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Natural zeolite cement blend for geothermal wellbore applications: the zeolite mechanism in making resilient cement formulations.

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Introduction

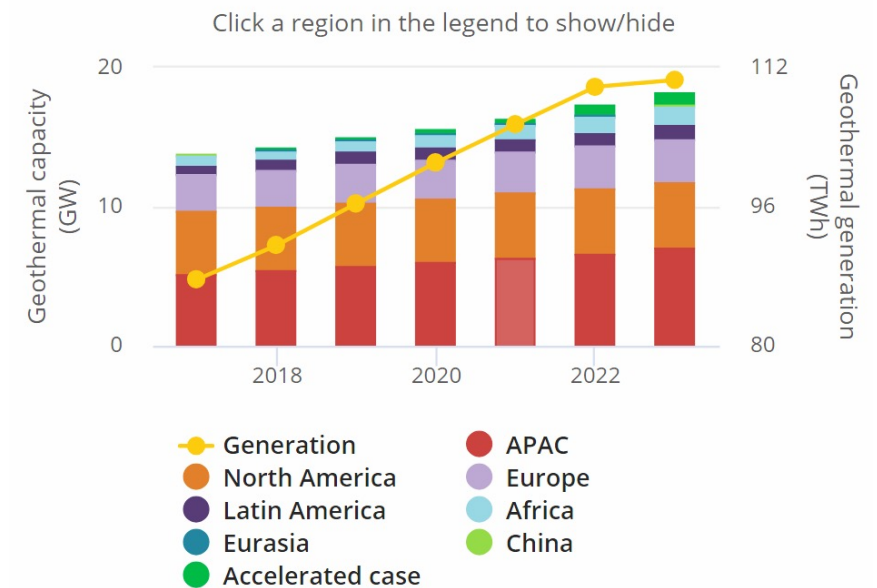
- **Geothermal wells:**

- Future of renewable energy – unending source of energy.
- Approximately 100,000 MWe [1] is predicted to be produced by Geothermal energy by 2050.

- **Challenges:**

- High pressure and high temperature (HPHT) conditions.
- Harsh chemical conditions in the geothermally active regions. Eg: Acidic brine, CO₂ Saturated fluids, H₂S etc.
- Temperature cycling due to influx of cold water from the plant and heat exchange from the geothermal formation producing steam.

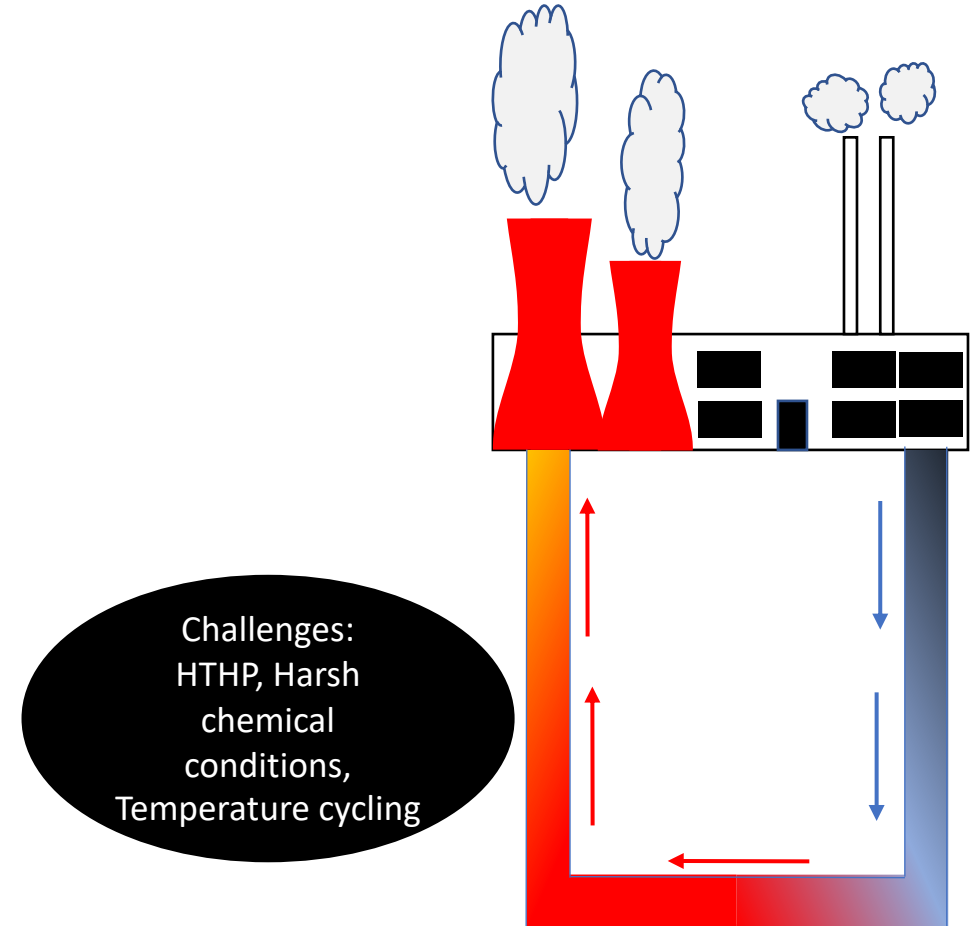
Geothermal power generation and cumulative capacity by region, 2017-2023



Source: https://geothermalresourcescouncil.blogspot.com/2018/11/finance-geothermal_13.html

Literature

- Many challenges faced by geothermal well cements [2,3]
- Addition of supplementary cementitious materials (SCMs) shown to enhance cement properties [4-6].
- Zeolite addition in cement had shown improvement in properties [7].
- Chemical stability of zeolites due to their geothermal origins could hold a key for enhancing cement stability [8].
- Zeolites have shown exceptional enhancements in cement properties compared to other SCMs [9-13]



Materials and methods

- **Materials:**

- Zeolite (Ferrierite(Fer)) rock used for the studies was obtained from Lovelock, Nevada, provided by the Trabits group.
- Class-H cement was obtained from Halliburton.
- KCFR-3 and D-air 5000 were obtained from Halliburton.
- Bentonite was obtained from performance minerals LLC.

- **Sample preparation:**

- Zeolite (Fer) was ground into fine micron sized particles ($\sim 95 \mu\text{m}$) to be added to cement
- Cement samples were cured in an Espec EGNL 12-4 NAL Environmental chamber at 90°C and 95% RH.
- Cut samples were polished using Allied Multiprep™ polisher to a uniformity of $\sim 0.1 \mu\text{m}$.
- Polished samples were dried for 24hrs after soaking them in Ethanol for 4-6 hrs.

- **Characterization:**

S.No.	Morphology and chemical analysis	Petrophysical properties	Mechanical properties:
1	SEM (Scanning electron microscopy)	Porosimeter (Porosity)	UCS (unconfined compressive strength)
2	EDS (Energy dispersive x-ray spectroscopy)	Permeameter (Permeability)	Triaxial test
3	Raman spectroscopy	Flow through system. (Future tests)	Micro-indentation.

Results (SEM)

- Morphology of cement matrix around a zeolite grain showing disjointed boundaries

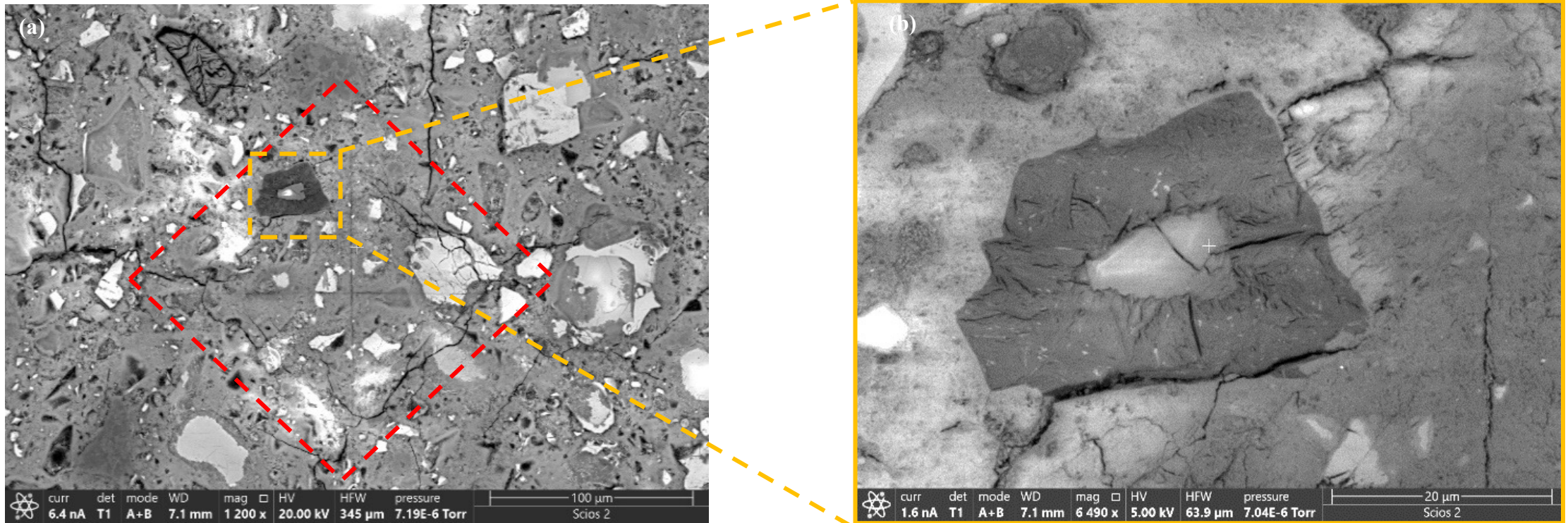


Fig-1. (a) An SEM image of an indenter mark on a polished uncoated 5% Ferrierite added sample. (b) A magnified SEM micrograph showing the ferrierite crystal right next to the indenter mark highlighting the failure of cement on indentation passing around the ferrierite crystal.

Results (EDS)

- EDS maps showing the phase stability of zeolite in the matrix after hydration

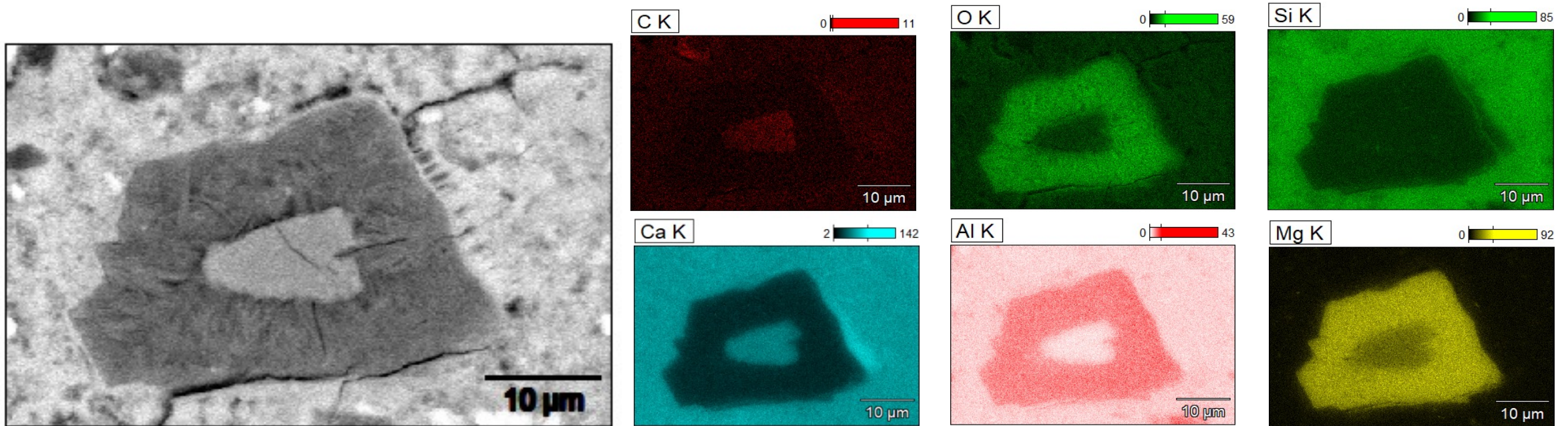


Fig-2. (a) EDS maps showing Aluminosilicate material (Zeolite) grain in the cement matrix. The grain interfaces need further high-resolution studies to show if Ferrierite has any pozzolanic activity like the other zeolites observed in literature.

Results (Raman)

- Raman maps showing the phase distribution and distinct ferrierite peaks in the plots.

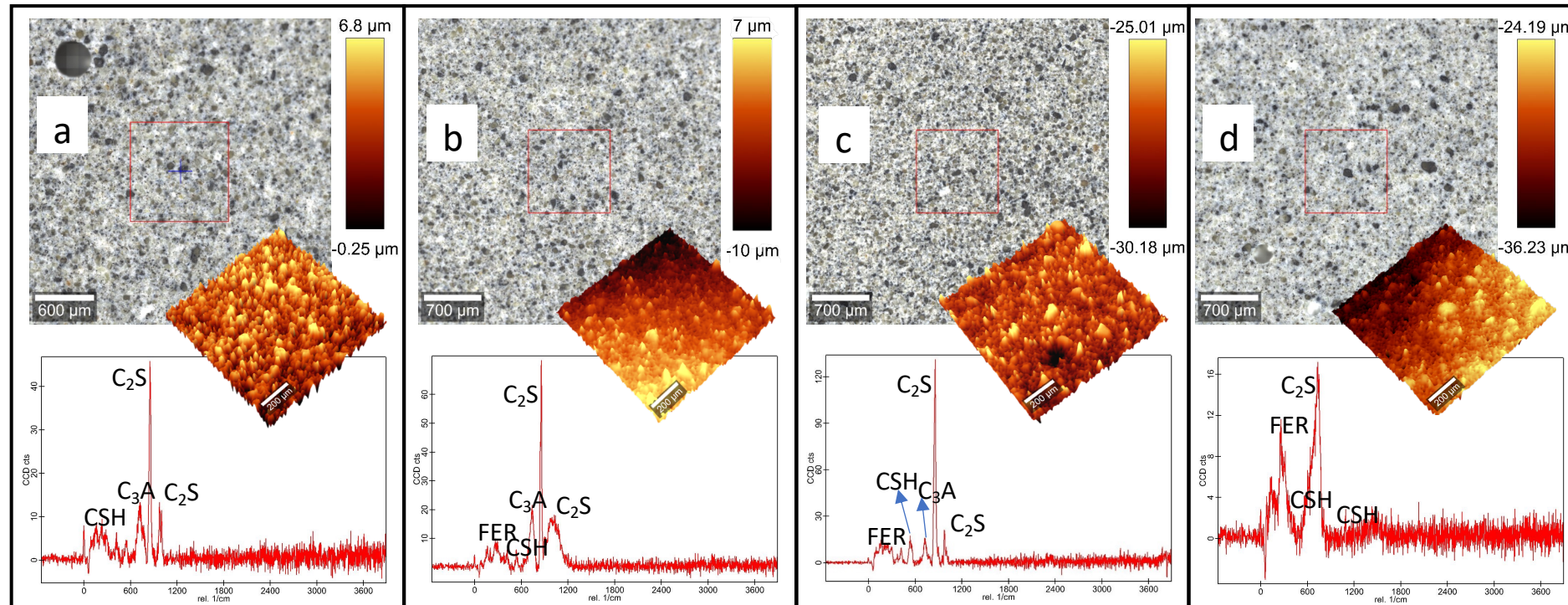


Fig-3. Raman results for polished cores Showing peaks for various cement phases : (a) Neat cement at 600-630nm,(CSH) 740nm, (C3A) 842nm and 972 nm(C2S) (b) 5% ferrierite added cement at 416nm,(Ferrierite) CSH ,C3A, C2S; (c) 15% ferrierite added cement- Ferrierite, CSH ,C3A, C2S ; (d) 30% ferrierite added cement Ferrierite, CSH (also at 1015nm), C2S. The ferrierite peaks observed fall in favor of the XRD studies done in earlier stages of this research which showed the phase stability of ferrierite which means that the ferrierite does not take part in hydration.

Results (Strength tests)

- Unconfined compressive strength (UCS) compared to hardness and elastic modulus results from indentation.

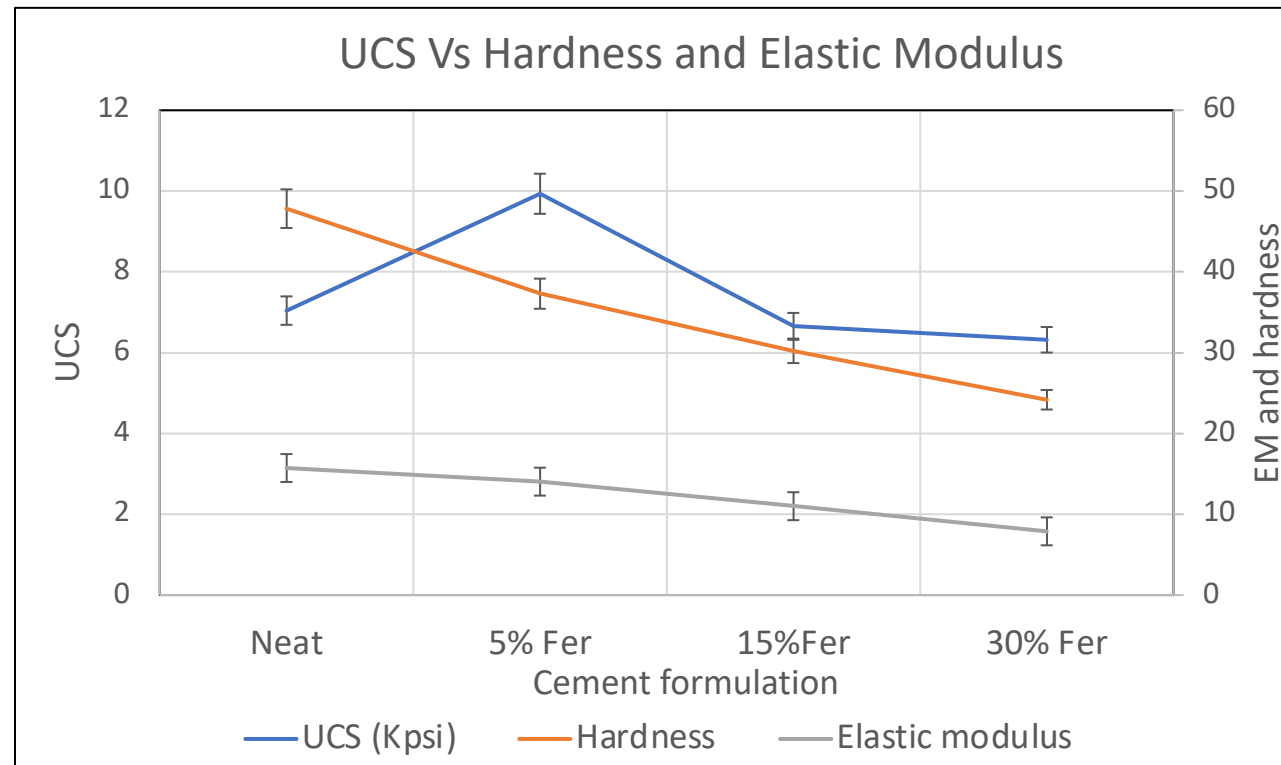


Fig-4. UCS Vs Indentation for Neat Class-H, 5%,15%,30% ferrierite added Class-H cement cores showing slightly similar trends. However, indentation is a representative of microscale properties and increasing the sample size affects the magnitude of the properties.

Results (Indentation)

- Indentation performed on a 5% Fer added sample which had the best UCS results.

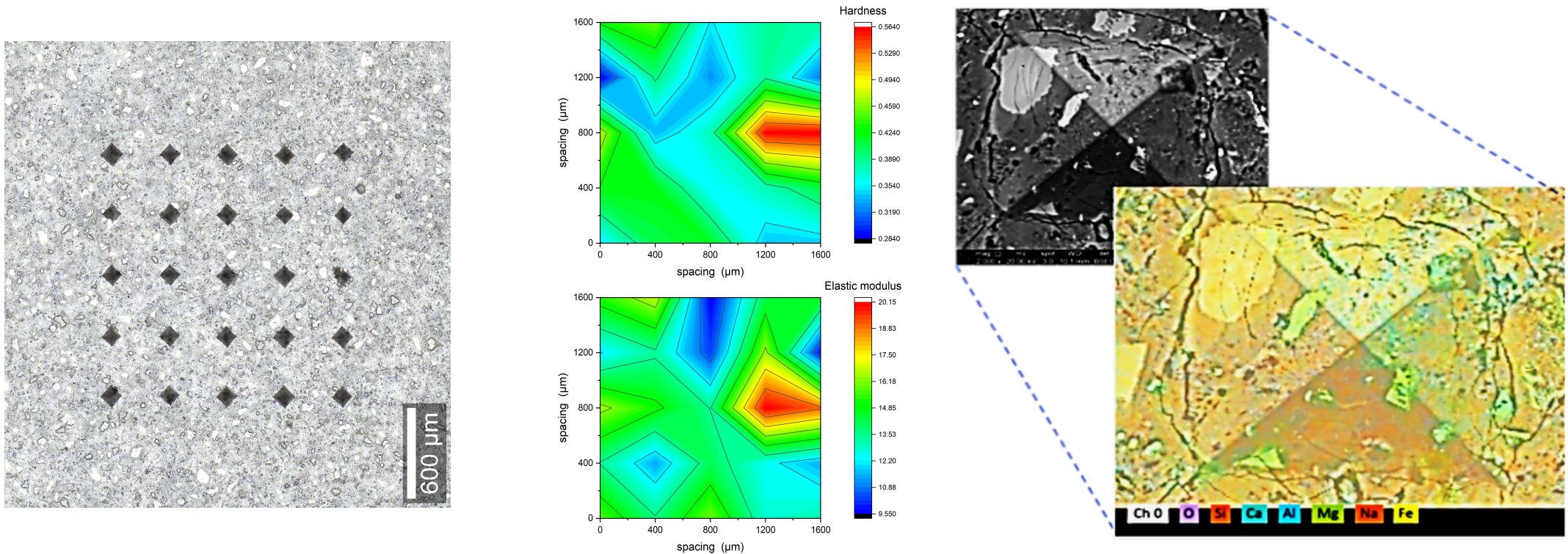


Fig-5. (a) Indentation results for 5% Fer added cement polished cores with 25 indents and maps of hardness (Avg 0.506 GPa) and elastic modulus (Avg 15.72 GPa). (b) An EDS map overlapping and SEM image showing a single indent. Indentation was done for all the formulations (for 5%, 15%, 30% ferrierite added Class-H cement) as well, and SEM and EDS studies are under progress to see if there is any noticeable surface chemical change on failure.

Results (Triaxial)

- Triaxial test results showing best performance for the 5% Fer added sample.

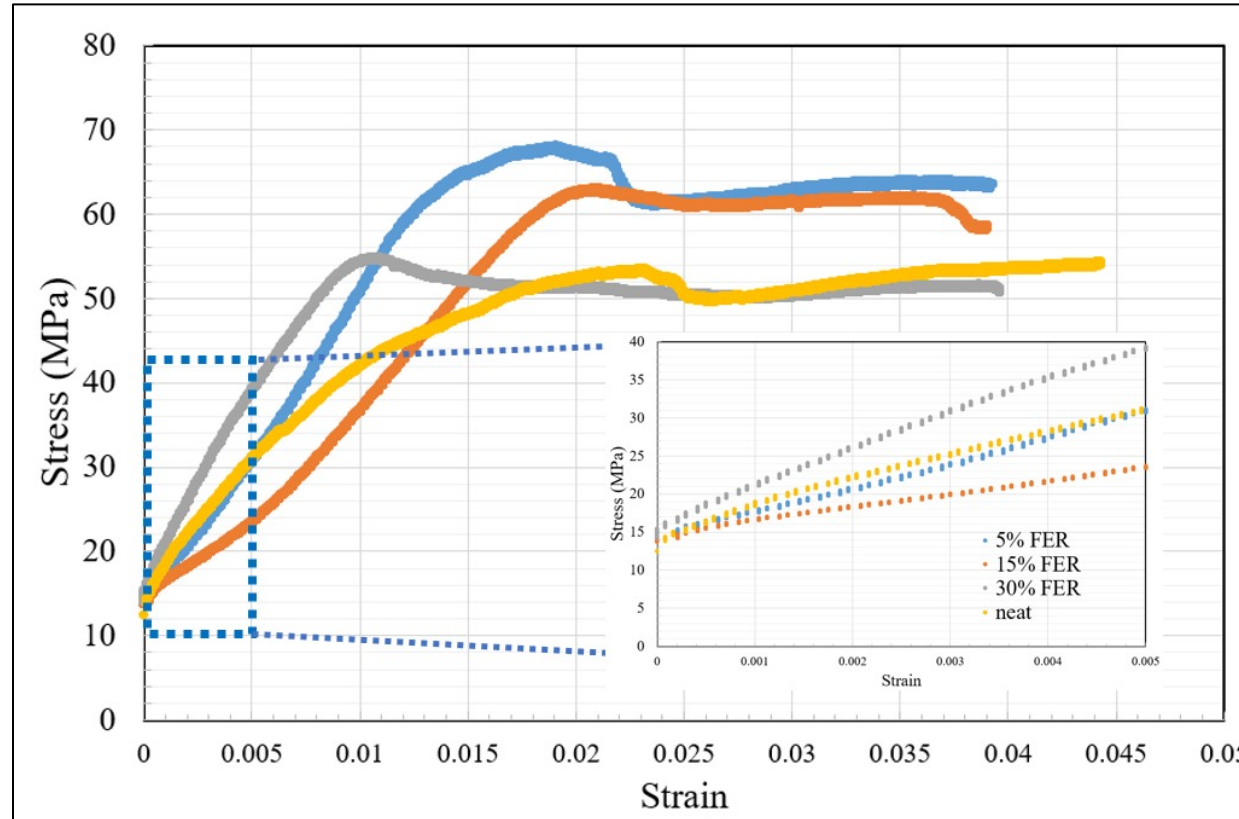


Fig-6. Triaxial test results for 5%, 15%, 30% ferrierite added and neat class-H cement at 13.7M.Pa and 90°C. 5% ferrierite added cement the highest axial stress which coincides with the UCS results showing a similar trend. The initial linear regime is shown in a magnified scale in the inset and the slope of this initial linear regime is used to calculate the Young's modulus.

Results (Petrophysical properties)

- Permeability and porosity measured for the 5%, 15% and 30% Zeolite (Fer) added cement samples

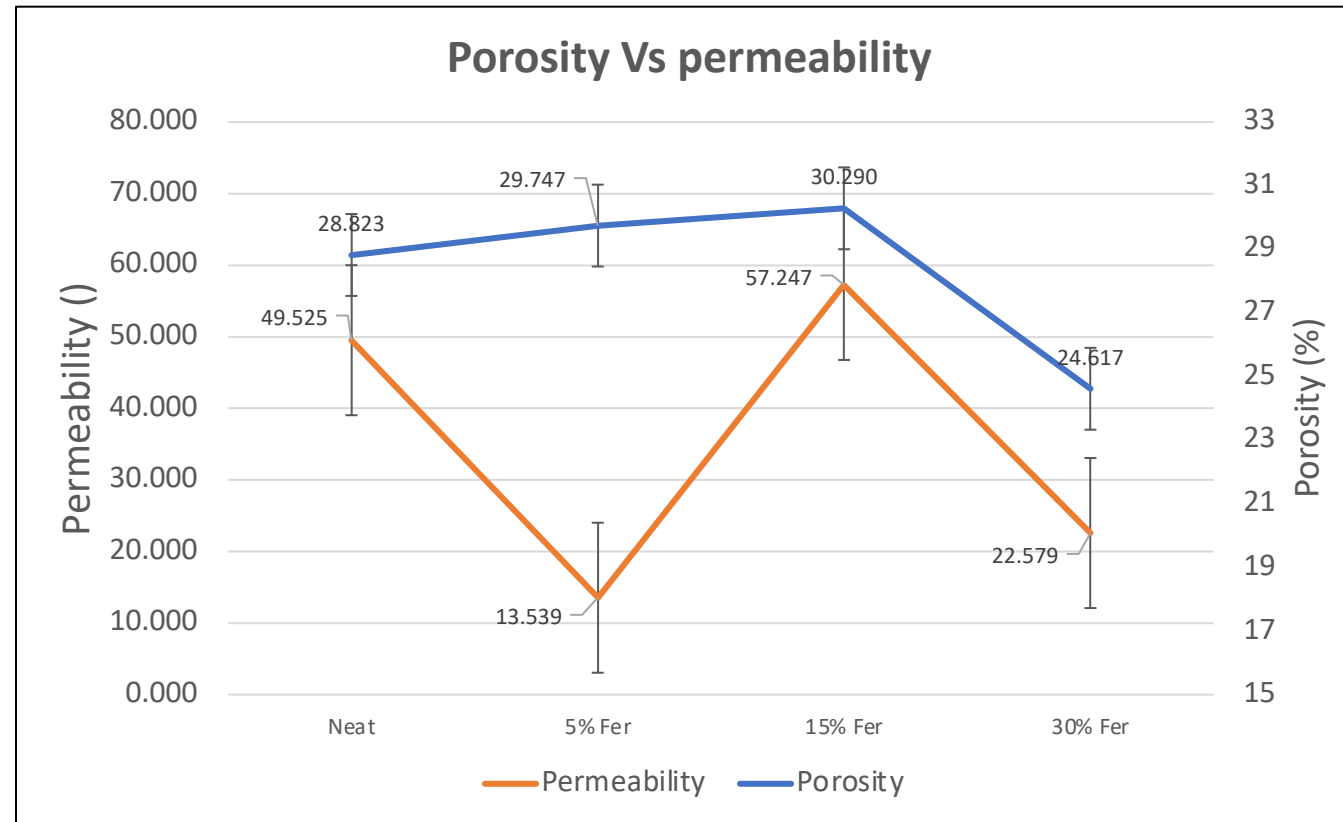


Fig-7. Average porosity and permeability values of 5%, 15%, 30% ferrierite added, and Neat class-H cement measured using Corelab ultrapore 300 porosimeter and Nanoperm permeameter

Discussion

- SEM,EDS and Raman studies show the phase stability of zeolites in cement.
- UCS and Triaxial tests indicate superior performance in 5% ferrierite added cement.
- Indentation results show optimum results of hardness and elastic modulus for 5% Fer added cements.

	Indentation		Triaxial		UCS
	Hardness (Gpa)	EM (GPa)	Axial peak stress (psi)	EM (GPa)	Comp. strength (psi)
Neat	0.506	15.72	7730	9.65	7041
5% Fer	0.394	14.03	9882	8.82	9934.3
15% Fer	0.319	11.006	9133	7.72	6652
30% Fer	0.256	7.88	7944	11.29	6319

- Permeability is also superior in cores made of 5% Fer added cement slurry.
- Porosity is gradually increasing for increasing amounts of zeolites but decreases for 30% Ferrierite added cement owing to its increased water to cement (w/cm) ratio due to correction from absorbed water in zeolite pore structure.

Future work

- Aimed at understanding the self healing in zeolite added cements for geothermal applications.
- More in-depth studies into superior performance of 5% Ferrierite added cement
 - Grain boundary studies, hydration properties, effect of pore water from zeolites.
- Petrophysical properties studied after exposure to geothermal conditions (Flowthrough etc.)
- CT studies of fractured cores after Triaxial tests to get a better understanding of the failure mechanisms of zeolite added cement.



Thank you

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