SHANNON ENTROPY AND HYDROTHERMAL PROCESSES

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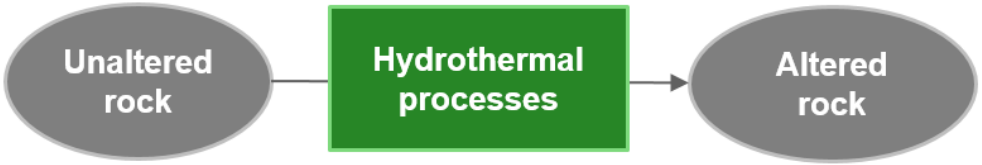
AIM

To apply concepts from information theory to investigate:

- The effect of hydrothermal processes on rock
- The measurement and quantification of these effects

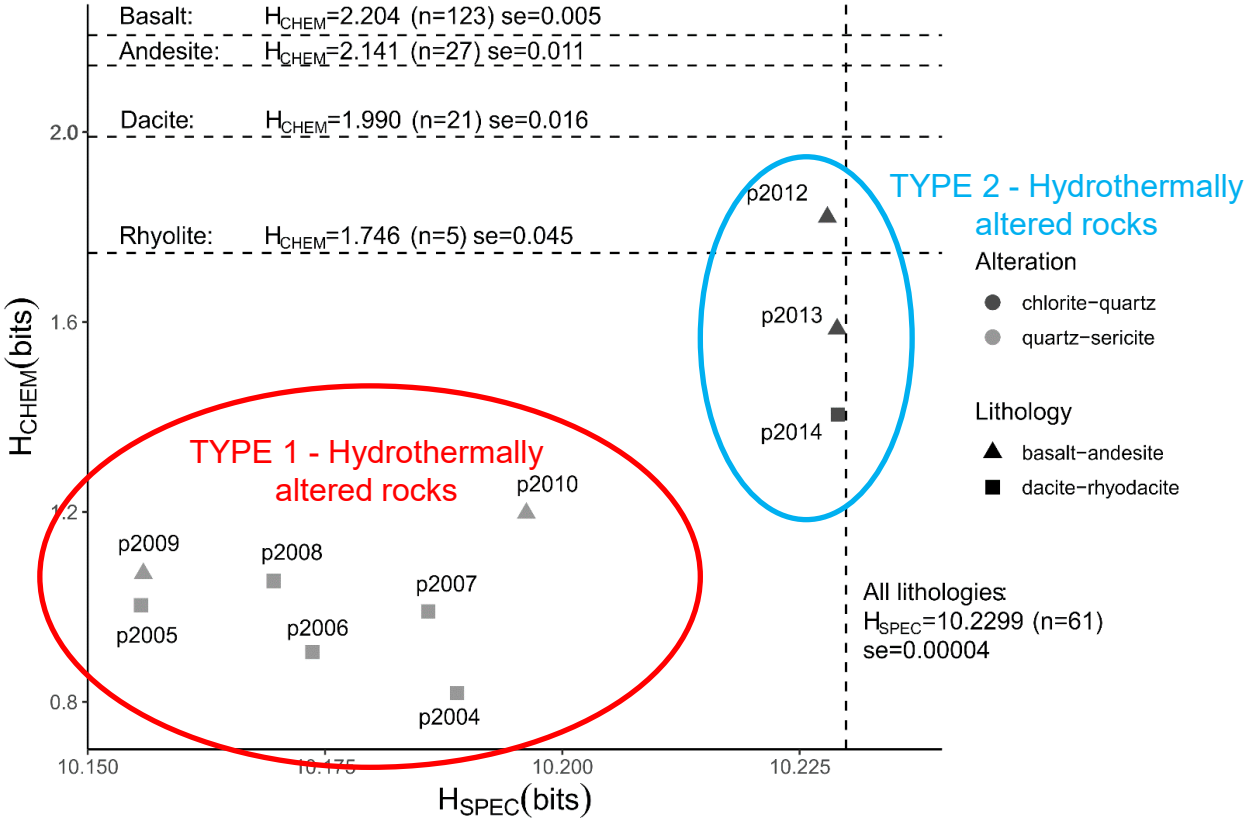


Importance of hydrothermal processes:

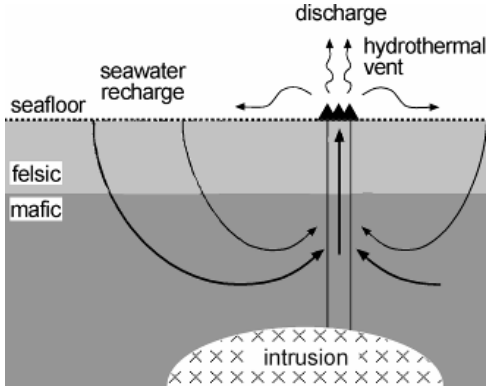
- Linked to possible origin of life
- Formation of mineral deposits

HIGHLIGHT

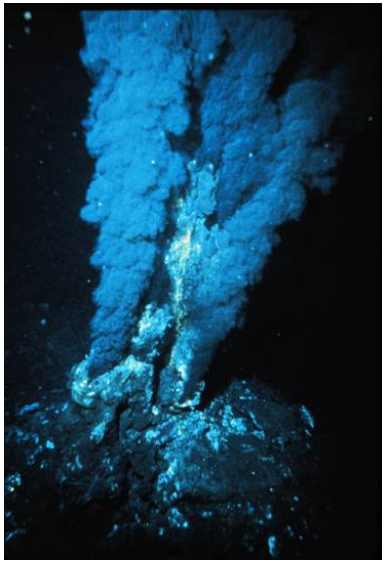
Spectral versus chemical Shannon entropy



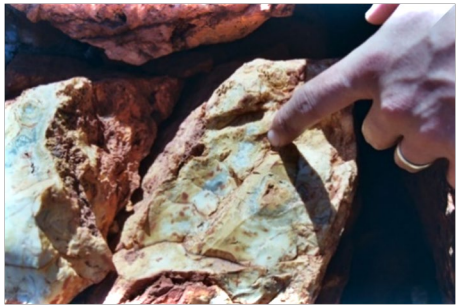
HYDROTHERMAL PROCESSES

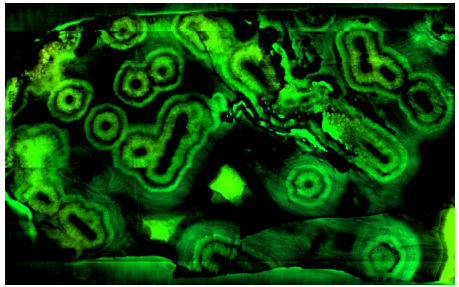


Fluid convection in submarine hydrothermal system



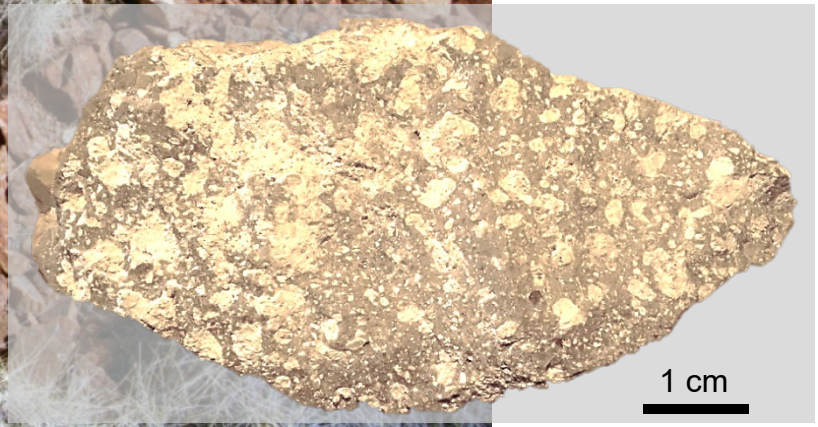
Active hydrothermal vent
Credit: P. Rona, OAR/ Nurp





Early life microfossils, oncolite

HYDROTHERMALLY ALTERED ROCK



SHANNON ENTROPY

- Shannon (1948) “A mathematical theory of communication”
- Means to study and solve problems of communication and transmission of signals over channels.
- The amount of uncertainty of a probabilistic choice system:

$$H(P) = -\sum_{i=1}^{m} pi \times \log pi$$

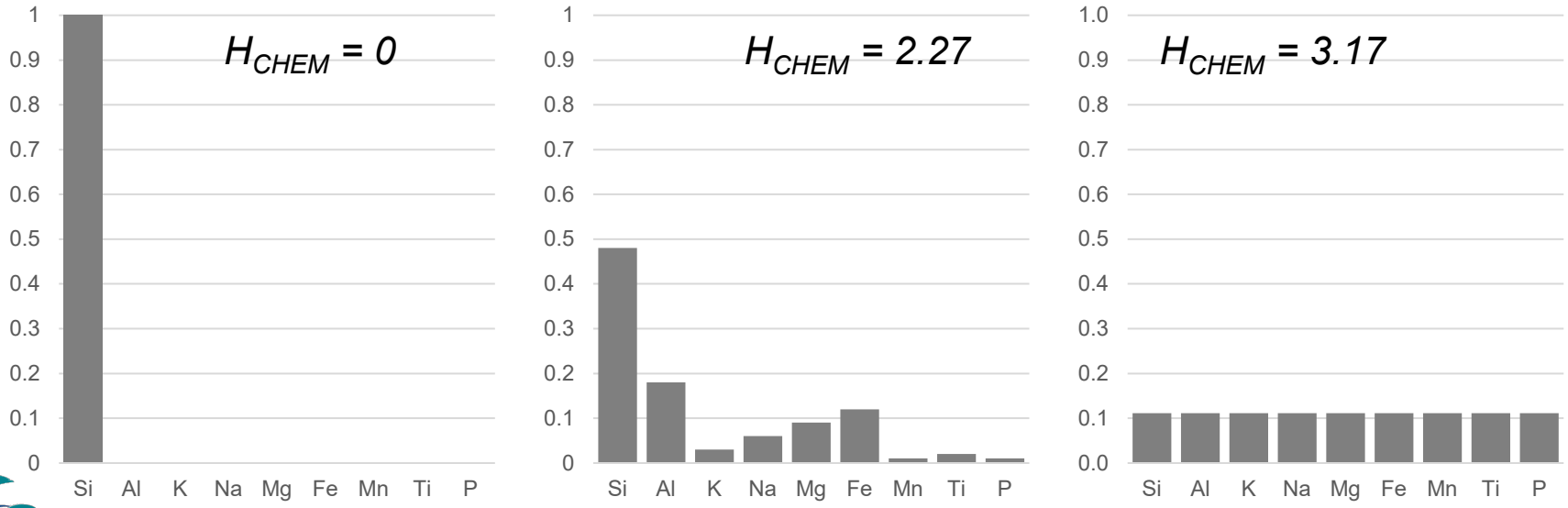
m = number of possibilities
pi = probability of possibility i

- *H(P)* is called the *Shannon entropy,* units are in *bits* or *shannon*

CHEMICAL SHANNON ENTROPY (H_{CHEM}) FROM WHOLE ROCK CHEMISTRY

Sorting of chemical elements

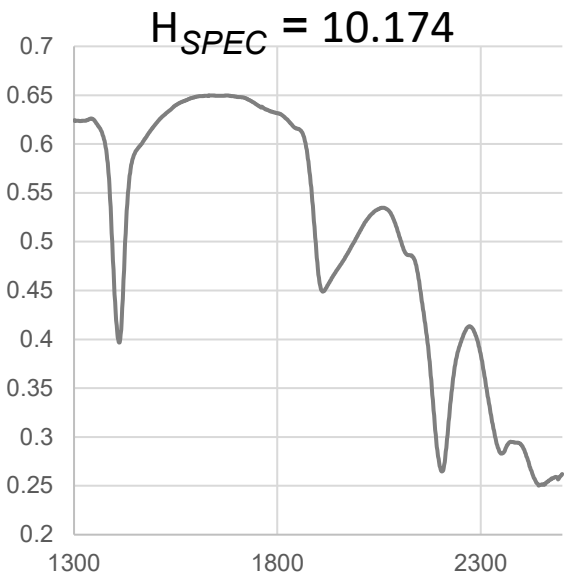
No uncertainty — Entropy - uncertainty — Maximum

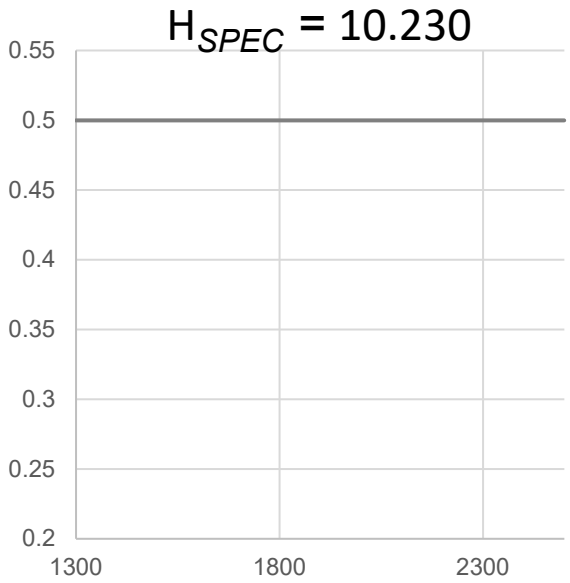


SPECTRAL SHANNON ENTROPY (H_{SPEC}) FROM REFLECTANCE SPECTRA (1-R)

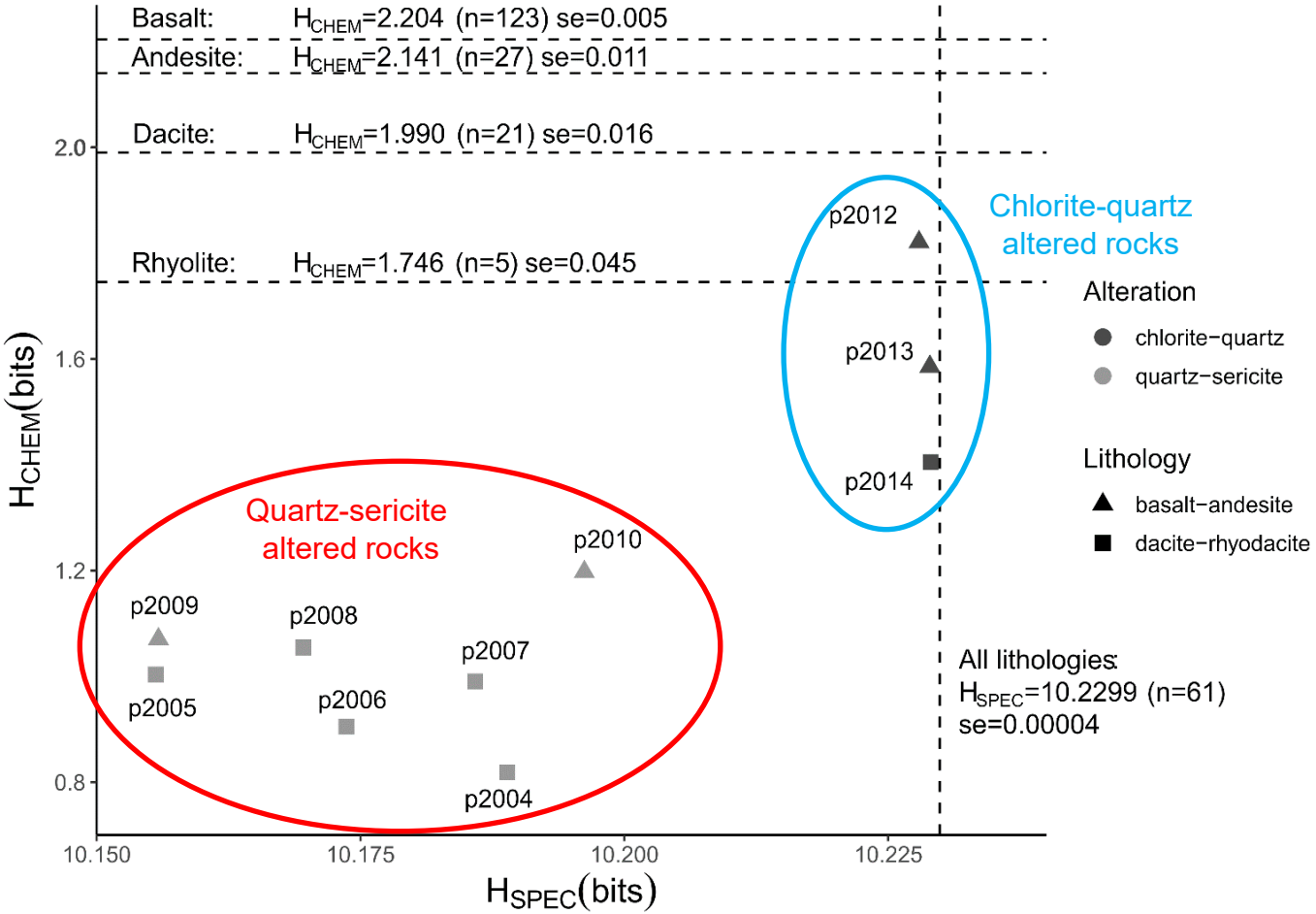
Sorting of absorption features

Less uncertainty — Entropy - uncertainty — Maximum uncertainty





SPECTRAL VERSUS CHEMICAL SHANNON ENTROPY



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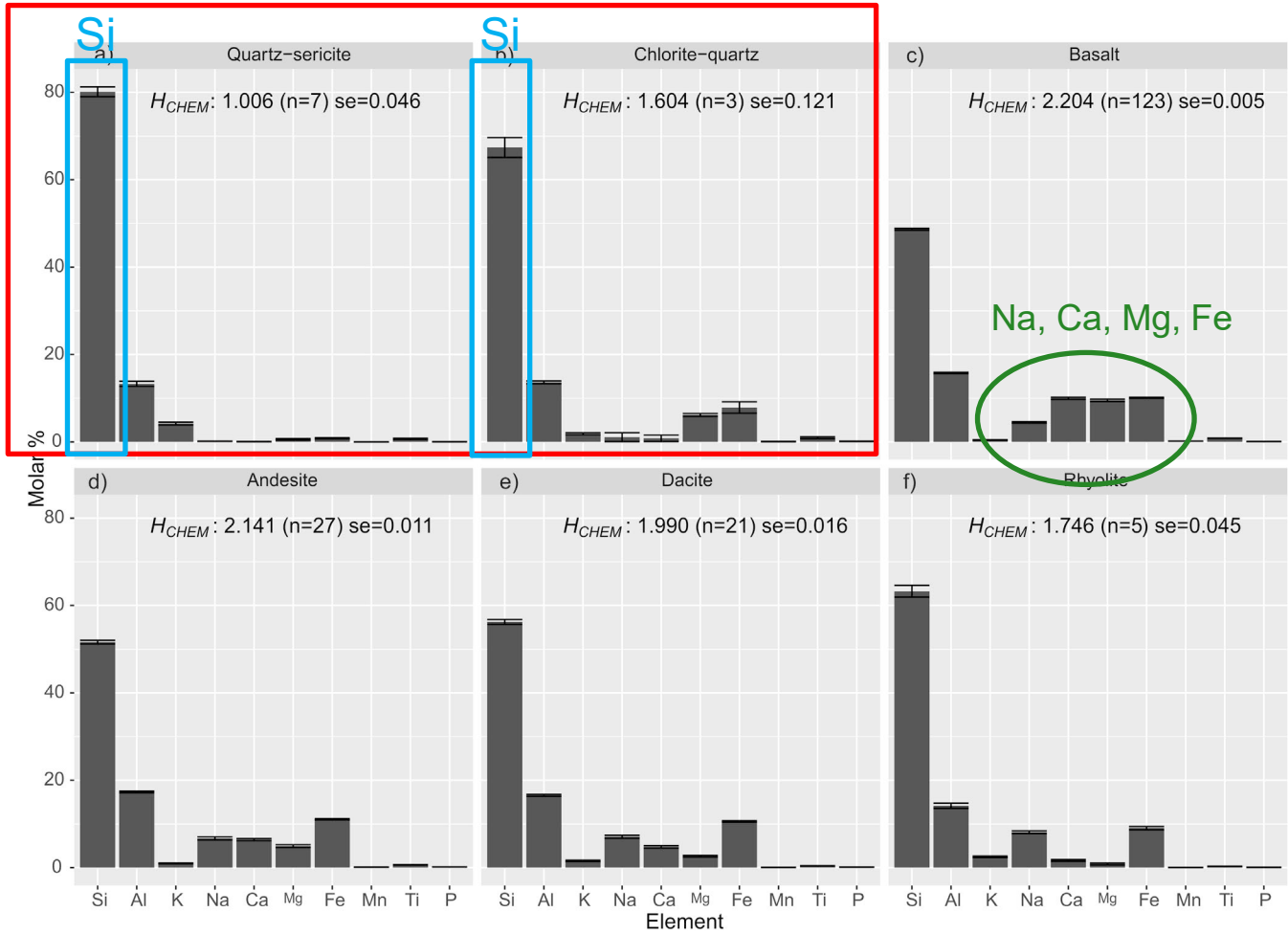
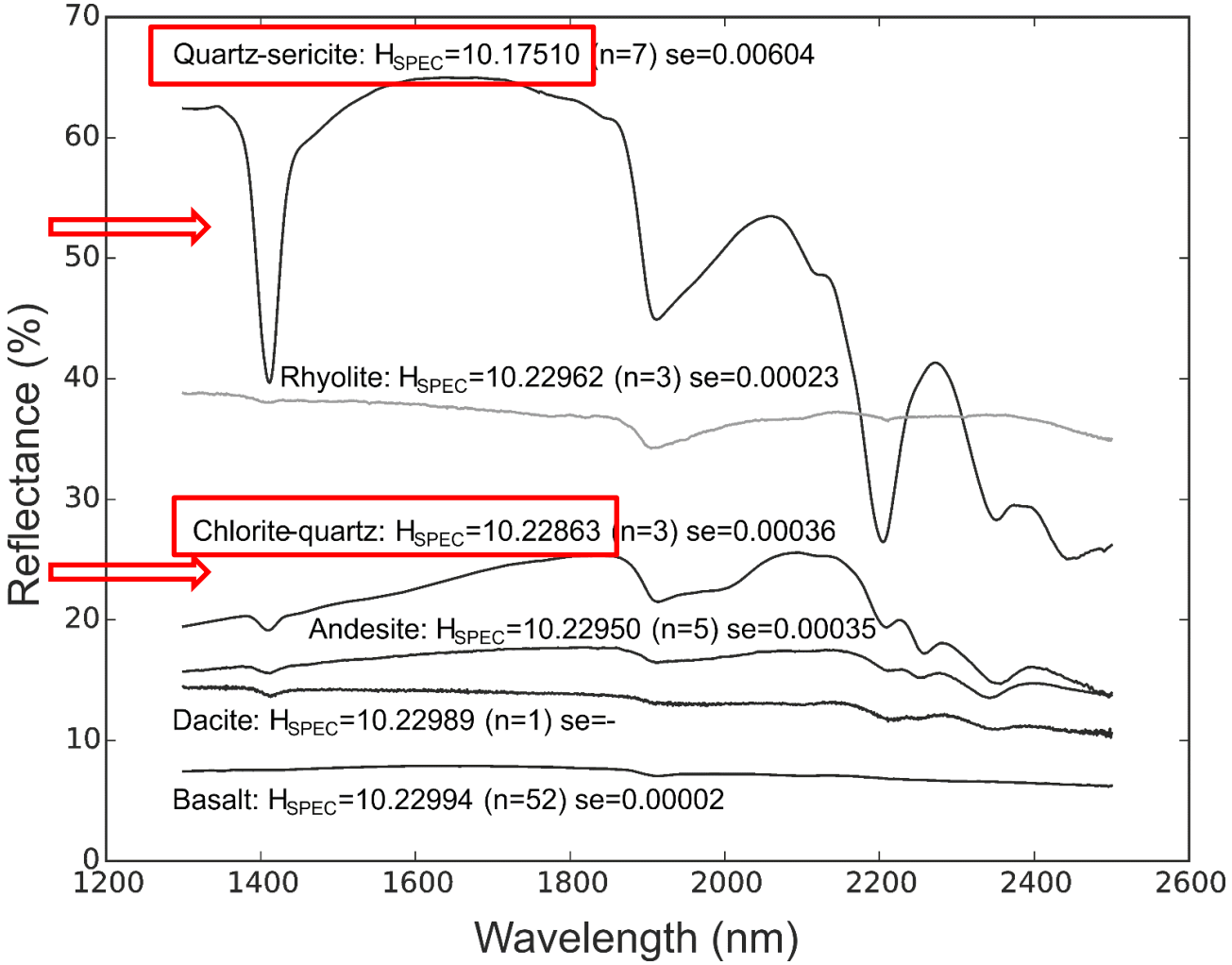
Hydrothermally altered rocks




Quartz-sericite: H_{SPEC}=10.17510 (n=7) se=0.00604
Rhyolite: H_{SPEC}=10.22962 (n=3) se=0.00023
Chlorite-quartz: H_{SPEC}=10.22863 (n=3) se=0.00036
Andesite: H_{SPEC}=10.22950 (n=5) se=0.00035
Dacite: H_{SPEC}=10.22989 (n=1) se=-
Basalt: H_{SPEC}=10.22994 (n=52) se=0.00002
Reflectance (%)
Wavelength (nm)
0
10
20
30
40
50
60
70
1200
1400
1600
1800
2000
2200
2400
2600

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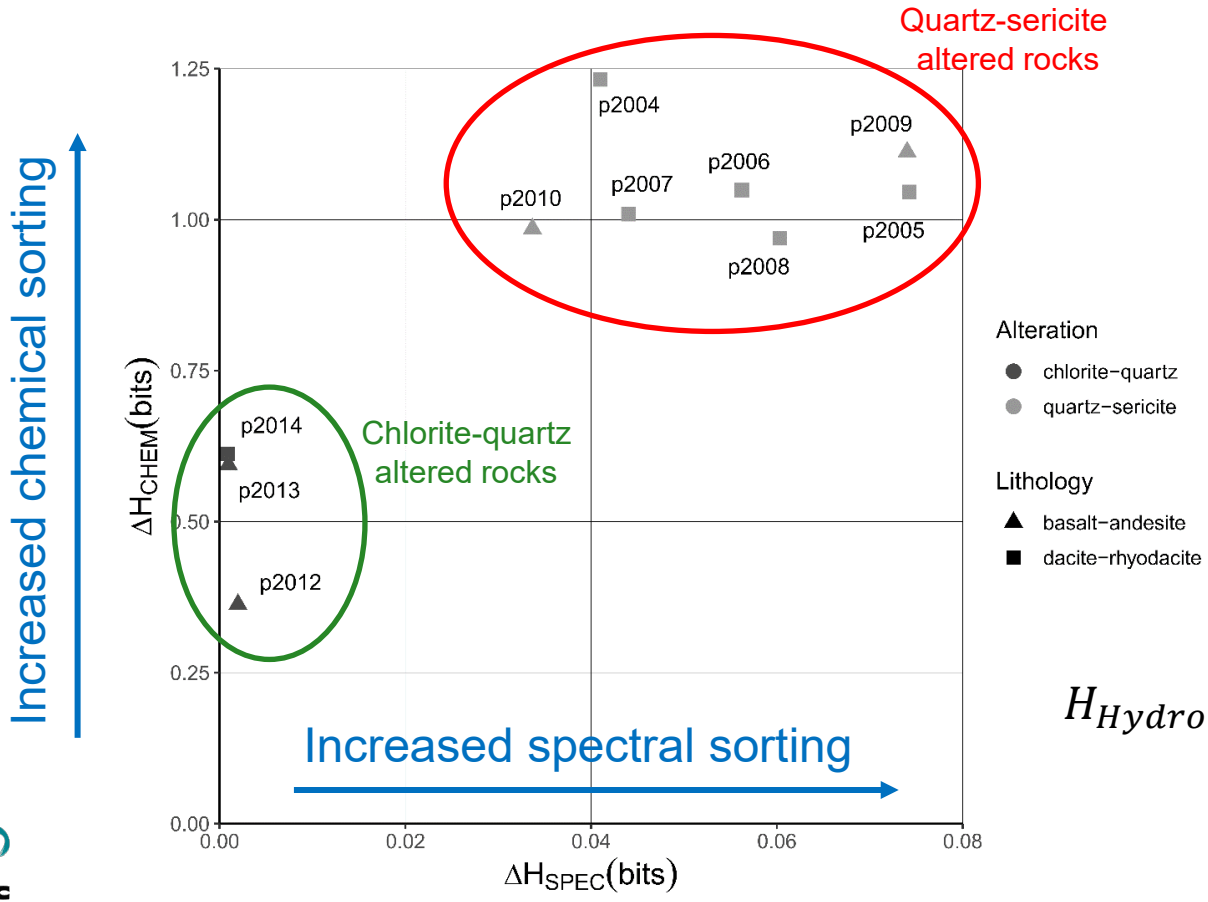
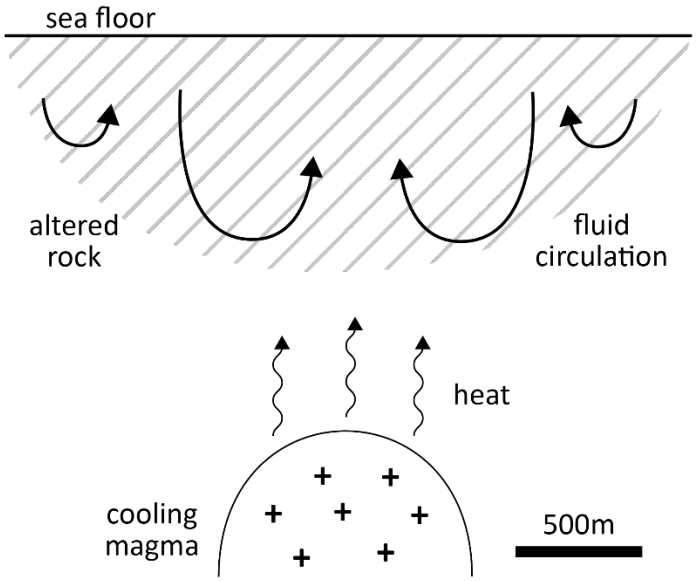
SORTING PROCESSES BY HYDROTHERMAL ALTERATION



$$\Delta H = H_{Hydrothermally\ altered\ rock} - H_{Precursor}$$

Relationship between heat and Shannon entropy



Heat (intrusion or thermal gradient)

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Hydrothermal fluid convection

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Destabilization of wall-rock

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Changing chemical and mineralogical composition

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Decreasing Shannon entropies

CONCLUSIONS

- The Shannon entropy can be used for the identification of hydrothermally altered rocks;
- Shannon entropy is an indicator of sorting processes in hydrothermal systems and can quantify the effects of sorting;
- Hydrothermal processes provide a natural mechanism for transforming energy from heat to increased order in rock.

OPEN QUESTIONS

- Is there a relationship between low-Shannon entropy rocks in hydrothermal environments and occurrences of early life forms that typically maintain a low thermodynamic entropic state?
- Can the Shannon entropy act as proxy of a thermodynamic (statistical) entropy? For instance, the entropy formulated by Boltzmann?
- Does the relationship between molecular vibrations at specific frequencies and molecular vibrations in the rock-fluid interface in hydrothermal systems influence the habitability of early life environments?

THANK YOU

Further reading:

van Ruitenbeek, F. J., Goseling, J., Bakker, W. H., & Hein, K. A. (2020). Shannon Entropy as an Indicator for Sorting Processes in Hydrothermal Systems. *Entropy*, *22*(6), 656.

https://doi.org/10.3390/e22060656