Investigating the Effect of Water on the Modulus and Yield Strength of Quartz via Nanoindentation

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Introduction

- Hydrolytic weakening of quartz has been shown to occur at temperatures of ~400°C, but has not been shown to occur in the Low Temperature Plasticity (LTP) regime.
- Understanding of the yield strength of earth materials in this regime has important implications for interpreting the strength of the lithosphere.
- As part of the RORD REU, we explore the influence of water content on the elastic modulus and hardness of quartz at room temperature.

Methods

- Synthetic single crystal of quartz with water contents (H/Si):
  - ~2480 ppm
  - ~1280 ppm
  - ~160 ppm
- Nanomechanics Nanoindenter fitted with a Berkovich tip (Figure 1 and Figure 5).
- Samples indented // to *C*-axis, loaded to 600 mN with at maximum depth of 5000 nm.
- Additional tests on rotated samples (relative to the fixed tip orientation) to test for anisotropic modulus and hardness (Figure 4).

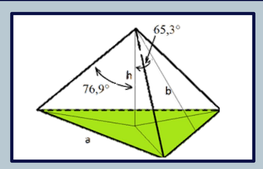

Figure 1 | Berkovich Indenter Tip Geometry (Modified from Maugeri et al., 2016).

Main Result: No influence of water content on hardness of quartz at room temperature.

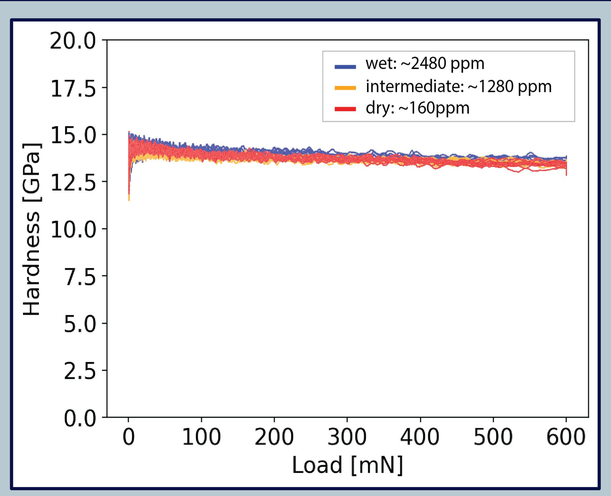

Figure 2 | Load versus Hardness of quartz with varying intracrystalline water content at room temperature. Hardness is proportional to the yield strength. For each water content, there are data from ten indentations graphed.

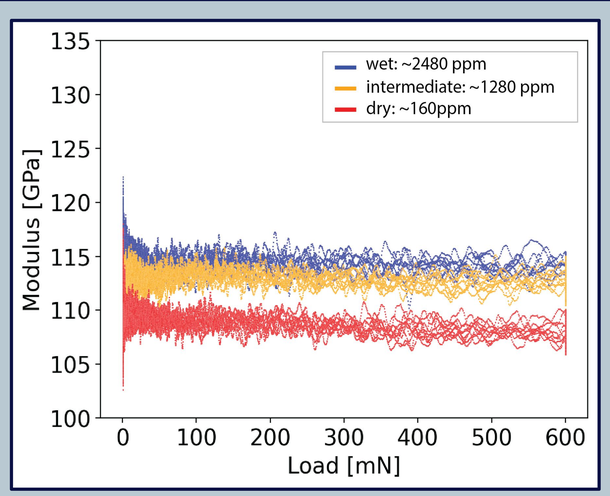

Figure 3 | Load versus Elastic Modulus of quartz with varying intracrystalline water content at room temperature. For each water content, there are data from ten indentations graphed.

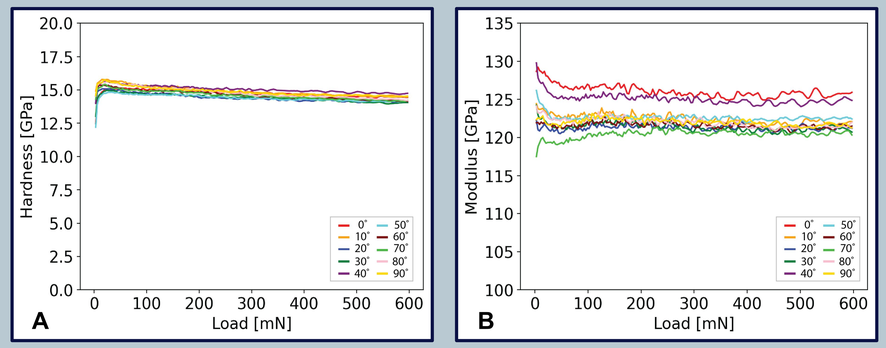

Figure 4 | Synthetic quartz sample with water content of ~1280 ppm rotated in 10 degree increments between each indentation. **A)** Load versus Hardness of Quartz. **B)** Load versus Elastic Modulus of Quartz.

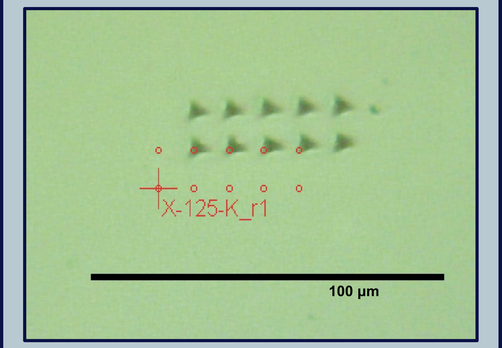

Figure 5 | Photograph of indents left by the Berkovich tip in synthetic quartz.

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Discussion

- Our results show:
  - Hardness values of ~14 +/- 0.5 GPa (Figure 2)
  - Modulus values of ~113 +/- 5 GPa (Figure 3)
- This indicates that there is no effect of water content on the hardness of quartz at room temperature.
- The lack of an effect on water is consistent with with other work done on hydrolytic weakening in the LTP regime.
- There appears to be a systematic increase in modulus with increasing water content in our samples, however this variation falls into the range of variation due to orientation effects (Figure 4).

Future Research

- Test additional samples with water content between 1280 & 160 ppm (H/Si).
- Test at a range of temperatures to determine specific temperature where hydrolytic weakening is initiated.

References

Ceccato, A., Menegon, L., & Hansen, L. N. (2022). Strength of Dry and Wet Quartz in the Low Temperature Plasticity Regime: Insights From Nanoindentation. *Geophysical Research Letters*, *49*(2). https://doi.org/10.1029/2021gl094633

Evans, B. (1984). The effect of temperature and impurity content on indentation hardness of quartz. *Journal of Geophysical Research: Solid Earth*, *89*(B6), 4213–4222. https://doi.org/10.1029/jb089ib06p04213

Griggs, D. (2010). Hydrolytic Weakening of Quartz and Other Silicates*. *Geophysical Journal of the Royal Astronomical Society*, *14*(1-4), 19–31. https://doi.org/10.1111/j.1365-246x.1967.tb06218.x

Maugeri, F., D'Arrigo, G., & Calabretta, M. (2016). *Nanoindentation Testing for Al-Cu Bulks. 1712.* https://ceur-ws.org/Vol-1712/p04.pdf

Oliver, W. C., & Pharr, G. M. (1992). An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments. *Journal of Materials Research*, *7*(6), 1564–1583. https://doi.org/10.1557/jmr.1992.1564

Strozewski, B., Sly, M. K., Flores, K. M., & Skemer, P. (2021). Viscoplastic Rheology of αQuartz Investigated by Nanoindentation. *Journal of Geophysical Research: Solid Earth*, *126*(9). https://doi.org/10.1029/2021jb022229