SWELLABLE PROPPANTS FOR IN-SITU STIMULATION

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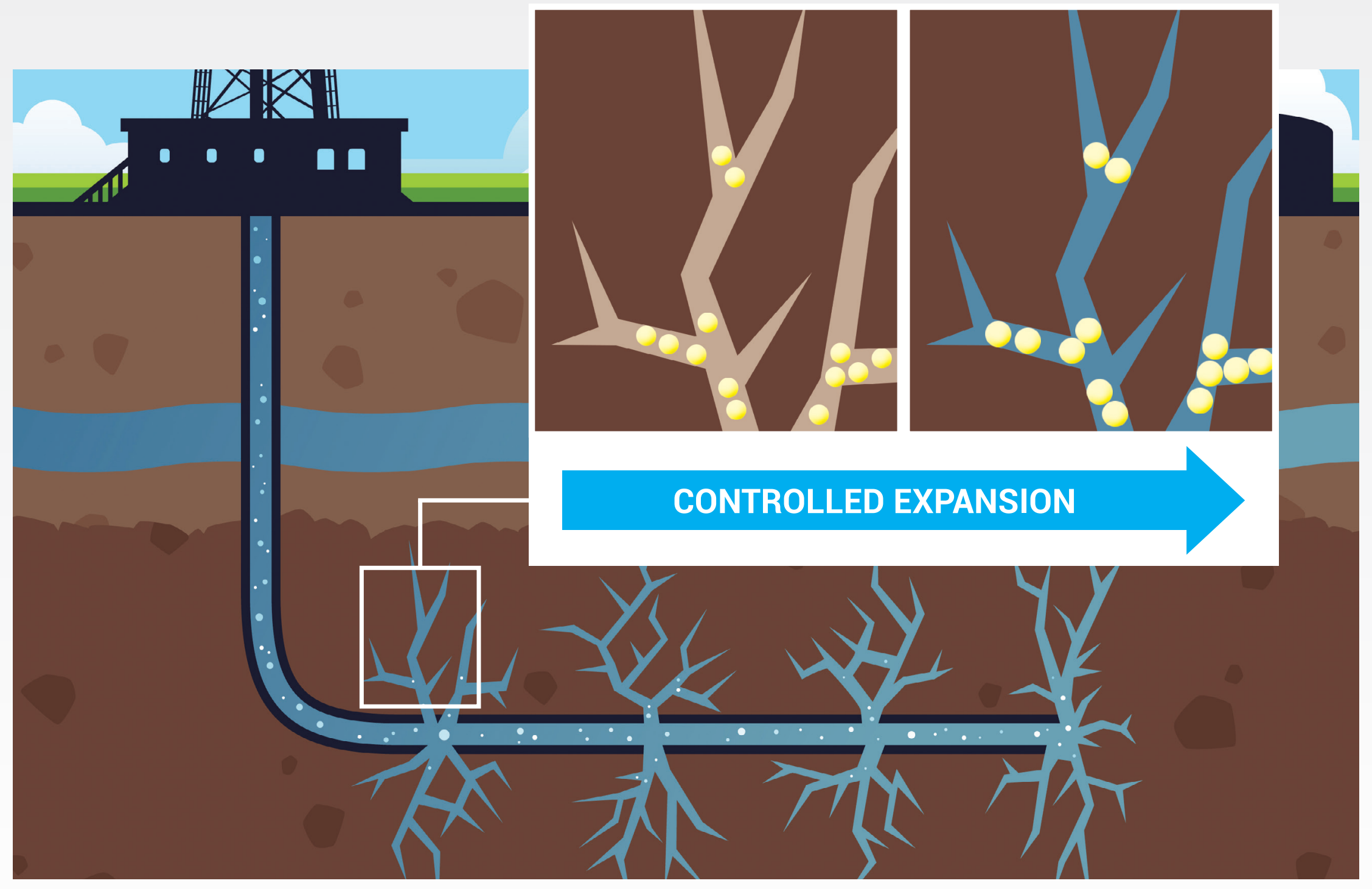
INTRODUCTION

The extraction of resources from geologic formations, including geothermal energy, oil and gas, and in-situ mineral recovery relies on the ability to communicate hydraulically (through fluid) with the formation. Many, if not most, of these formations must be accessed through relatively low permeability rock. Extracting these resources requires gaining access through drilling and stimulation (enhancing fracture conductivity) techniques. The ability to characterize, develop, and control complex fracture networks through geologic formations is essential to the extraction of geologic assets. It is estimated that >50% of the rate decline in the production of oil and gas from tight reservoirs is due to closure of unpropped fractures due to natural closure forces as fluids are removed from the fractures. Hydraulic stimulation is used to create and extend fractures to create a greater drained area at great expense, while proppants and acid treatments are used to maintain conductivity. The ability to initiate, extend, maintain, and control fracture formation and conductivity over the life of a well is essential to improved efficiency in subsurface development.

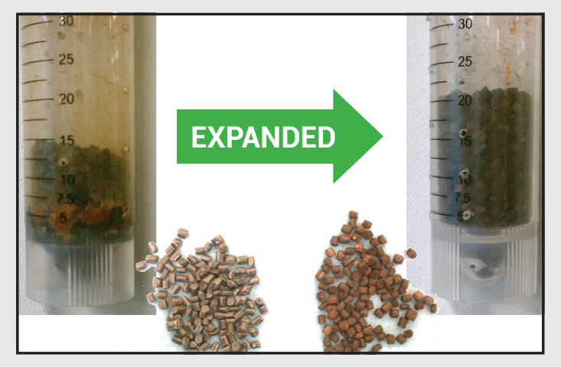
This project is investigating the formation, application, and subsurface and production effects of novel, high modulus, swellable (expandable) proppants. The development of multifunctional proppants, such as expandable proppants, can be enabling in development of subterranean resources. Expandable proppants are theorized to provide the following benefits:

- **Enhanced transport:** smaller, lighter proppants can be transported farther into the formation, and into fractures perpendicular to main flow channels.
- **Fracture Initiation and extension:** Expandable rigid proppants with GPa modulus can apply 1000-10,000(+) PSI force while retaining permeability and fluid access. These forces are sufficient to initiate and extend fractures.
- **Offset closure forces:** Expanding proppants can apply force, and increase contact area to offset embedment and closure forces, shifting the production decline curve.
- **Control proppant flowback:** Expandable proppants can be used to quickly lock in proppant packs, reducing or preventing proppant
- **Impart and control formation stresses.** The targeted delivery of force can be used to manipulate formation stresses

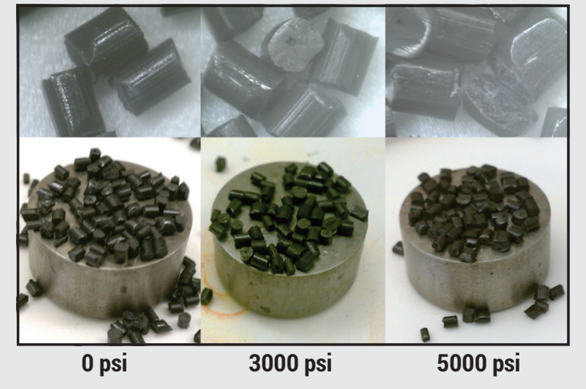


FABRICATION

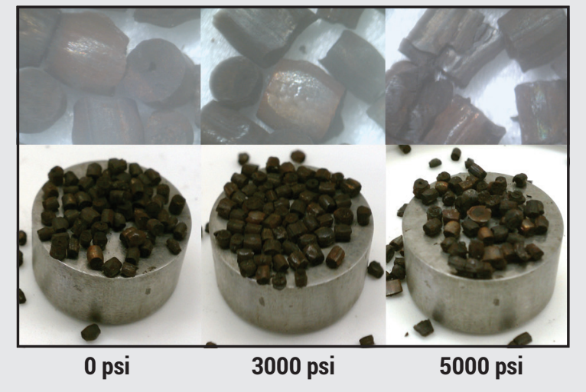
Swellable proppants are prepared as a nanocomposite of a water-reactive metal or compound with a hydrolysis-resistant polymeric binder. The original proof of principle used iron particles in a polysulfone polymer, appropriate for 150-180°C formation conditions. Above about 150°C under anaerobic conditions, the iron reacts with water and forms black Fe3O4, undergoing a 217% volumetric expansion. Other reactions evaluated included hydration of oxides such as CaO and MgO, hydration of lamellar materials such as clays, and hydration/oxidation of reactive metals such as Zn, n-Si, and Ca. Different polymers including epoxies, nylons, polycarbonate, and polyurethanes were evaluated for stability and properties. For typical oil and gas conditions of 70-90°C, CaO-epoxy systems were selected for further development.



UNEXPANDED PROPPANT, Without Reinforcement



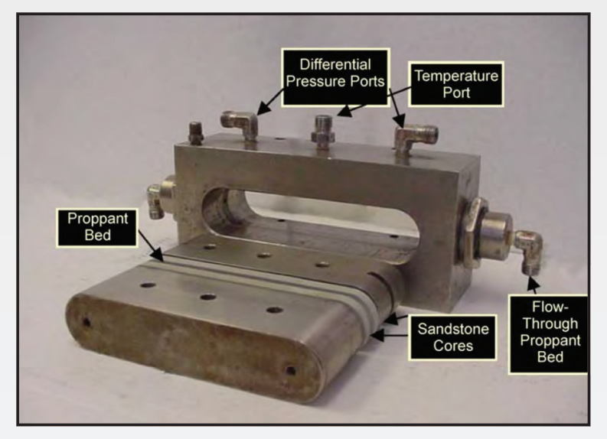
EXPANDED PROPPANT, Without Reinforcement



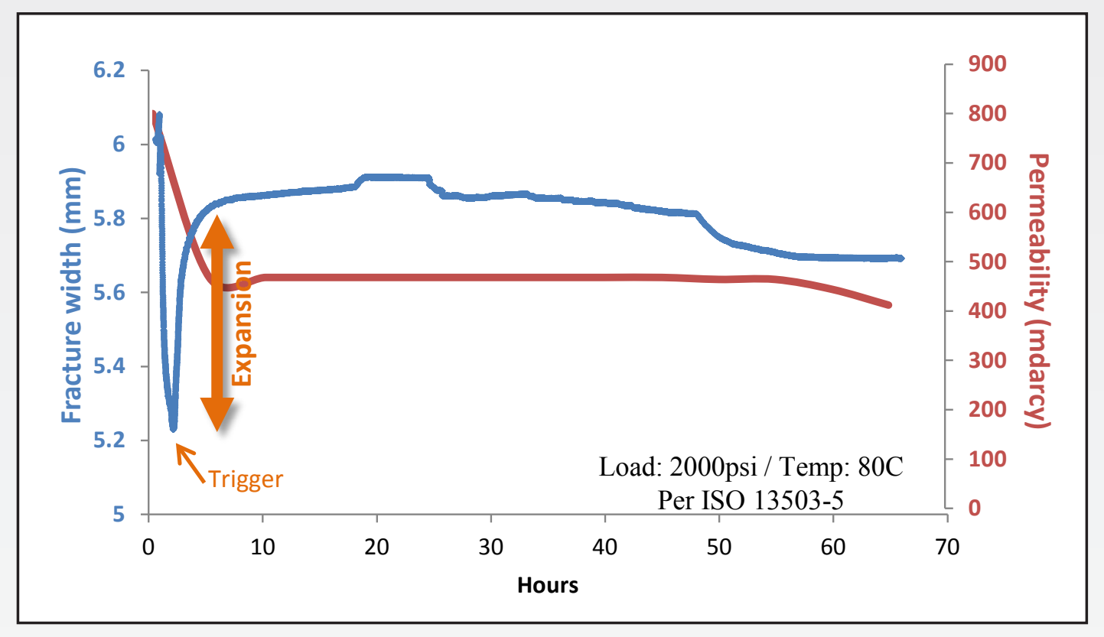
Spherical proppants using bead-forming technology, and proppant expansion of beads.

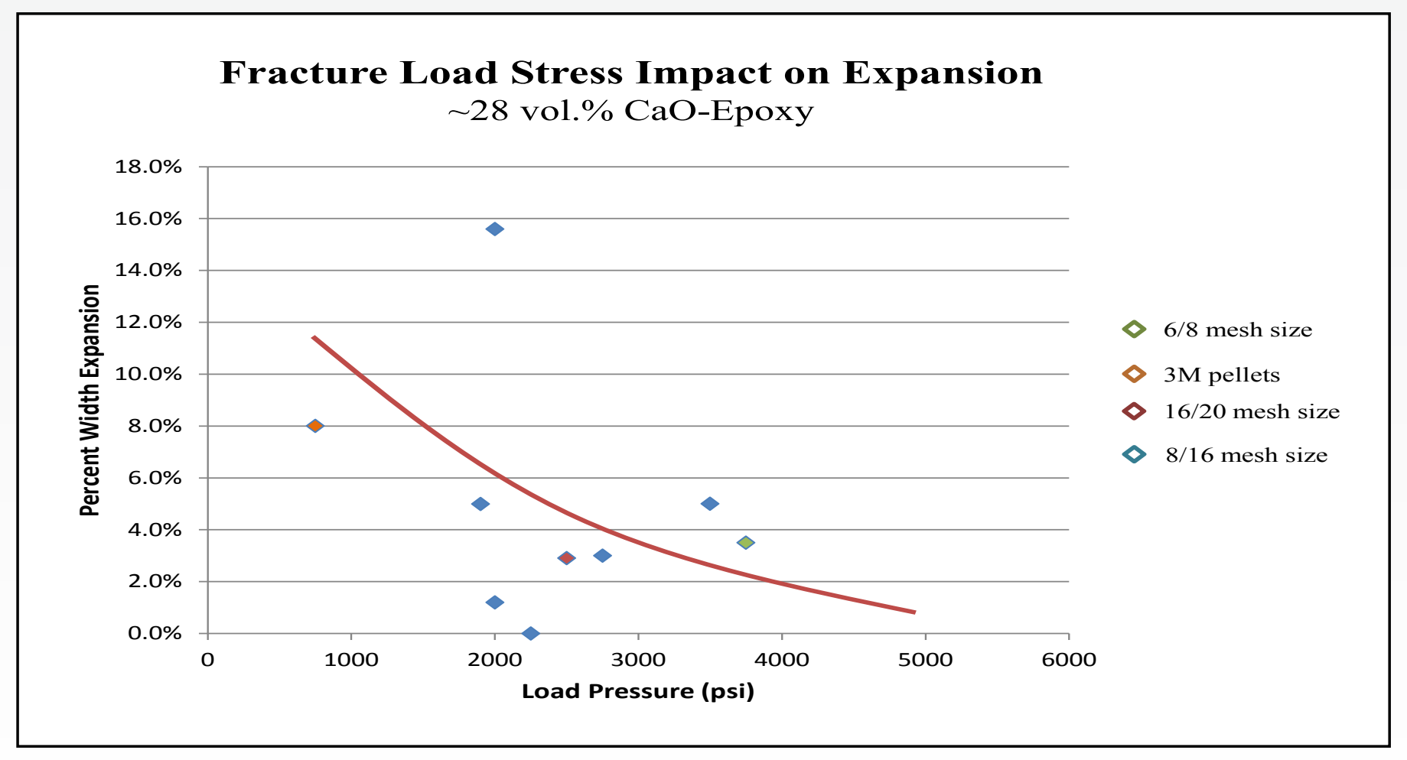
API CONDUCTIVITY TEST CELL RESULTS

An API conductivity test cell was fabricated and used for conductivity tests. The press was modified to enable a constant load to be applied while enabling expansion of the platens, which were instrumented with extensometers.



API conductivity test cell results showing expansion under loan and permeability retention





Effect of closure force on fracture width expansion for 28% CaO-epoxy swellable proppant

SIMULATION AND MODELLING

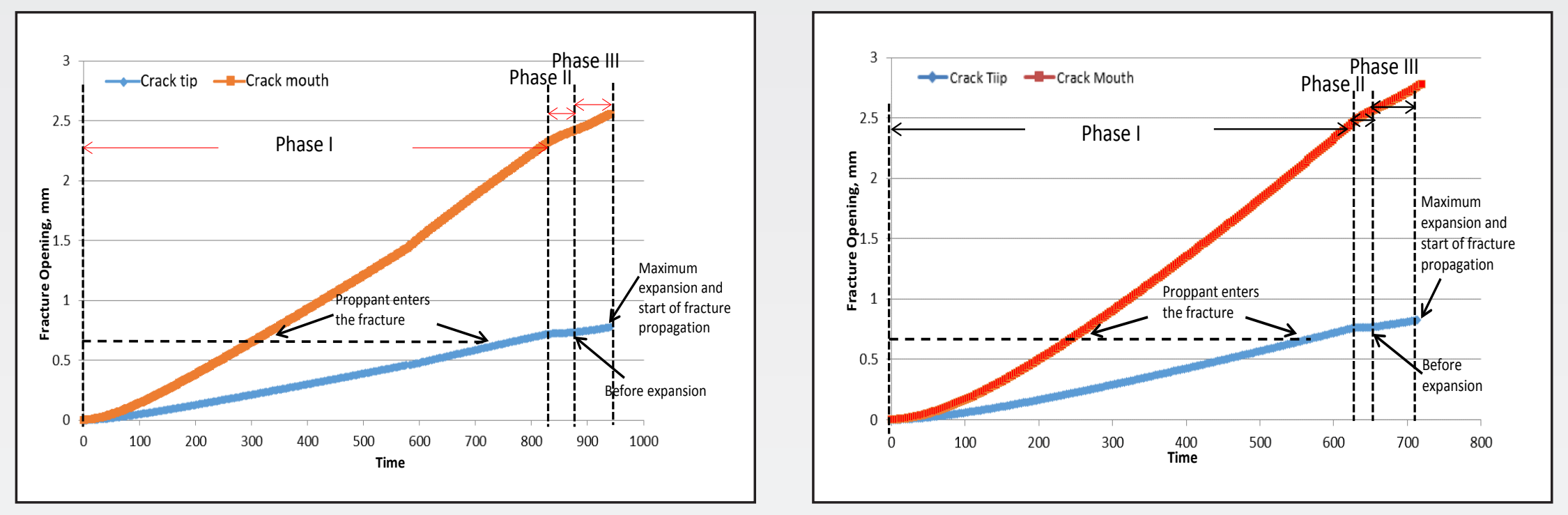
A rigid sphere model was developed to evaluate effective porosity and safety margins of baseline XOProp™ versus commercially available ceramic and ultralight proppants.

Proppant size: 400 micron Fracture Load: 2,000 psi	Elastic Modulus	Yield Strength of the Proppant	a *(load press contact face, radius)*	Applied load to proppant face full cubic packing	Percent failure over load	Porosity
	Gpa	Mpa	inches	psi		
Fused Silica	41	1108	0.000918045	187328.2273	17%	0.209209
Bauxite (Al2O3)	165	2100	0.000577161	473954.4606	56%	0.212483
Nylon 6	2.3	55	0.002398185	27451.48711	244%	0.175246
Polycarbonate	2	70	0.0002512554	25009.24893	146%	0.171279
FracBlack (ROM theoretical ave. upper and lower)	4	125	0.001994215	39699.70805	119%	0.188132
XOProp (ROM theoretical ave. upper and lower) epoxy + CaO (20% vol)	9.37	162	0.00150157	70022.94616	198%	0.199919
XOProp expanded (experimental)	2.51	75	0.002328673	29114.83238	169%	0.177824

The impact of using expandable proppant on well production was simulated using production simulation by FracGeo, using its geosimulation codes. Contributions from crack extension were analyzed, as well as increasing fracture width in slowing the decline curve by offsetting crack closure due to formation stresses. Using estimated closure-stress applied over time due to fluid depletion versus fracture width and permeability, production curves for a typical carbonate unconventional formation were simulated.

FRACTURE EXTENSION

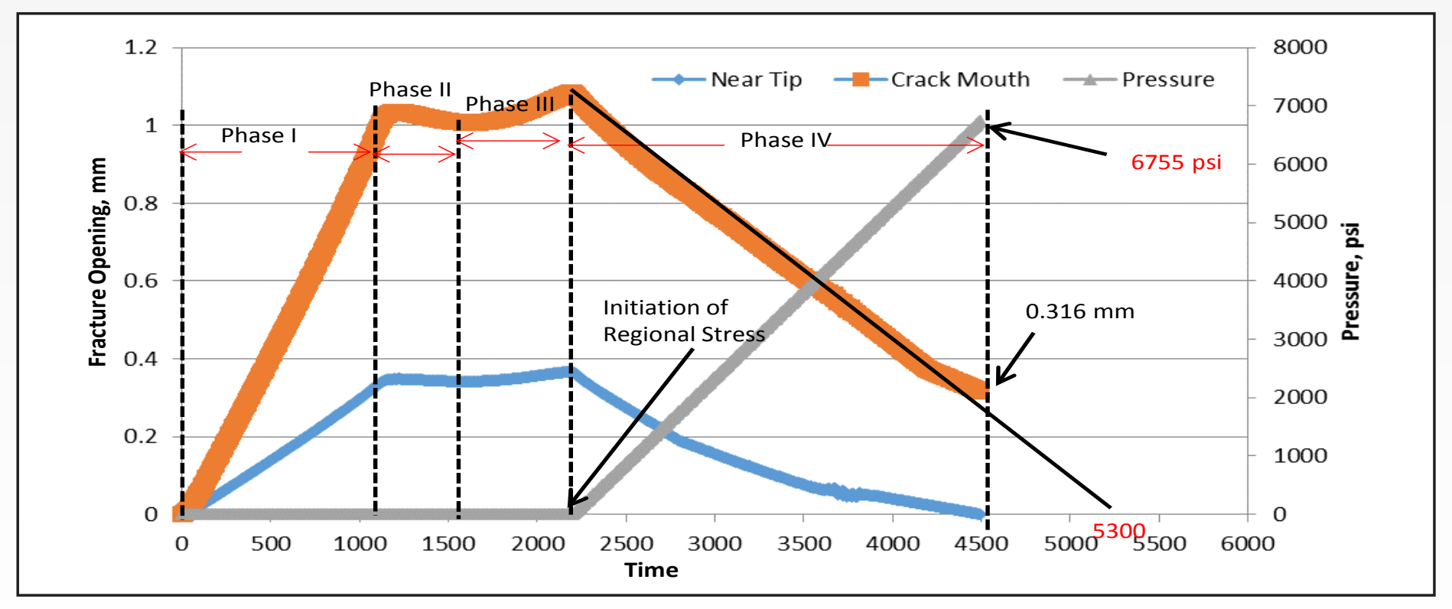
Extending fractures offers the opportunity to intercept high angle natural fractures and enhance the amount of formation accessed by stimulation. Three phases of natural fracture expansion: **Phase I** - fracture opening and proppant transport due to hydraulic forces, **Phase II** - fluid removal/drawdown, fluid pressure equal to closure force. **Phase III** - fracture opening due to proppant expansion.

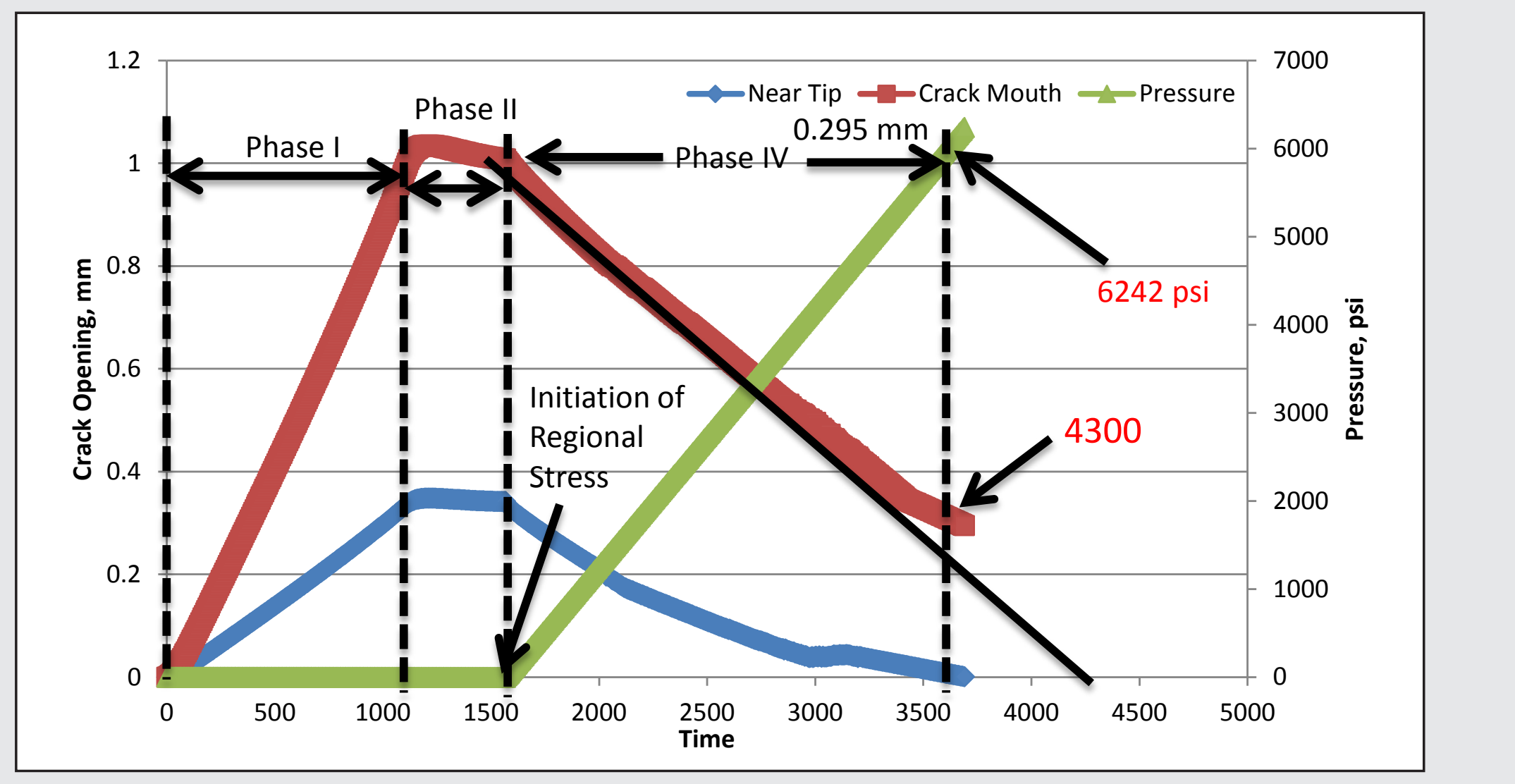


Increase in fracture opening during proppant placement, flowback, and expansion for 45 and 30 degree natural fractures

OFFSETTING EMBEDMENT

A major issue with softer formations is the embedment of proppants into clay-bearing or more flexible systems. Empirical Exxon embedment data was used.

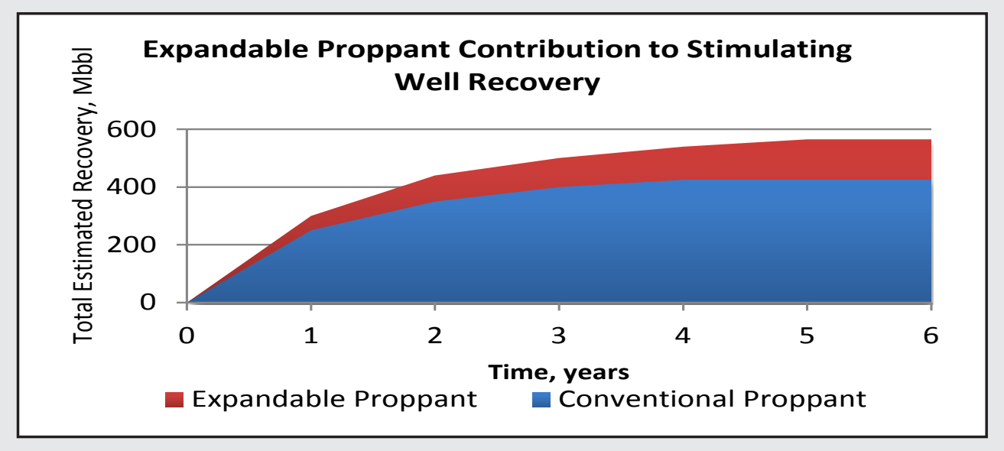




With sand. Closure at lower stress (6242 psi vs 6755 psi), or shorter time (4300 versus 5300 units)

IMPACT ON PRODUCTION

The net impact on production due to the delayed closure of the natural fractures is eroughly 23% for the well modelled.



LESS THAN MONOLAYER COVERAGE

In lower strength formations, polymer and expandable proppants outperform hard proppants at less than monolayer coverage due to embedment/rock fracture. This is illustrated using a rock failure point of 2000 psig.

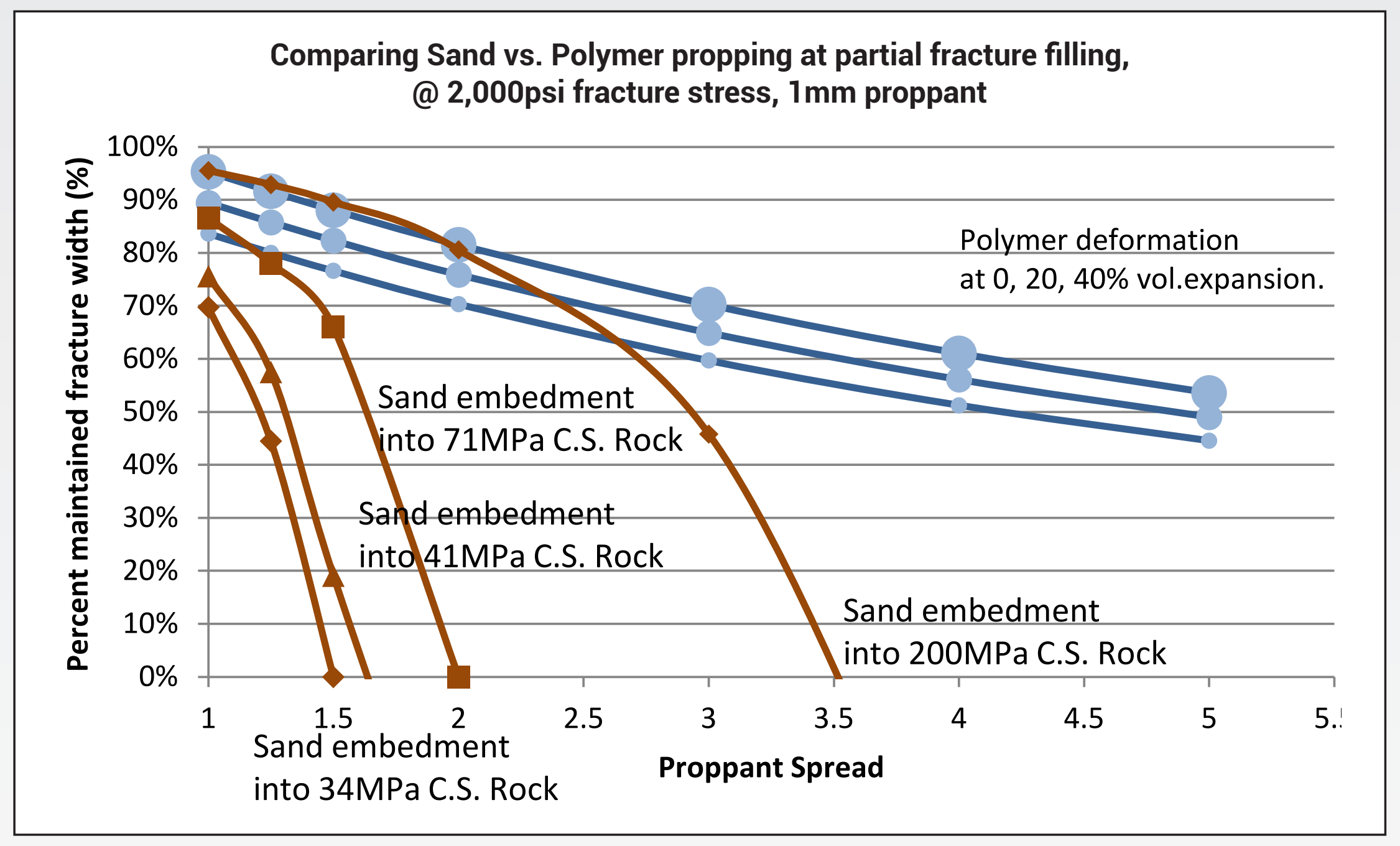


Illustration of proppant embedment in natural fractures in different strength rocks, versus deformable proppant. Effect of expansion shown.

FUTURE WORK

proppant conductivity testing with different rock types. Evaluation and modelling of embedment in simulated real rocks, evaluation of proppant transport into far field and natural fractures, optimizing proppant design (modulus/deformability) in different unconventional formations. Evaluating production effects with FEA simulated embedment and real (not rigid) rock properties.

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