



# How Fast Did That Crystal Grow? Quantifying the Growth Rate of Natural Quartz Crystals

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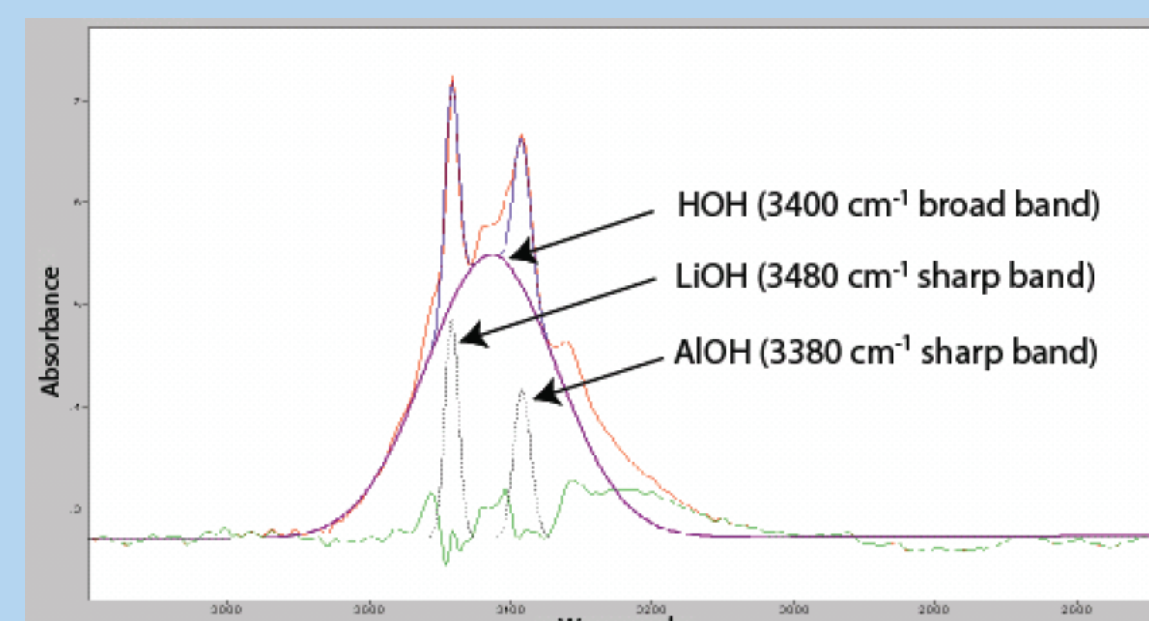
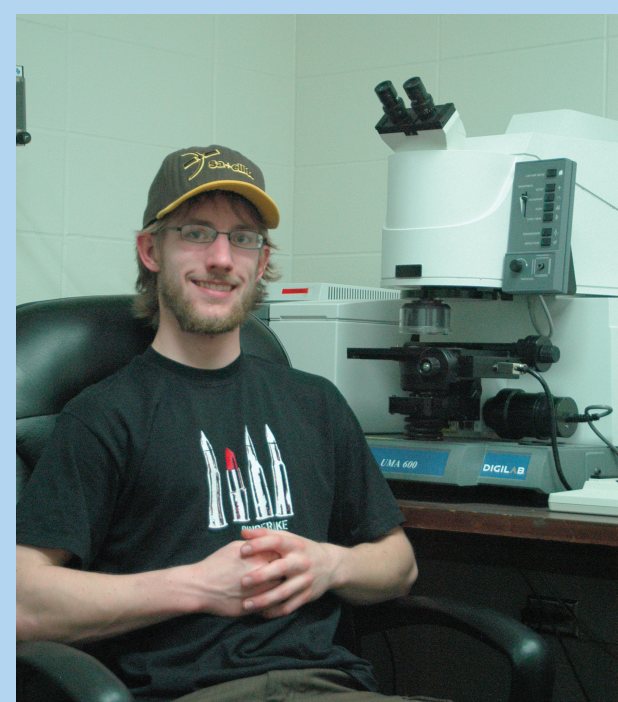
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## Abstract

Circulation of hydrothermal fluids controls the timescales of cooling in the Earth's crust and allows for large-scale exchange of matter between different levels of the crust. The time required to grow quartz crystals within these systems governs how long individual fluid-filled fractures remain open. Every hydrothermal quartz crystal contains small amounts of impurities that were trapped on the growing crystal face at the time of mineral growth. The trace constituents record the physical and chemical conditions that were present as the mineral was growing. Here, we present micro-FTIR measurements that characterize the morphologic evolution of a series of quartz crystals grown from a single hydrothermal vein from China. Our analyses show that each crystal grew as successive layers were added to the terminal rhombohedral faces. Measurements from different heights within each crystal define diffusion profiles toward the crystal boundaries that document the time-dependent impurity concentrations that were trapped during growth; diffusion profiles at the bottom of the crystals are more pronounced than profiles observed at the tips. The time elapsed between growth at the bottom and growth at the terminus represents a novel new approach to investigating crystal growth kinetics.

## The Micro-IR technique



The vibrational states of molecules trapped in the crystal lattice (such as AlOH, LiOH, HOH, and KOH) are excited by IR radiation. The photons that are absorbed are specific to the energy of each individual impurity species.

## High-Resolution IR Spectroscopy of Hydrothermal Quartz

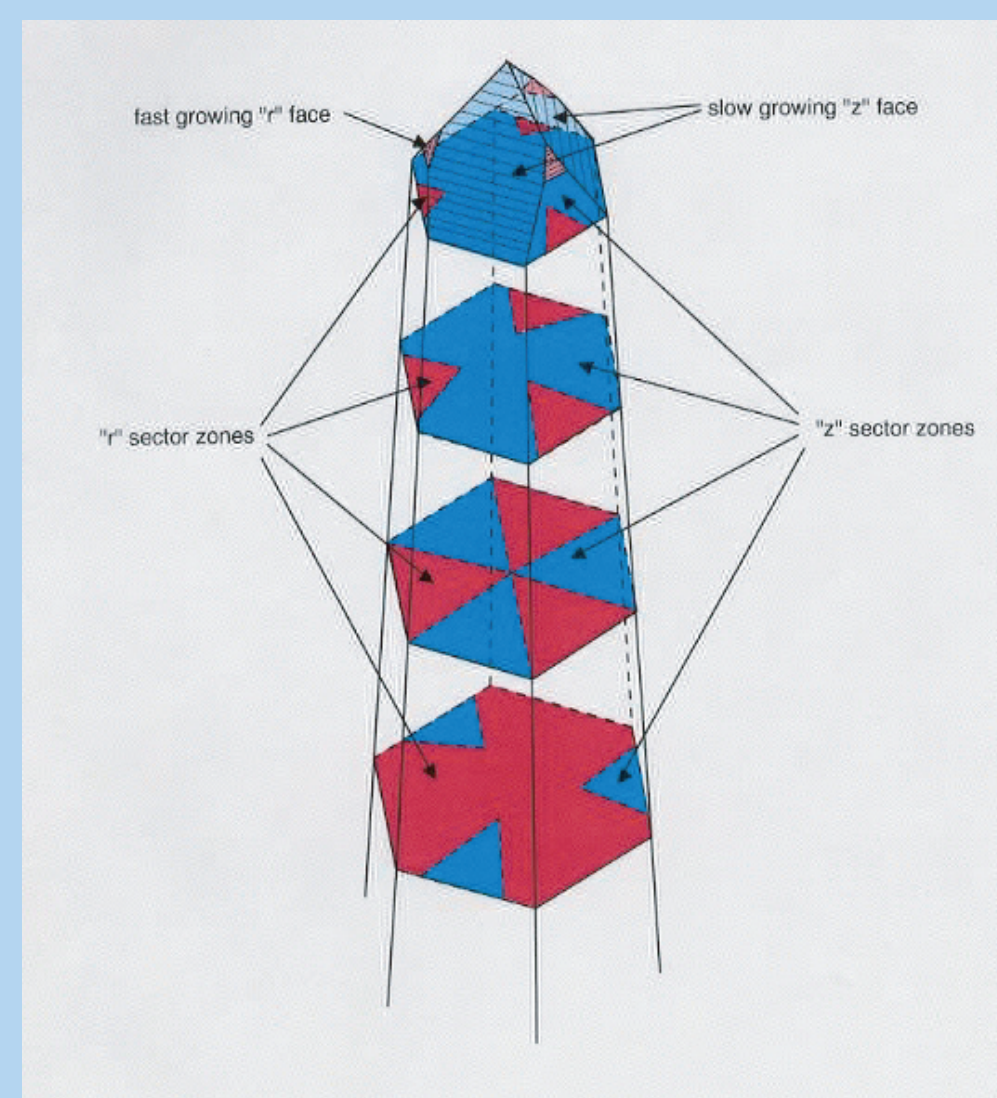
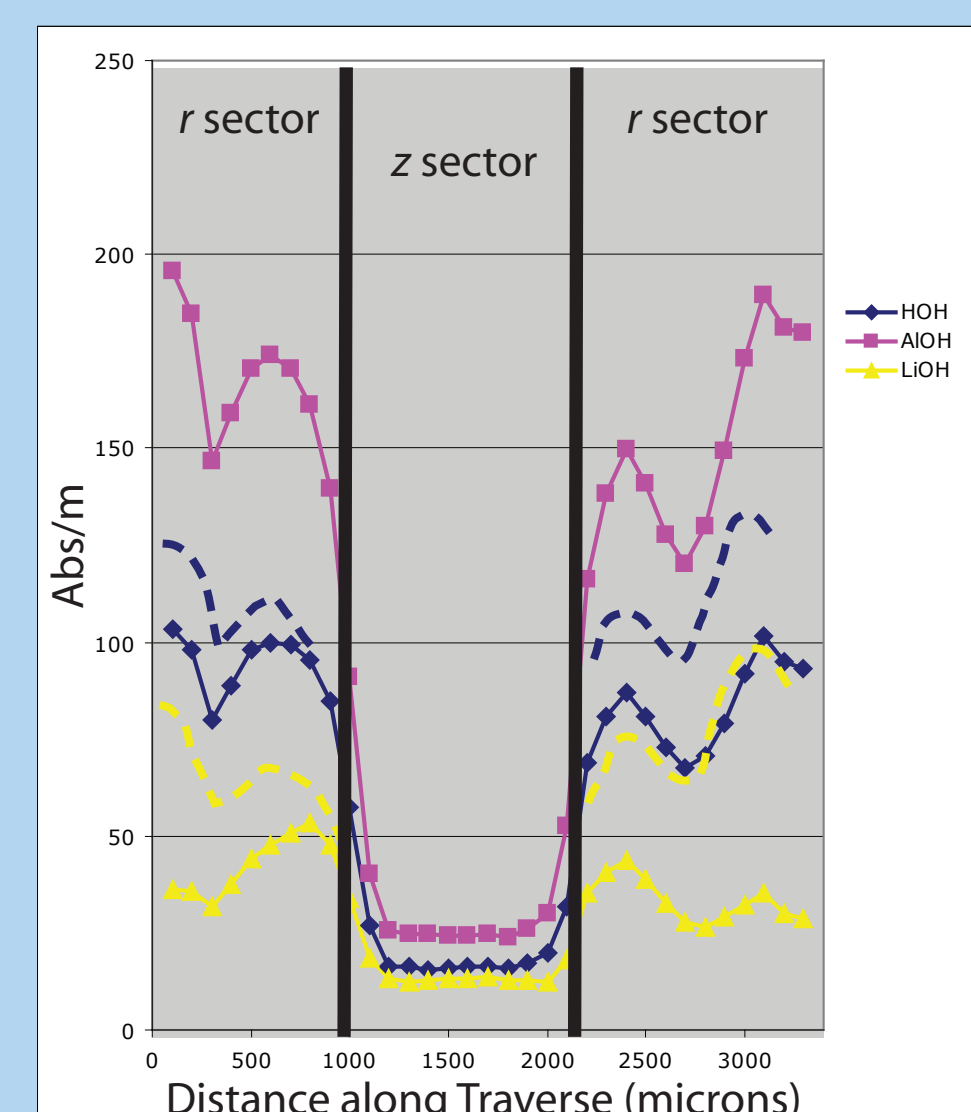


Figure from Ihinger & Zink, 2000



Previous work has shown that growth of hydrothermal quartz crystals occurs predominantly on the terminal rhombohedral *r* and *z* faces (Ihinger and Zink, 2000). Six sector zones with significantly different impurity concentrations delineate six distinct regions within the crystal that represent growth on the six terminus faces without concurrent growth on the six *m* prism faces. Here, we present new measurements on hydrothermal quartz crystals that demonstrate growth on the six *m* prism faces does occur in some hydrothermal environments.

## Multiple Quartz Crystals: One Vein

More than twenty individual quartz crystals were extracted from a cluster of crystals sampled from a single hydrothermal vein from Le Chang, China. Several crystals were chosen for analysis and sliced into ~1 mm thick wafers perpendicular to the *c*-axis. All wafers were doubly polished using 0.3 micron alumina grit in preparation for IR analysis.

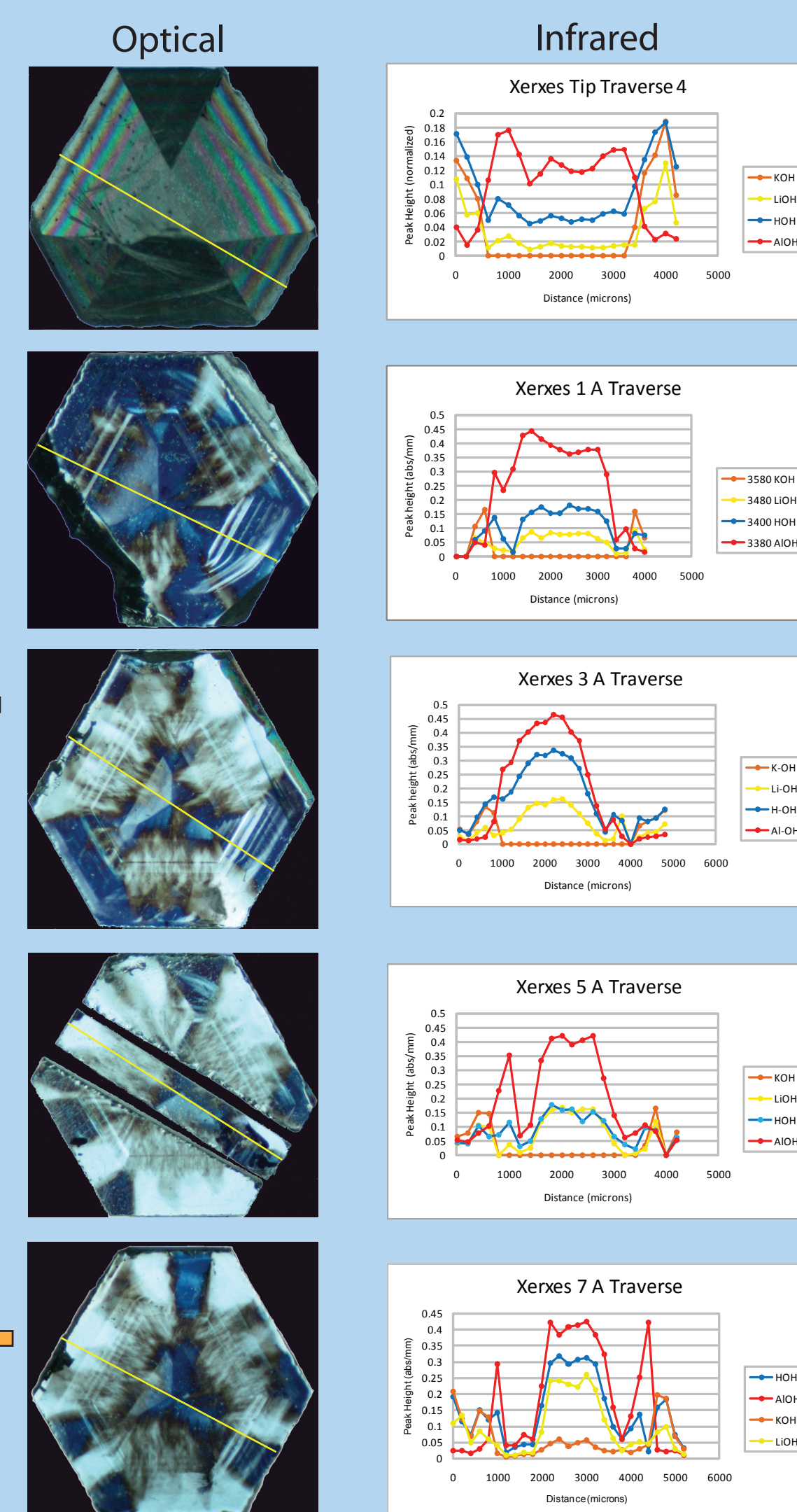
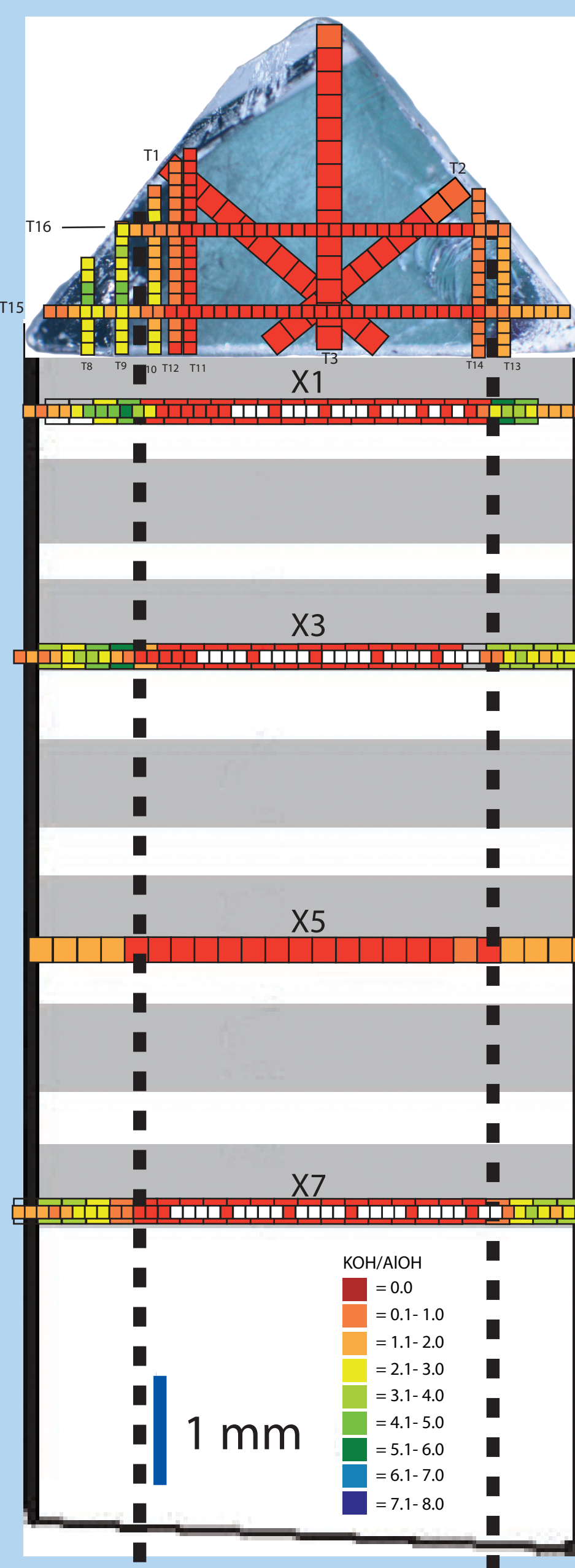
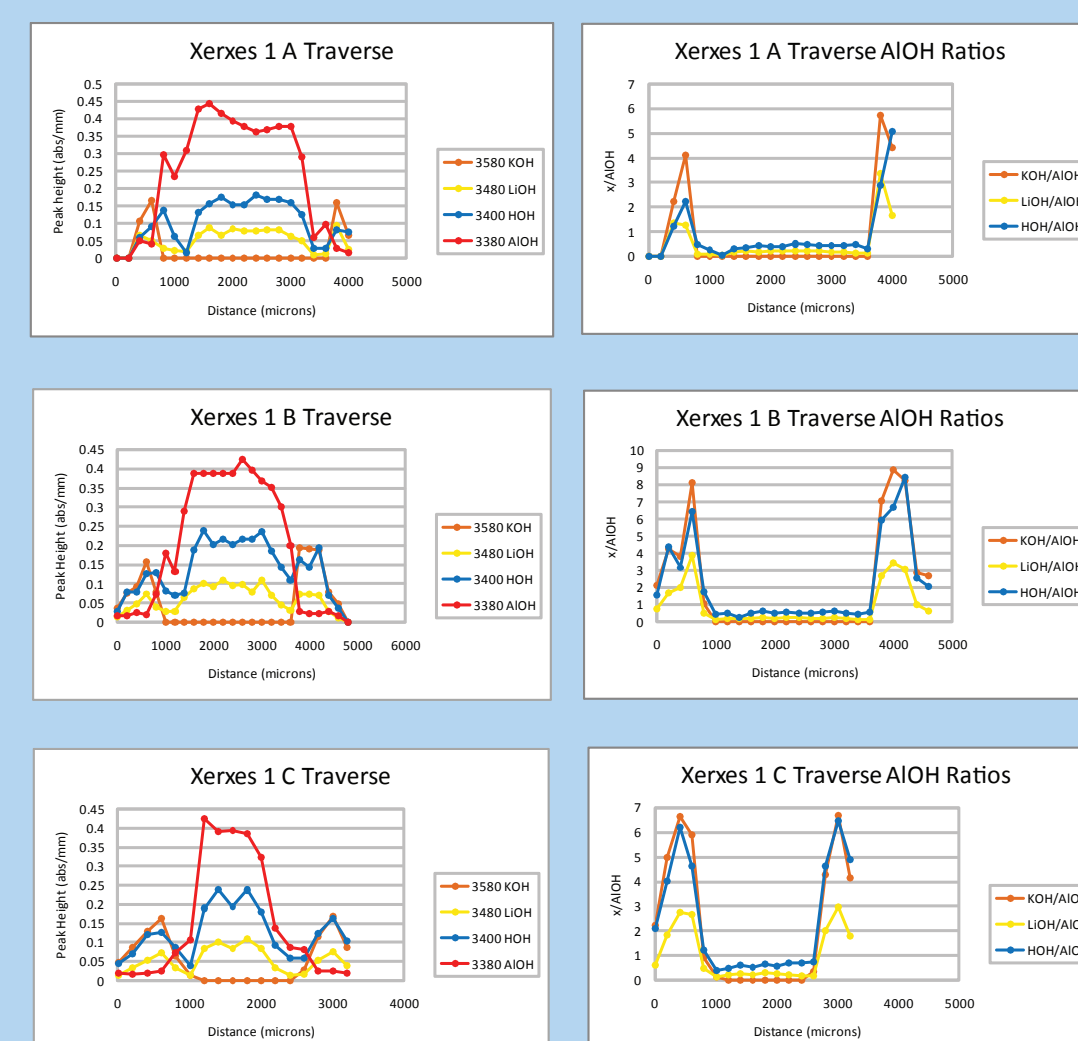
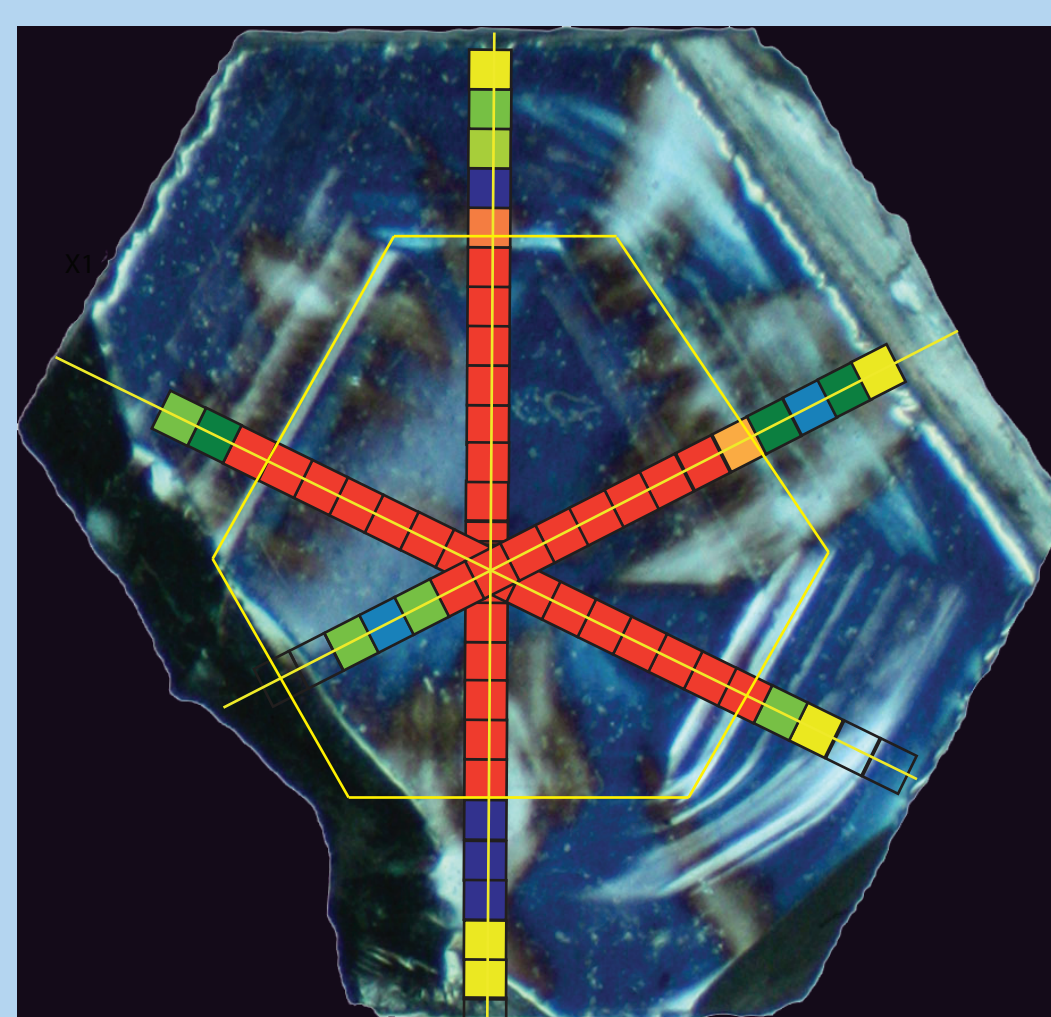


## Anatomy of a Crystal:

### Micro-IR Results of Xerxes

FTIR analyses document a 2-stage growth evolution for each crystal in the LeChang vug: an inner 'core' formed by growth entirely on rhombohedral faces, and an outer rind of even thickness formed by addition of material onto each of the six prism faces. Diffusion profiles of hydrous species within the core can be used to quantify the time evolved since crystallization (see panel below).

### Rim Thickness within Level 1

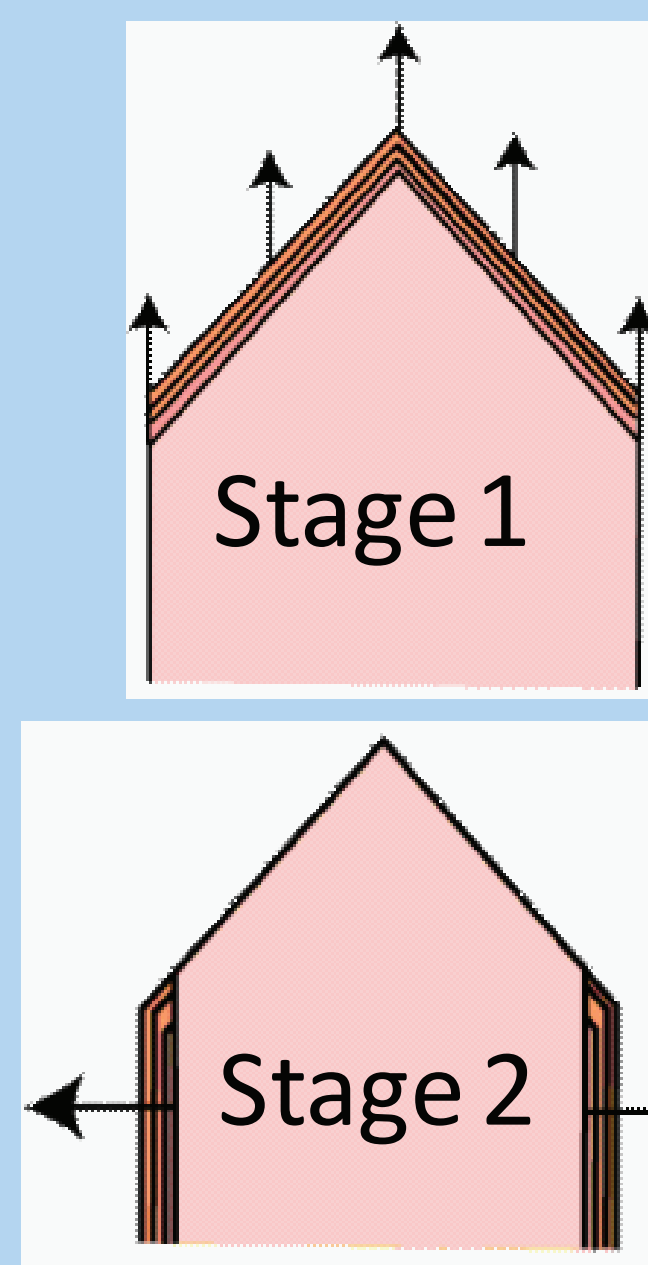
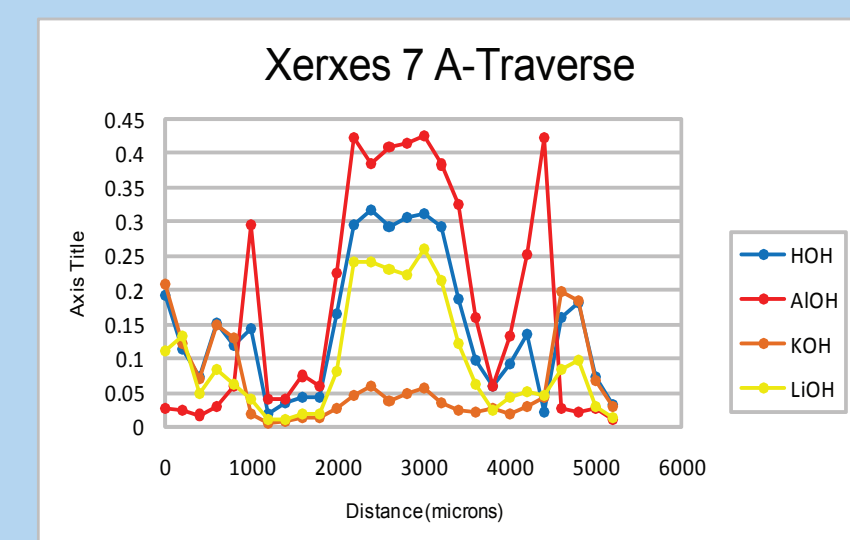
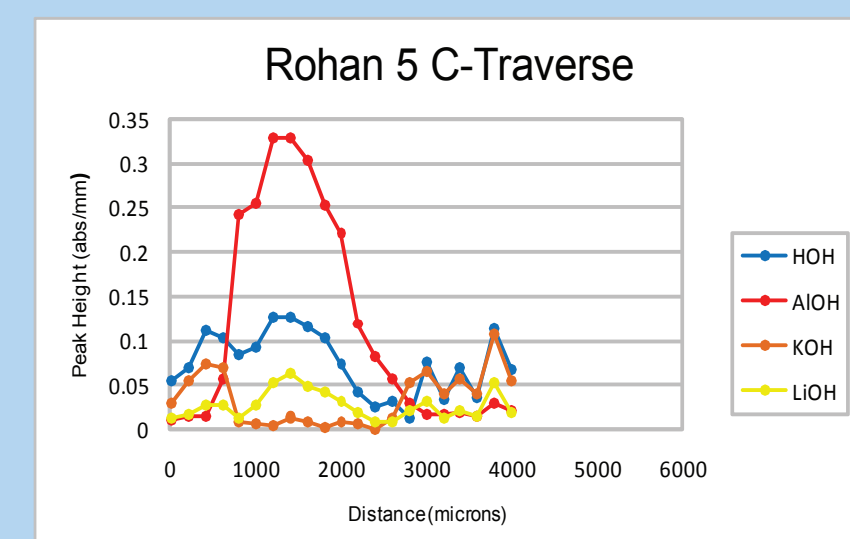
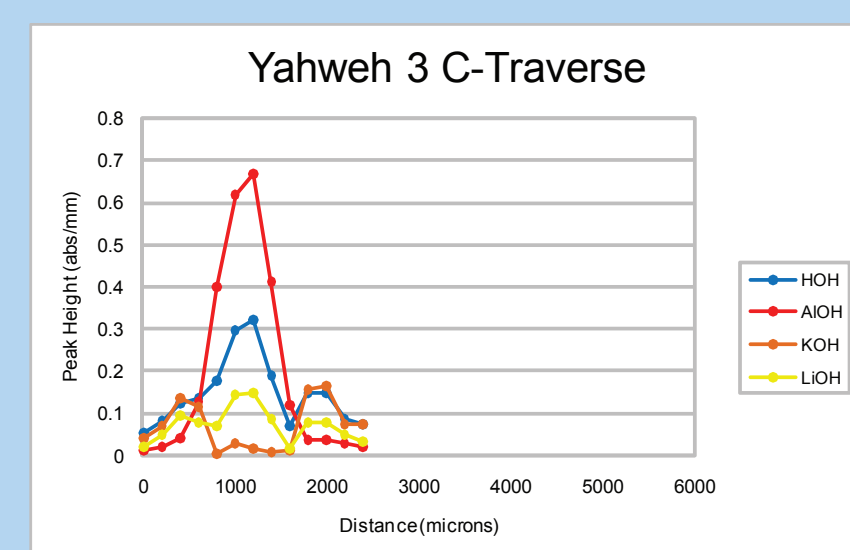


## Two Stages of Growth for All Crystals in the LeChang Hydrothermal Vein

Impurity abundances in three crystals extracted from the same vug reveal similar growth patterns, despite large differences in their sizes. An AIOH-rich, KOH-deficient core forms separately from the AIOH-deficient, KOH-rich mantle of each crystal.

We believe this occurs as two separate events:

- 1) An initial growth event generating an AIOH-rich core via growth entirely on the terminal 'r' and 'z' rhombohedral faces; and
- 2) A second growth event generating a KOH-rich rim via growth on the six 'm' prism faces.



## Diffusion of Hydrous Species: The Key to Quantifying Crystal Growth Rate

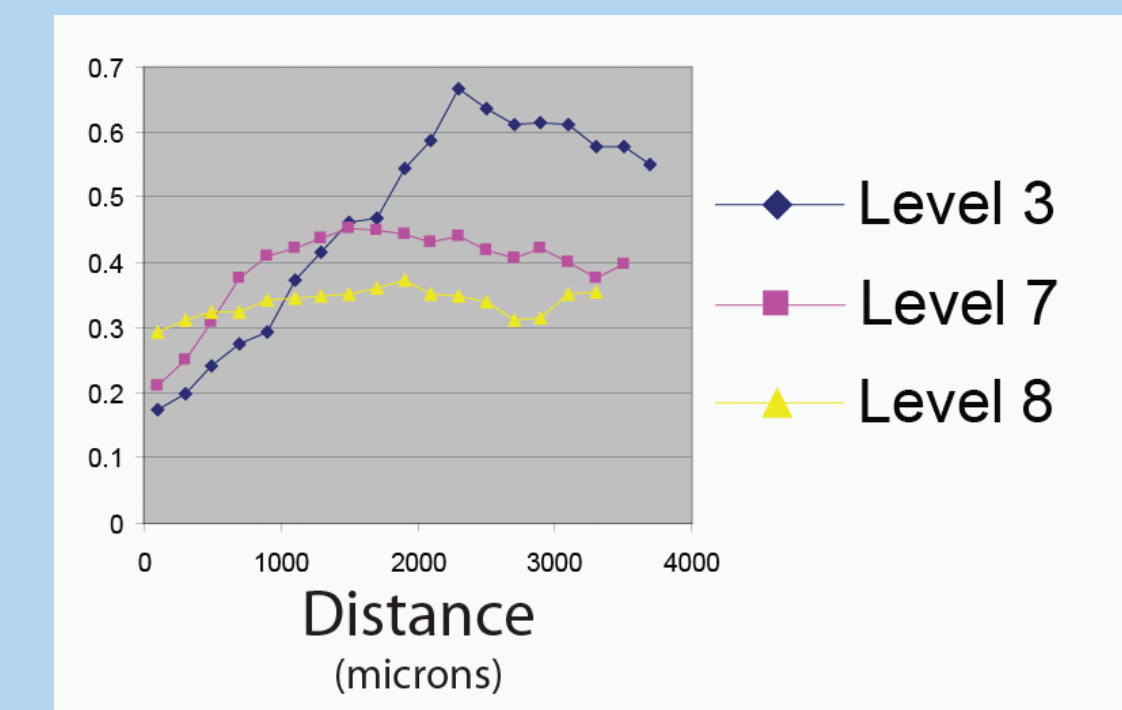
Natural diffusion profiles from core to rim can be fit using known diffusion coefficients to find the time elapsed between growth at the base and growth at the terminus of the crystal, providing the total time involved in the growth of the crystal (Ihinger et al., 2006).

Described by Fick's First Law:  $J_x = D_i \frac{\partial C_i}{\partial X}$

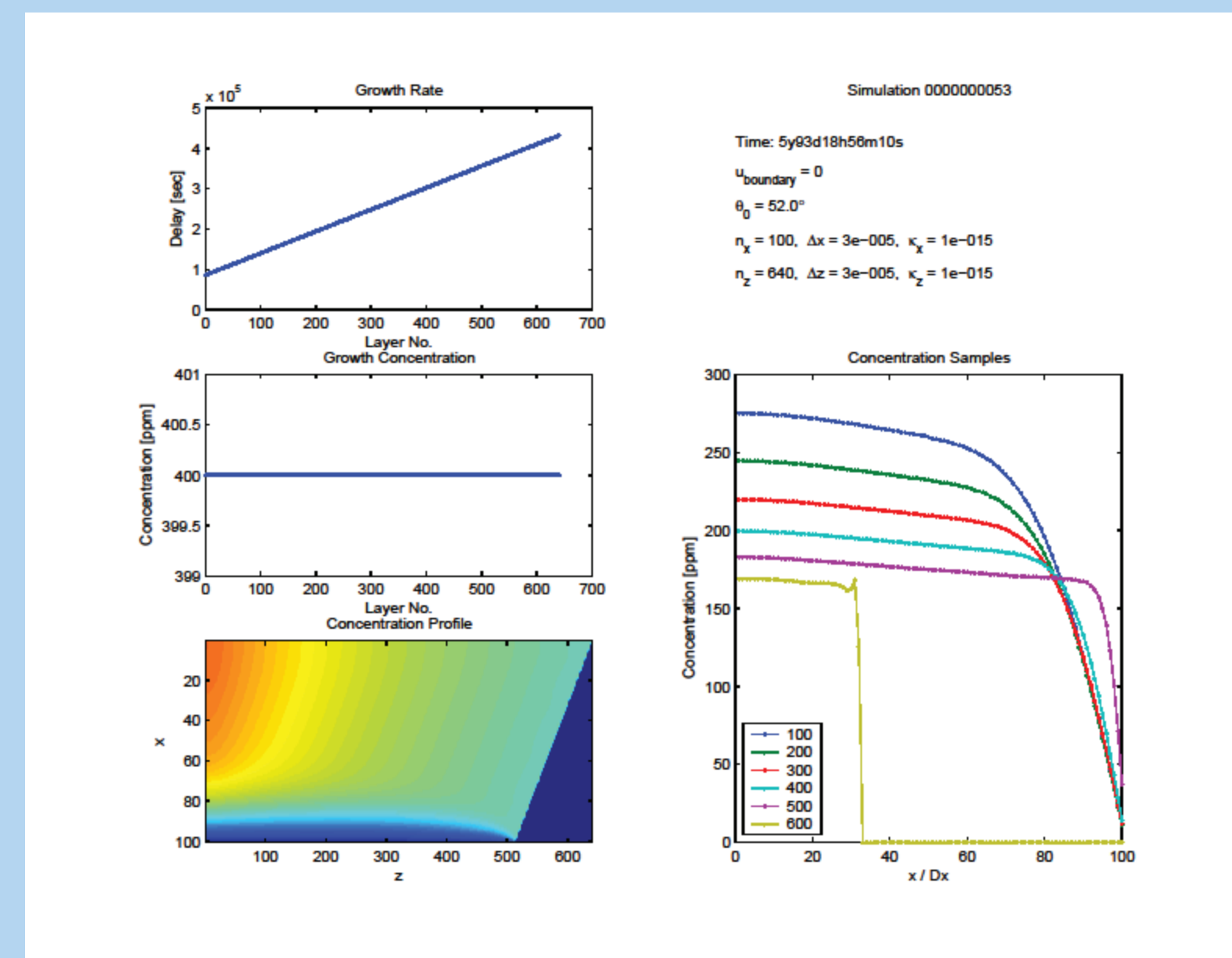
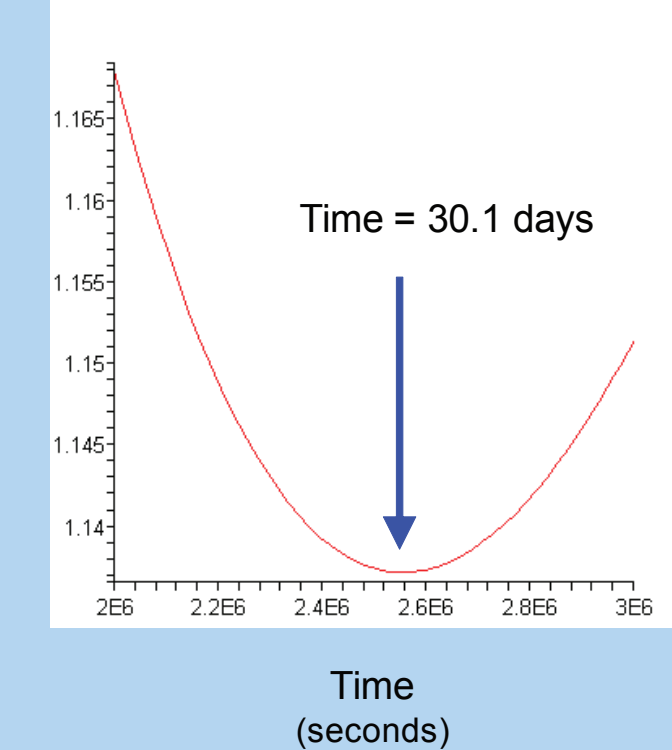
Dependence on Time:  $\frac{\partial C_i}{\partial t} = D \frac{\partial^2 C_i}{\partial X^2}$

Solution to Fick's Second Law:  $\frac{C}{C_0} = \frac{1}{2} + \frac{1}{2} \operatorname{erf}\left(\frac{X}{2\sqrt{Dt}}\right)$

$$\operatorname{erf}(y) = \frac{2}{\sqrt{\pi}} \int_0^y e^{-u^2} du$$



Diffusion profiles of HOH in Brazilian hydrothermal quartz (Ihinger et al., 2006).



Finite element modeling can simulate the natural process and successfully reproduce diffusion profiles observed in natural samples (Henke et al., 2009).

## Acknowledgments

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## References

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## What's Next

We aim to expand our study and investigate the distribution of hydrous impurities in quartz crystals sampled from well characterized hydrothermal veins from the Alpine Orogeny in Switzerland and from different facies of well characterized ore deposits associated with gold, lead, and zinc precipitation.

## Results and Conclusions

- Hydrous impurities define sector zones in hydrothermal quartz crystals. In vug quartz from Le Chang, China, crystals document two types of sector zones: one type (identified by high AIOH and low KOH abundance) represents growth on the six rhombohedral terminus faces, and the second type (identified by low AIOH and high KOH abundance) represents growth on the six prism faces.
- Detailed IR measurements in the terminus suggest that the second stage of growth occurred primarily by coating of the six prism faces, with little growth on the terminus.
- Diffusion profiles from core to rim in hydrothermal crystals from natural environments can be used to determine the time it took for individual crystals to grow. The best-fit time measured for a quartz crystal from Minas Geras, Brazil is 30 days.