U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Development of an Improved Cement for Geothermal Wells

Project Officer: Eric Hass   Total Project Funding: $2,154,238

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Principal Investigator

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Track 2 Materials

Relevance/Impact of Research

Project Objective

- Develop a novel, zeolite-containing lightweight, high temperature, high pressure geothermal cement, which will provide operators with an easy to use, flexible cementing system that saves time and simplifies logistics.

Impact of New Cement Development

- Eliminate the requirement to “sterilize” pumping equipment before use.
- Eliminate the need to foam the slurry to achieve lightweight qualities.
- Eliminate incompatibility issues in the selection of retarders and accelerators.
- Provide predictability and minimize the effect of down-hole temperature fluctuation.
- Facilitate the development of geothermal resources in remote locations.

Scientific/Technical Approach

Methodology

- Build on existing zeolite-containing cement technology for low temperature, weak formation applications.
- Systematic, scientific approach on trial cement blends to consider the variables of:
  - Zeolite type
  - Zeolite particle size
  - Zeolite percentage by weight of cement
  - Additives for thermal stability and resistance to carbonation
- Clear and concise performance characteristics provide a systematic method for initial screening, second stage development and ultimately for the final stage of cement development.
- Involvement of industry for guidance on actual cementing practices.
- Solicit industry expert peer review on research methods and results.
- This logical progression of scientific study results in five Tasks that lead to realistic project milestones and go / no-go decisions points.

Scientific/Technical Approach

TASK 1 – RESEARCH
- Literature Search
- Geothermal Cementing Practices and Constraints
- Mechanisms of Geothermal Well Failure

TASK 2 – DESIGN
- Compile Research Findings
- Modification of Project Tasks 3 and 4

TASK 3 – DEVELOP
- Zeolite Sample Acquisition
- Zeolite Type Confirmation
- Zeolite Particle Size Preparation
- Initial Screening of Cement Formulations

TASK 4 – TEST
- Second Stage Cement Development
- Final Stage Cement Development

TASK 5 – DEMONSTRATE
- Laboratory Scale Demonstration
- Logistics and Ease of Use Field Demonstration – Chena Hot Springs Resort
- High Temperature EGS Well Demonstration – Ormat Technologies

Accomplishments, Results and Progress

Original Planned Milestone/ Technical Accomplishment		Actual Milestone/Technical Accomplishment	Date Completed
Task 1	Research	Completed as planned	July 2011
Task 2	Design	Ongoing Task	Ongoing
Task 3	Develop	Completed as planned	Oct.2012
Task 4	Test	Second stage HPHT cement development started	In Process
Task 5	Demonstrate	Resistance to carbonation started	In Process

Variances

- Industry partner ThermaSource was unable to participate resulting in loss of cost share and lab testing equipment availability.
- Schedule slippage resulting from delays in the fabrication of Chandler Engineering specialized high pressure/high temperature cement testing equipment.

Accomplishments, Results and Progress

<u>Zeolite Preparation</u>

- Five zeolites types were selected for cement properties screening.
- Following XRD, XRF and SEM confirmation of zeolite type three hundred pound bulk samples were shipped to CCE Technologies for preparation.
- Micronized using Jet Mill Technology.
- Prepared sizes with 80% in range:
  - 5 micron
  - 10 micron
  - 44 micron
- Alternate 44 micron prepared using Collider Mill Technology

A systematic series of tests were run using the 5 primary zeolites. Each zeolite was tested for three particle sizes: 5 µm, 10 µm, and 44 µm. For each particle size, tests were conducted at 15%, 27.5%, and 40% cement replacement by zeolite. Screening test were conducted at 13.5 ppg density.

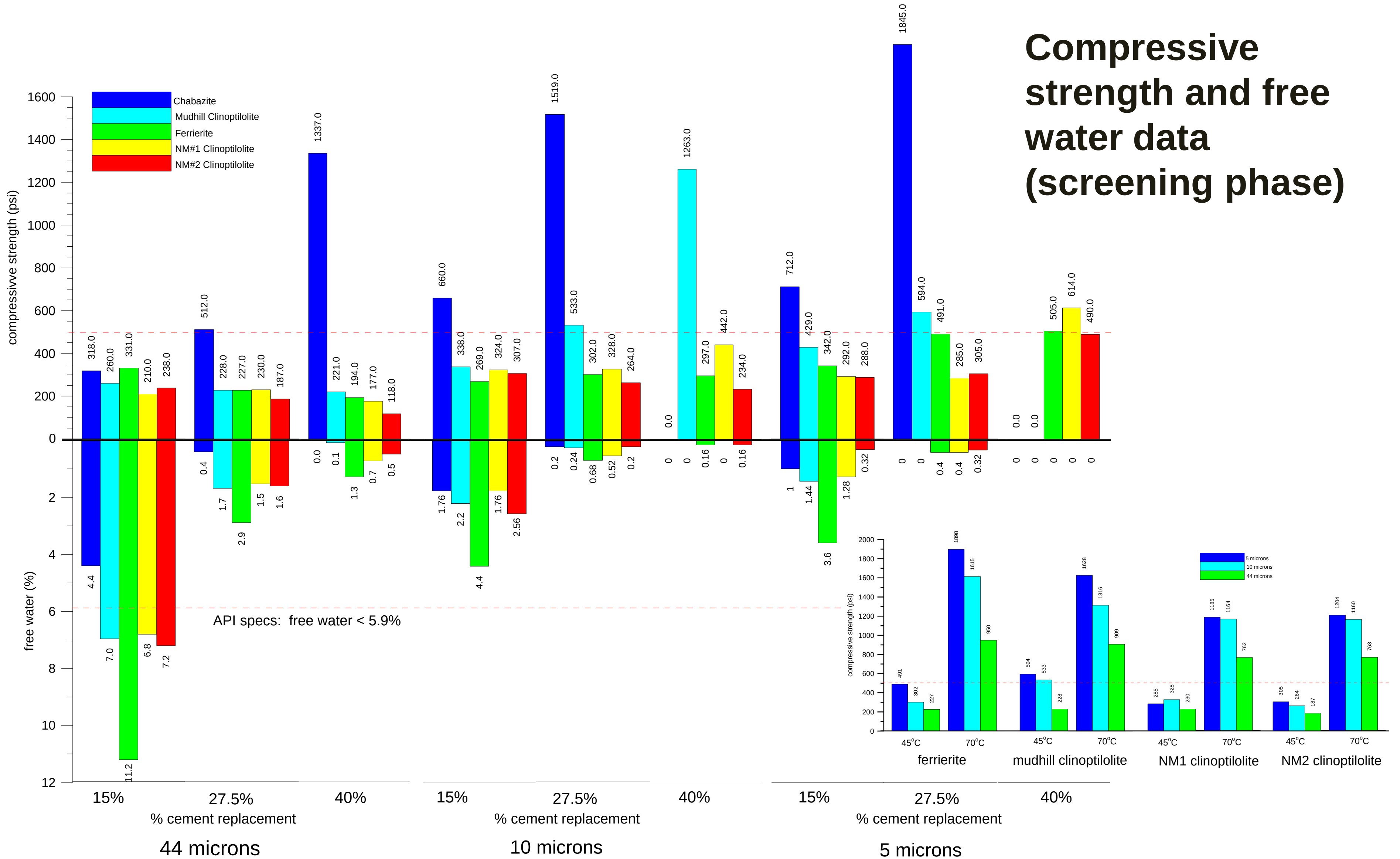
Primary Screening Criteria:

- **24 hour compressive strength: 500 psi**
- **Free water: less than 5.9% (API Specs)**
- **Thickening time**
- **Consistency**

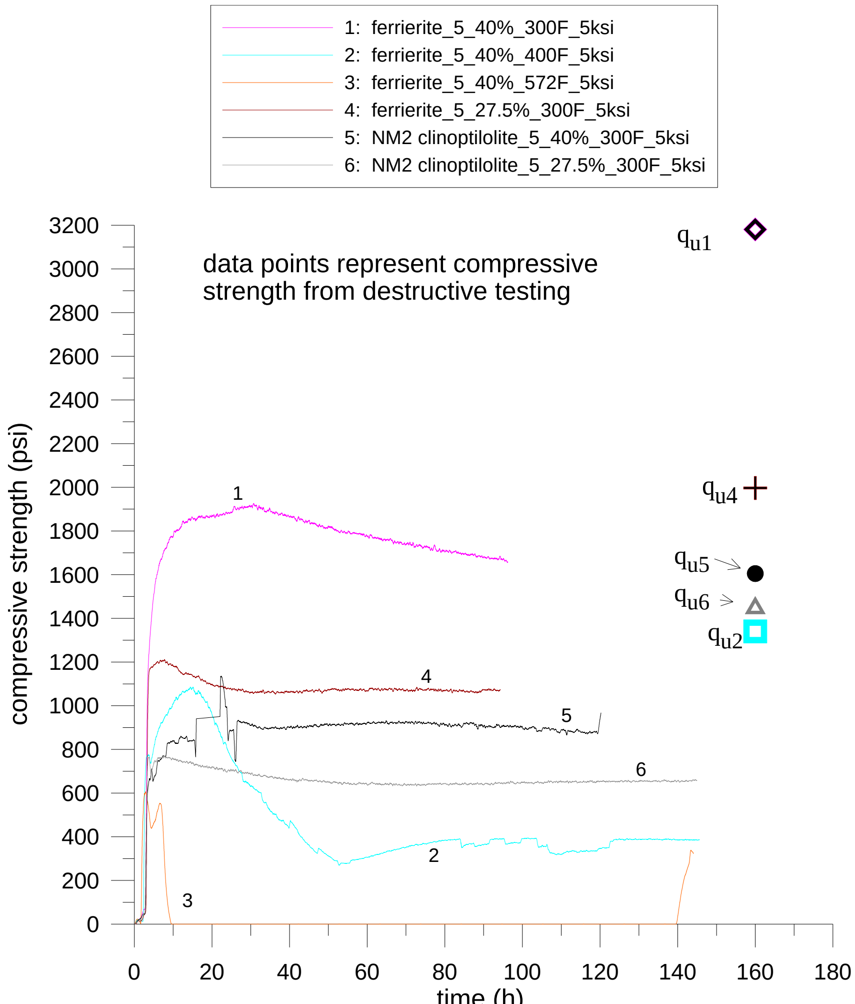
Evaluate zeolites

chabazite	Good properties, not retained due to high cost.
ferrierite	Passed criteria for particle size <10 µm, **Retained.**
Mudhill clinoptilolite	Passed criteria, not retained due to small size of deposit.
NM1 clinoptilolite **NM2 clinoptilolite**	NM1 and NM2 exhibit nearly identical properties and test response. Meets strength criteria at 70°C and fine particle size. Economical and adventitious deposit. **Retained.**

Compressive strength and free water data (screening phase)



Ferrierite and NM2 clinoptilolite were advanced to the HPHT testing phase along with pozzolanic additives including diatomaceous earth



- Plot shows real time UCA compressive strength data along with the destructive compressive strength for base zeolite/cement mixes (27.5% and 40% replacements).
- UCA data under predicts the compressive strength, but provides strength development trends.
- Results suggest ferrierite offers increased strength over clinoptilolite. However, recent data suggest with increasing temperatures, clinoptilolite may not show the sharp decrease in strength observed for ferrierite.
- To date, all mixes provide adequate compressive strength up to 400^{o}F
- Elastic properties are similar between the ferrierite and clinoptilolite.

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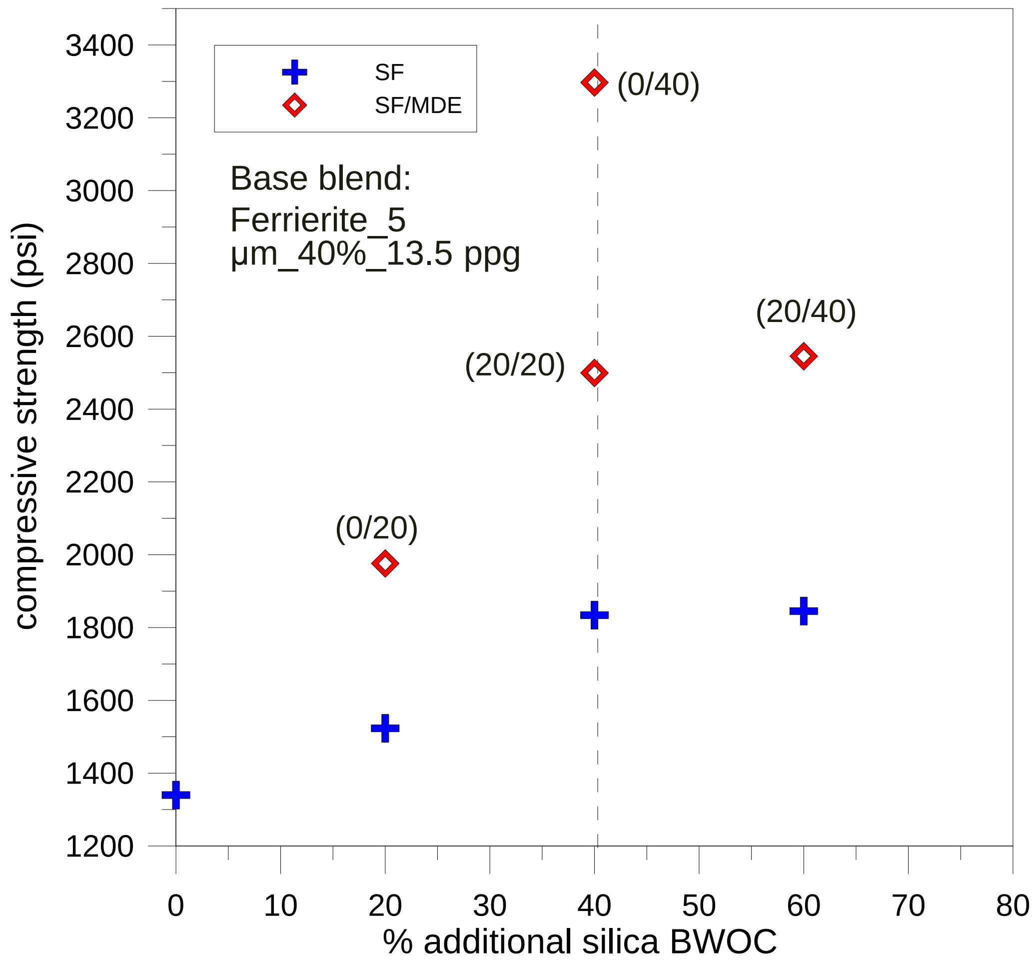
Addition of Silica for Thermal Stability



- Two silica sources were tested including silica flour (crystalline) and diatomaceous earth (amorphous)
- Test conditions: 400°F for 7 days
- Silica flour: confirms literature sources suggesting 40% BWOC is necessary for thermal stability. This is also confirmed by UCA data.
- Diatomaceous earth: increases the compressive strength and modulus of elasticity
- The long term affects of diatomaceous earth are unknown , but intriguing .

Note: for figure, values in parenthesis indicate (% silica flour/% diatomaceous earth)

Accomplishments, Results and Progress

HPHT Consistency

Sample	retarder	Time (min) 30 Bc	Time (min) 70 Bc
Ferrierite_10µm_40%	base, no retarder	21	57
	Baker Hughes R8 1.3% BWOC	91	104
	citric acid 1% BWOB	61	91
	citric acid 1%: 3% Borax BWOB	peak 36 min, post peak drop	>22 hrs
	citric acid 0.6% : 1.5% Borax BWOB	36	63
	tartaric acid 0.5% BWOB	177	228
	tartaric acid 0.6% BWOB	256	338
	tartaric acid 1.0% BWOB	peak (40-60 min), drop then 910 min	>16.5 hrs.
Ferrierite_10µm_27.5%	base, no retarder	57	63
	tartaric acid 0.5% BWOB	619	662

Example of consistency data using 300°F results

At higher temperatures, the cement slurries require retarders to extend workability times. The aluminous nature of zeolites shortens working times due to early reactions. A basic principle of the study is to limit the amount of chemical additives to broaden the applicability the cement. We have been targeting generic, non proprietary retarders focusing on hydroxycarboxylic acids and borax. The hydroxycarboxylic are effective at 300°F. The addition of borax is necessary at higher temperatures. The addition of borax creates setting issues.

Carbonation vessels

Carbonation Studies

- Cement samples are being tested under CO_2 fluid conditions. The base zeolite mixes as well as mixes with additional silica are being tested. Research on carbonation suggests that high silica additions for thermal stability may promote enhanced carbonation.
- Cement samples are being cured in formation fluids from the Ormat Brawley geothermal field. These test run from 1 to 3 weeks. The fluid contains a 1.5% CO_2 content and high mineral content.
- Samples are initially cured at high temperatures up to 572^{o}F (300^{o}C) and further cured in the brine and CO_2 fluids at 350^{o}F.

Future Directions

- Data is being extended to 572^{o}F (300^{o}C) for base mixes and the addition of various silica sources.
- Both the ferrierite and clinoptilolite have met the basic criteria up to 400^{o}F.
- Further work needs to conducted on compatible retarders at temperatures above 400^{o}F. Commercial retarders may be necessary.
- Fluid loss is an issue. The effectiveness of additives will be explored.
- High demand pozzolanic additions such as diatomaceous earth and clays may accommodate cement slurries at densities below 13.5 ppg.
- X-ray diffraction and SEM analysis will be conducted on the hydrated cement samples for quantitative analysis of the phase assemblages.
- The phase assemblages may allow for extrapolation of the stability of the cement to longer time periods.
- Extension of the material properties data is an ongoing process.

Summary

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- The project is in keeping with Goal 2 of the MYRDD Technical Plan to develop low-cost, high-efficiency well construction which includes completion technology.
- The developed high temperature, high pressure geothermal cement, will provide operators with an easy to use, flexible cementing system that saves time and simplifies logistics.
- Systematic, scientific study is organized into five Tasks that lead to realistic project milestones with clear and concise performance characteristics.
- Primary screening tests completed on trial cement blends using 5 zeolite types each at 3 particle sizes (5µm,10µm and 44µm) and each at 3 percentages (15%, 27.5% and 40%) of replacement.
- Two zeolite types advanced to Second Stage cement development with HPHT blend testing in process.
- Effects of carbonation testing in process using actual brines from Brawley geothermal well.

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
1/29/2010	12/31/2012	3/27/2010	9/30/2013

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$2,154,238	$538,557	$2,080,778	$2,094,403	$2,045,258	$762,837

- Cost share lost with ThermaSource withdrawal has been totally offset by in-kind cost share from new industry participants.
- ThermaSource cement testing equipment that became unavailable to the project has been purchased by the project and installed at the University of Alaska Fairbanks (UAF) Petroleum Development Lab.
- Established a regular monthly Peer Review of research methods and results.
- Enlisted the guidance of industry partners in actual cementing practices and constraints.
- Coordinated training of UAF students in testing methods and equipment at industry partner labs in Bakersfield and Rock Springs.
- Project Update presentations to industry associations and industry partners.