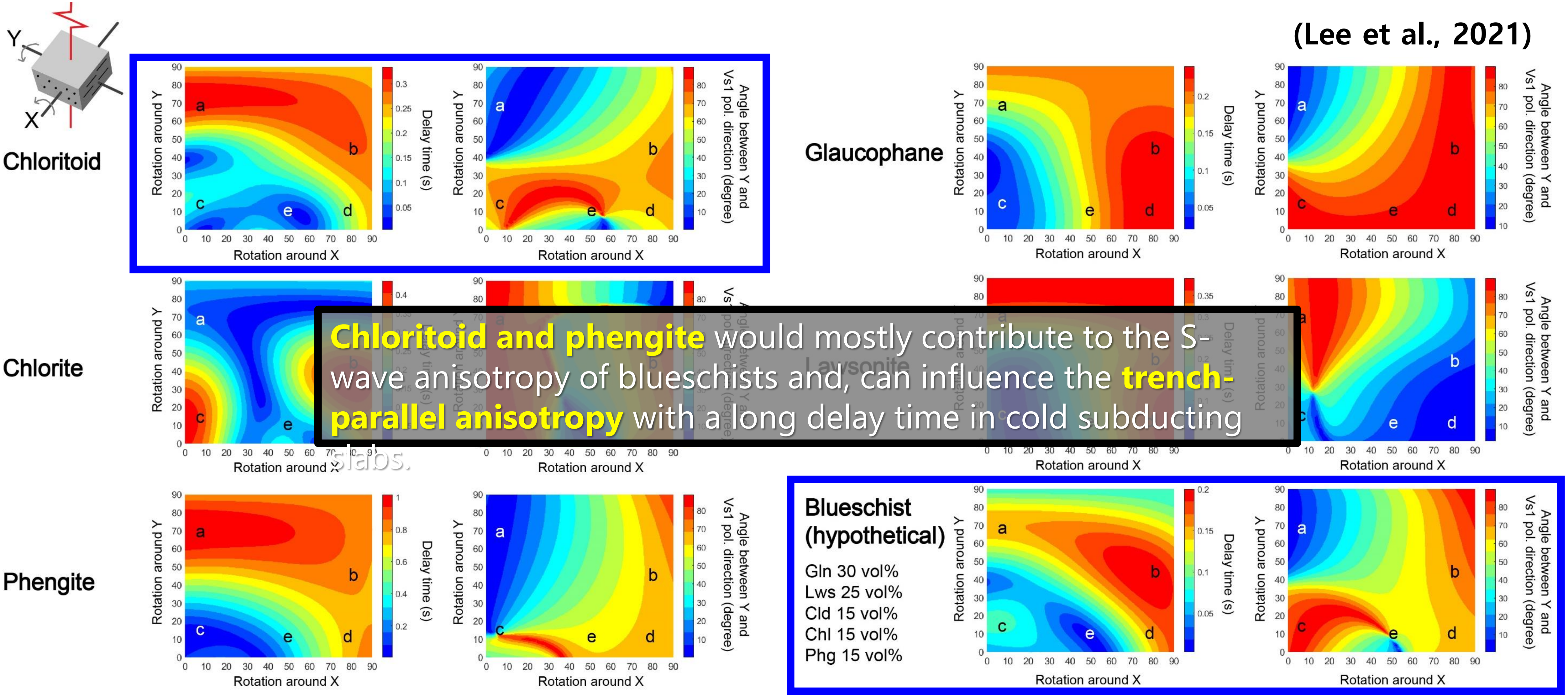
- Chloritoid only: 0.3 s
- Talc only: 0.5 s
- Whole rock + no Cld : 0.3 s
- Whole rock + Cld : 0.4 s



(Lee et al., 2021)

Discussion: effect of hydrous minerals in blueschist-facies rock

(Lee et al., 2021)



Chloritoid and phengite would mostly contribute to the S-wave anisotropy of blueschists and, can influence the **trench-parallel anisotropy** with a long delay time in cold subducting slabs.

If you are interested in this study, please see the recent paper (Lee et al., 2021) →

frontiers in Earth Science

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Seismic Anisotropy in Subduction Zones: Evaluating the Role of Chloritoid

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Subduction zones are often characterized by the presence of strong trench-parallel seismic anisotropy and large delay times. Hydrous minerals, owing to their large elastic anisotropy and strong lattice preferred orientations (LPOs), are often invoked to explain these observations. However, the elasticity and the LPO of chloritoid, which is one of such hydrous phases relevant in subduction zone settings, are poorly understood. In this study, we measured the LPO of polycrystalline chloritoid in natural rock samples, obtained the LPO-induced seismic anisotropy, and evaluated the thermodynamic stability field of chloritoid in subduction zones. The LPO of chloritoid aggregates displayed a strong alignment of the [001] axes subnormal to the rock foliation, with a girdle distribution of the [100] axes and the (010) poles subparallel to the foliation. New elasticity data of single-crystal chloritoid showed a strong elastic anisotropy of chloritoid with 47% for S-waves (V_S) and 22% for P-waves (V_P), respectively. The combination of the LPO and the elastic anisotropy of the chloritoid aggregates produced a strong S-wave anisotropy with a maximum AV_S of 18% and a P-wave anisotropy with an AV_P of 10%. The role of chloritoid LPO in seismic anisotropy was evaluated in natural rock samples and a hypothetical blueschist. Our results indicate that the strong LPO of chloritoid along the subduction interface and in subducting slabs can influence the trench-parallel seismic anisotropy in subduction zones with "cold" geotherms.

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Summary

» **Elastic constants of chloritoid** was calculated for the first time.

» The **LPOs of chloritoid** in natural schist samples were measured.

» The results showed **AVp and AVs of chloritoid** as 5 – 21 % and 10 – 49 %, respectively.

» Thermodynamic stability and modal abundance of chloritoid are re-evaluated. The results showed that chloritoid can be stable up to blueschist-eclogite facies conditions.

» The **S-wave anisotropy of chloritoid** could be large and important. The LPO of chloritoid needs to be considered to understand seismic anisotropy of cold subduction zones.