Beyond ultra-high pressure metamorphism: evidence for extremely high pressure conditions during frictional fusion in gigantic landslides using micro-Raman spectroscopy of quartz: the Tsergo Ri (Langtang Himal, Nepal) rockslide

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Introduction:

- The ***P-T* conditions** in extremely-rapid gravity-driven **rockslides** are **difficult to constrain** from the descended rock mass itself.

- Here, we report **mineralogical observations from the Tsergo Ri rockslide** and their interpretation.

- The **Tsergo Ri rockslide** represents one of the world's biggest rockslides in crystalline rocks (original volume: 10^{10} m^3). During mass-wasting, frictionites and microbreccias formed at the base of the rockslide (Weidinger et al. 2014).

Geological overview:

- The Tsergo Ri rockslide, occurred at about **51 ± 13 ka BP**.

- It appears to have resulted from the **collapse of a former 8,000 m mountain**.

- **Seismic activity** most likely was the trigger for the mass movement.

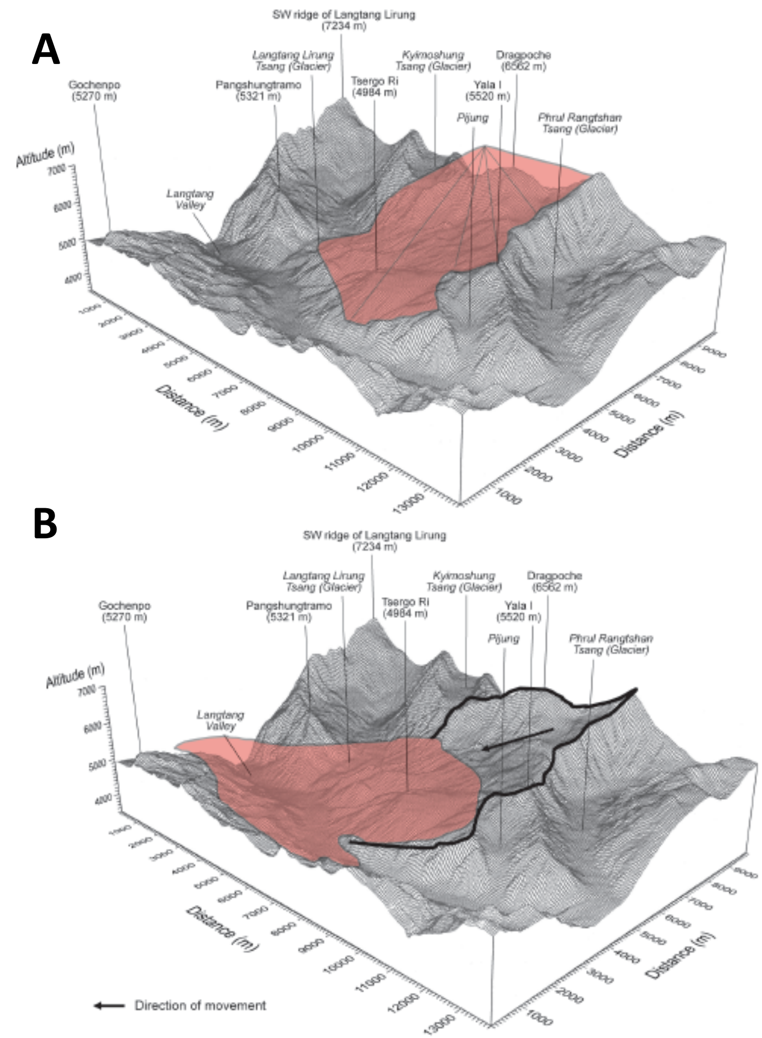

Figure 1: (A) Reconstructed pre-failure topography; (B) reconstruction of rockslide debris after the collapse (from Miehe & Weidinger, 2015).

Petrography:

- The frictionite is mainly composed of a glassy matrix containing biotite, quartz, and abundant plagioclase and K-feldspar.

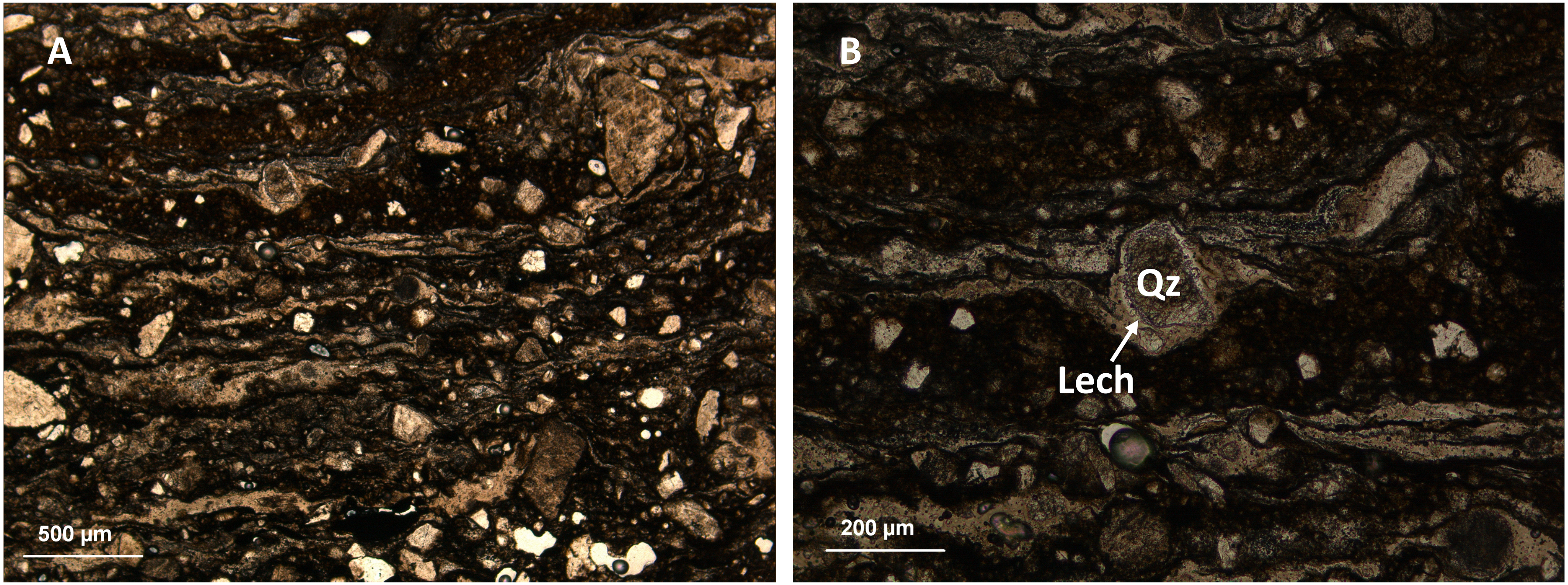

Figure 2: (A) Microphotograph of a frictionite sample (LT-2A); (B) Quartz (Qz) with lechatelierite (Lech) rim.

Petrography:

- Biotite locally shows a transformation to spinel (Sp) + glass (L) in highly glassy microdomains (Fig. 3A). Fe-rich layers in the glass indicate melting of biotite-rich layers of the protolith biotite-bearing orthogneiss (Fig. 3A). Locally, quartz grains (Qz) are rimmed by a thin layer of SiO_2 glass (lechatelierite, Lech, Fig. 3B).

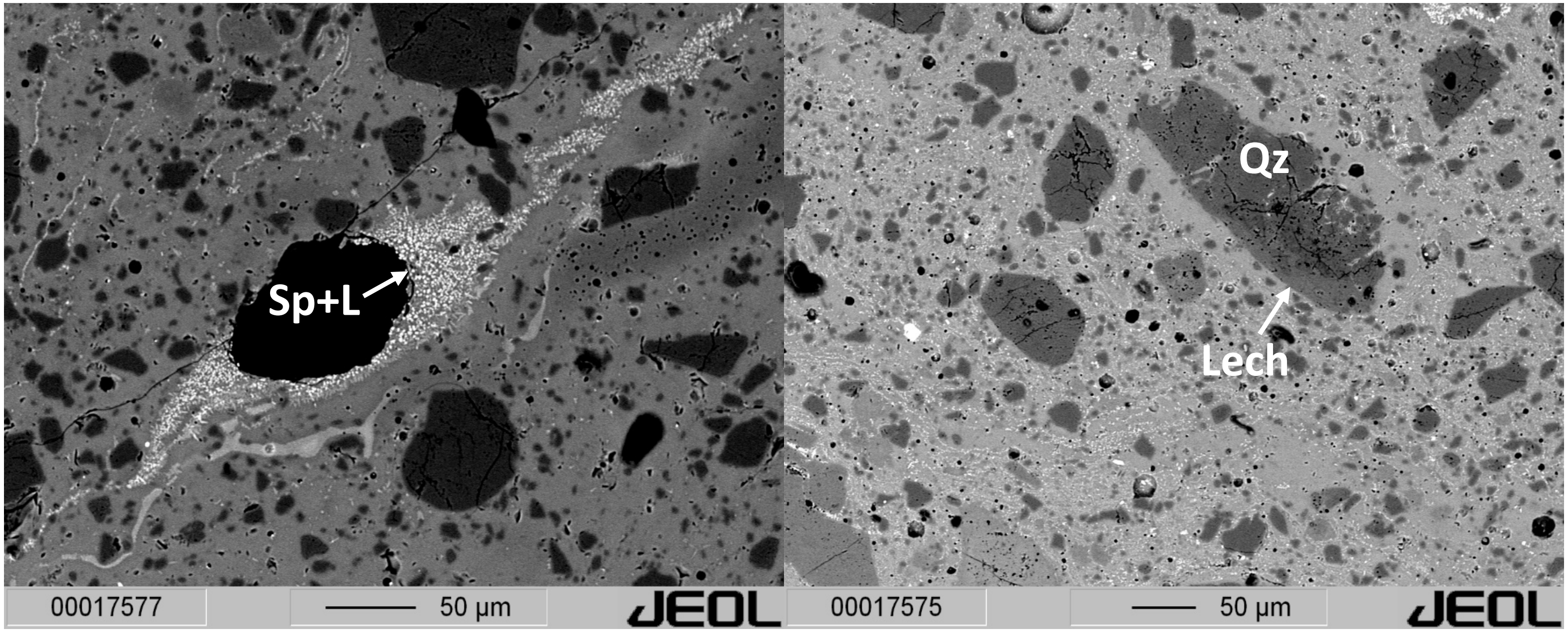

Figure 3: (A) left: biotite breakdown to spinel + glass; (B) right: lechatelierite rim at the edge of a quartz grain.

Micro Raman spectroscopy:

- Investigations by McMillan et al. (1991) and Kowitz et al. (2013) have shown that **shocked quartz shows a shift in the main A1 Raman mode** down to lower wavenumbers with increasing pressures.

- Tropper et al. (2017) and Sanders et al. (2020) found that quartz from the frictionites in the **Köfels landslide (Austria)** shows a significant **shift of up to 4 cm^{-1}** in the main A1 Raman mode.

- Therefore micro-Raman spectroscopy was applied to **quartz crystals with and without lechatelierite rims** in the Tsergo Ri frictionites. Raman maps of quartz grain areas were prepared using a HORIBA Jobin Yvon LabRam HR800 micro-spectrometer equipped with a 30 mW He-Ne laser (633 nm emission).

Micro Raman spectroscopy:

- Micro-Raman spectroscopy of 'normal' quartz yielded an intense A1 Raman mode at **464 cm^{-1}**, whereas quartz without lechatelierite rims shows a shift of this band down to **461.5 cm^{-1}** (Fig. 4).

- The **highest shifts down to 460.5 cm^{-1}** were observed in quartz grains rimmed by **lechatelierite** (Fig. 5).

- It is also noteworthy that these grains show an **internal gradient of A1 Raman shift** of up to 3 cm^{-1} from the core (463.5 cm^{-1}) to the rim (460.5 cm^{-1}) to just below the lechatelierite rims (Fig. 5).

Micro Raman spectroscopy: quartz without lechatelierite

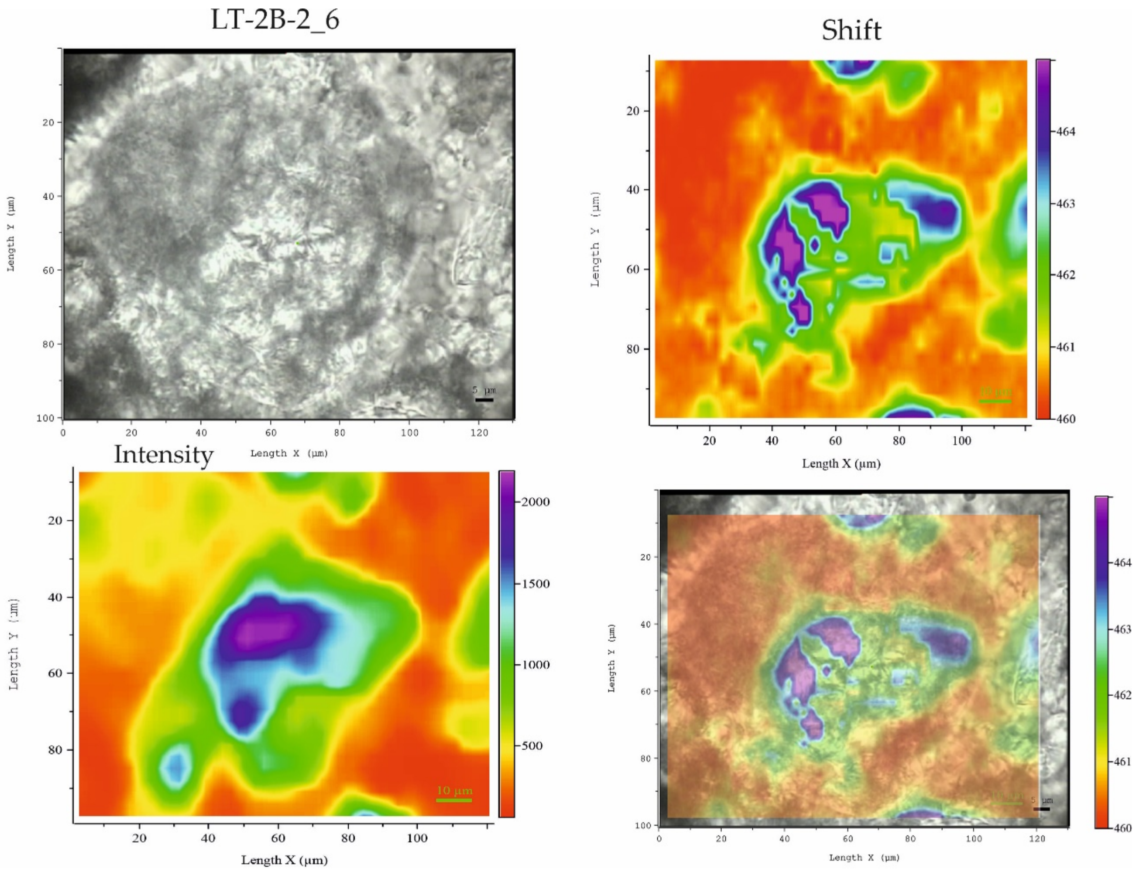

Figure 4: Raman spectroscopy of a quartz without a lechatelierite rim grain showing the internal gradient in the A1 Raman mode shift.

Micro Raman spectroscopy: quartz + lechatelierite

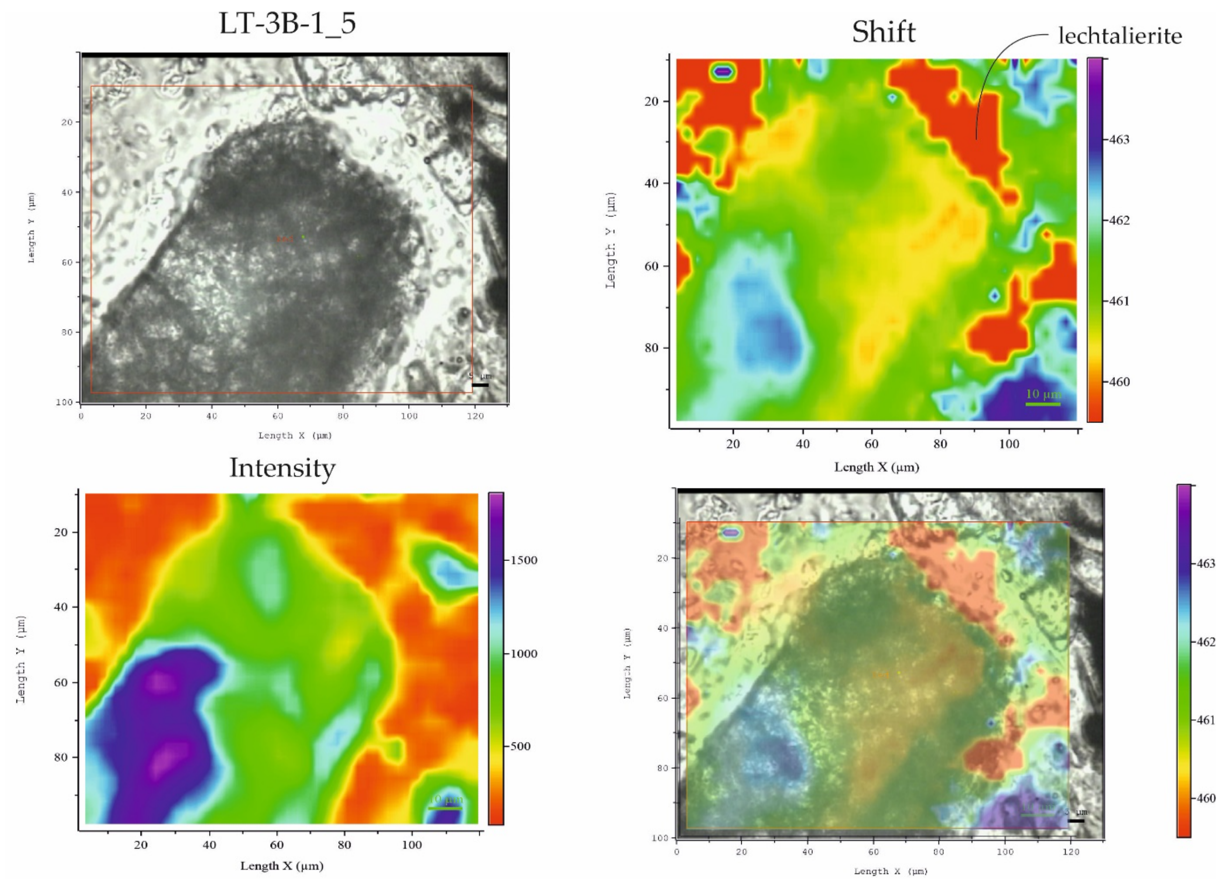

Figure 5: Raman spectroscopy of a quartz grain with a lechatelierite rim showing the internal gradient in the A1 Raman mode shift.

Geothermobarometry:

- The completely molten granitic matrix and the breakdown of biotite to spinel + melt indicates **minimum temperatures of 900-1000°**C.

- Sanders et al. (2020) showed that the shifted A1 mode of quartz is **stable only below 1100°C**, thus giving an upper limit of the temperature range.

- The observed Raman shift of the A1 mode and the presence of lechatelierite strongly suggest that a **pressure of possibly >24-26 GPa was attained** (cf. McMillan et al. 1991, Kowitz et al. 2013).

Conclusions:

- Up to date, **lechatelierite formation** in frictionites from rockslides was considered **to be a function of temperature** only.

- Because **lechatelierite only rims quartz with strongly shifted A1 band numbers**, we interpret lechatelierite formation to be driven by both **temperature and pressure**, at least under frictionite conditions.

- The data from **Köfels and Tsergo R**i provide the **first quantitative estimates of peak pressures during frictionite formation**, and show that UHP-modified quartz associated with lechatelierite is common in landslides of silica-rich rocks.

References:

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- Miehe G. Weidinger J.T. 2015: Royal Botanical Garden of Edinburg, 103-124, Edinburg. ISBN 978-1-910877-029
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