Renewed Experimental Hydraulic Fracturing Technique For Hard Rock In-situ Recovery Enhancement

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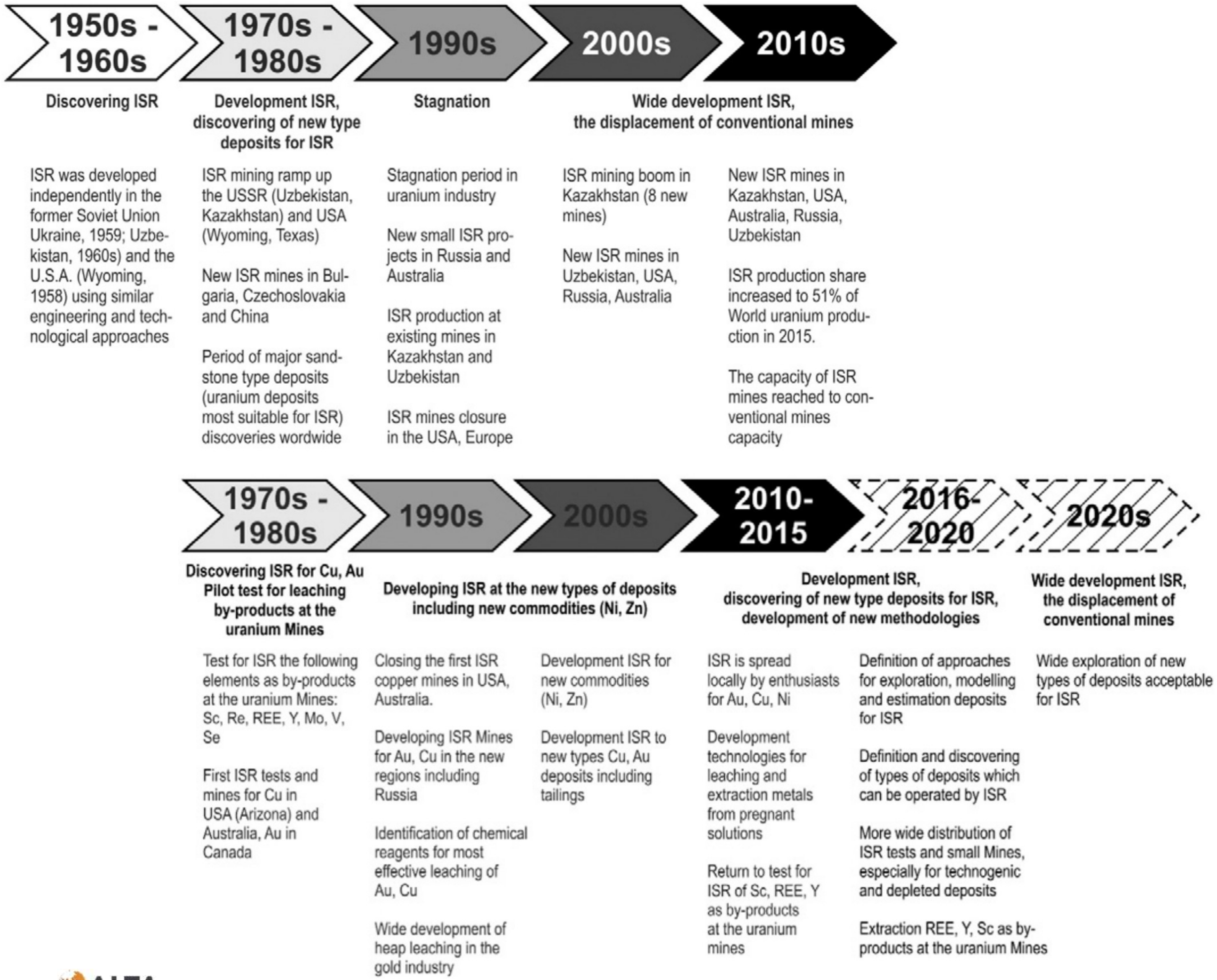
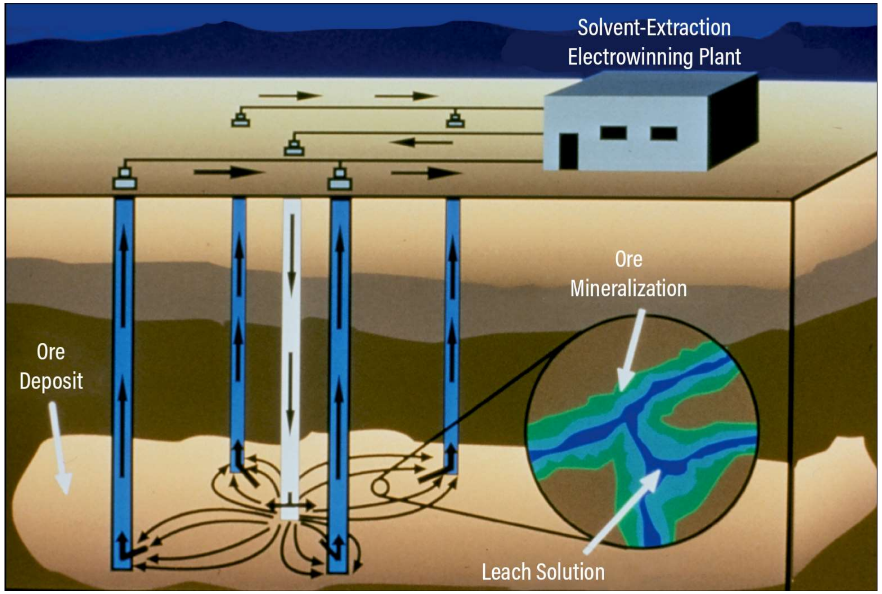
ISR, developments, limitations and solutions



(M. Seredkin et al. 2016)



(D. Earley III. 2020)

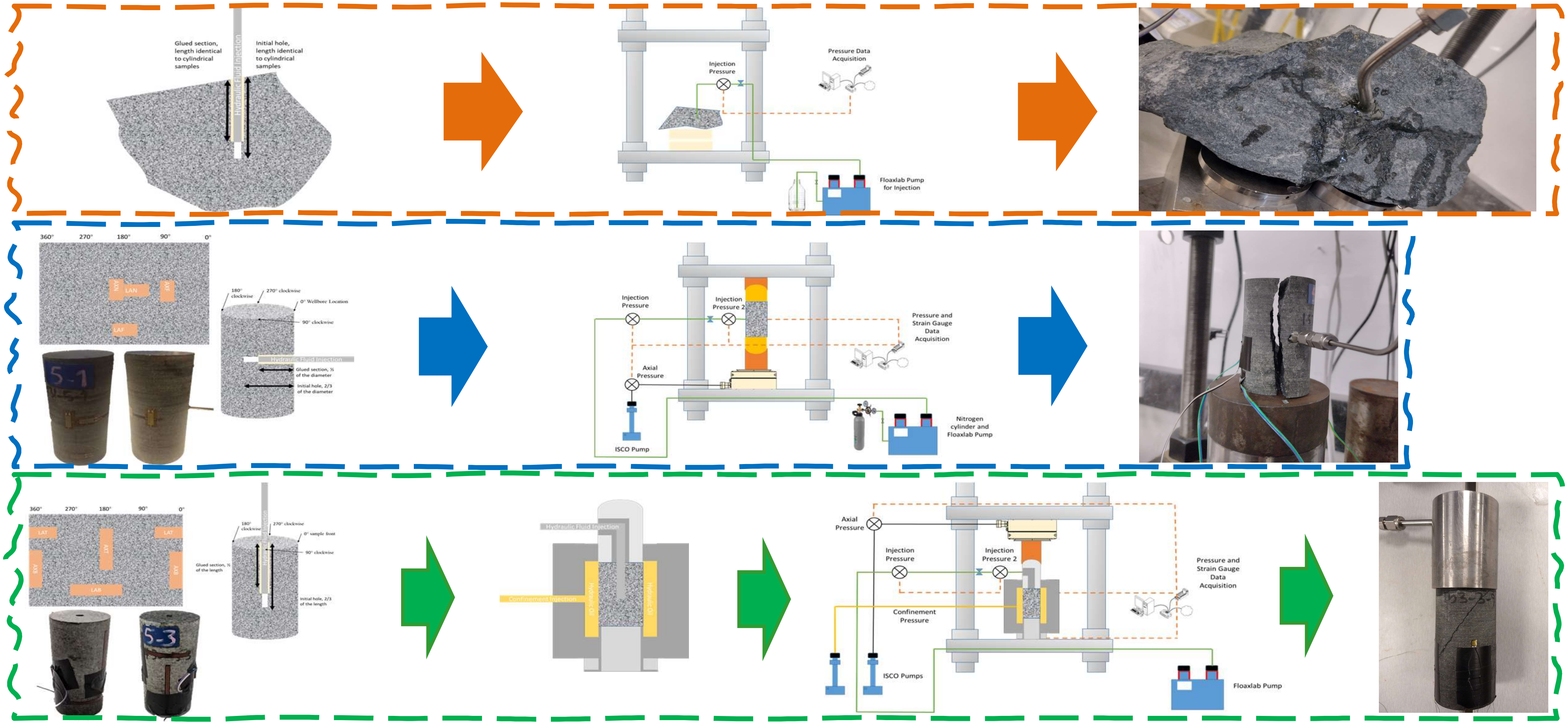
Artificial Permeability

- Other Techniques
- Hydraulic Fracturing

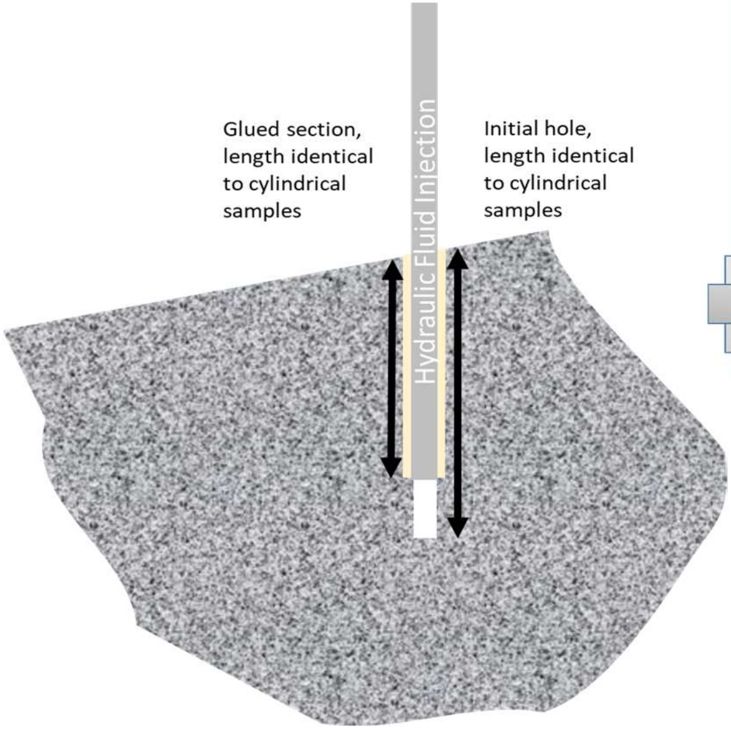
Experimental goals

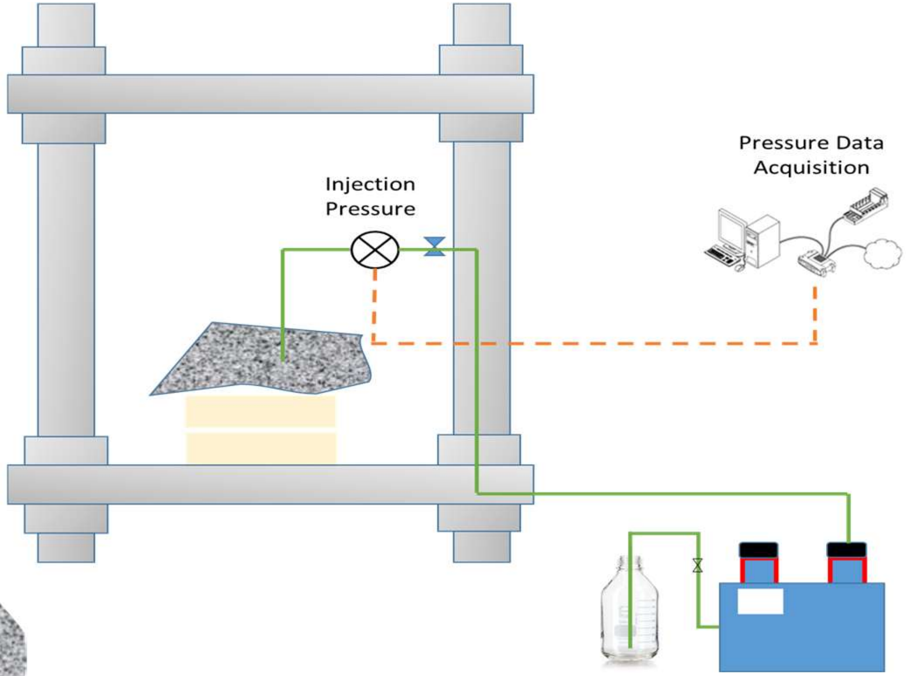
?	Flow rate	Higher injection rate is in favour of fracturing
	No external stress	
	Rich in natural fractures	The dominant parameter is natural fractures
?	Uniaxial stress	Higher uniaxial stress will affect breakdown pressure
	Brine vs Nitrogen comparison	Gaseous fracturing fluid has equivalent performance of liquid counterparts
?	Biaxial stress	Stress distribution will alter fracture geometry

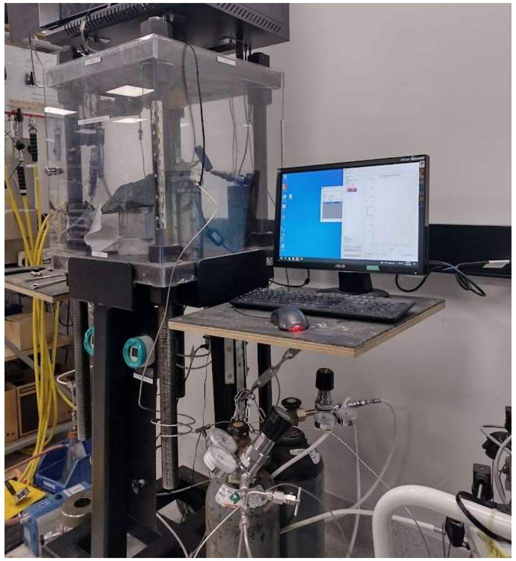
Free-standing, Uniaxial, and Biaxial HF experiments



Free-standing HF experiments



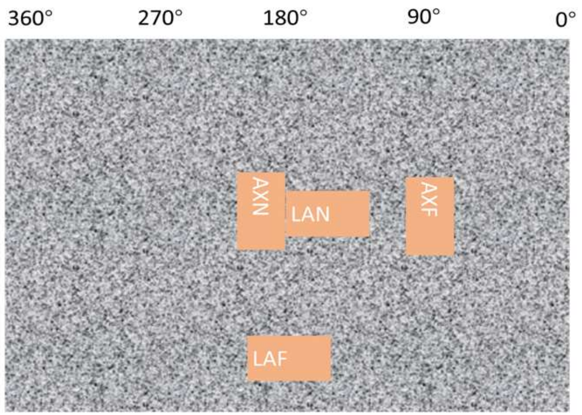


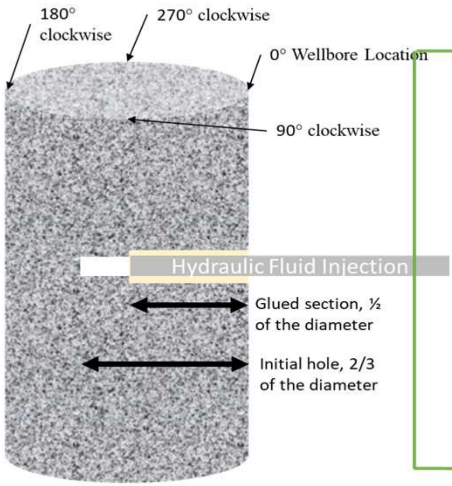


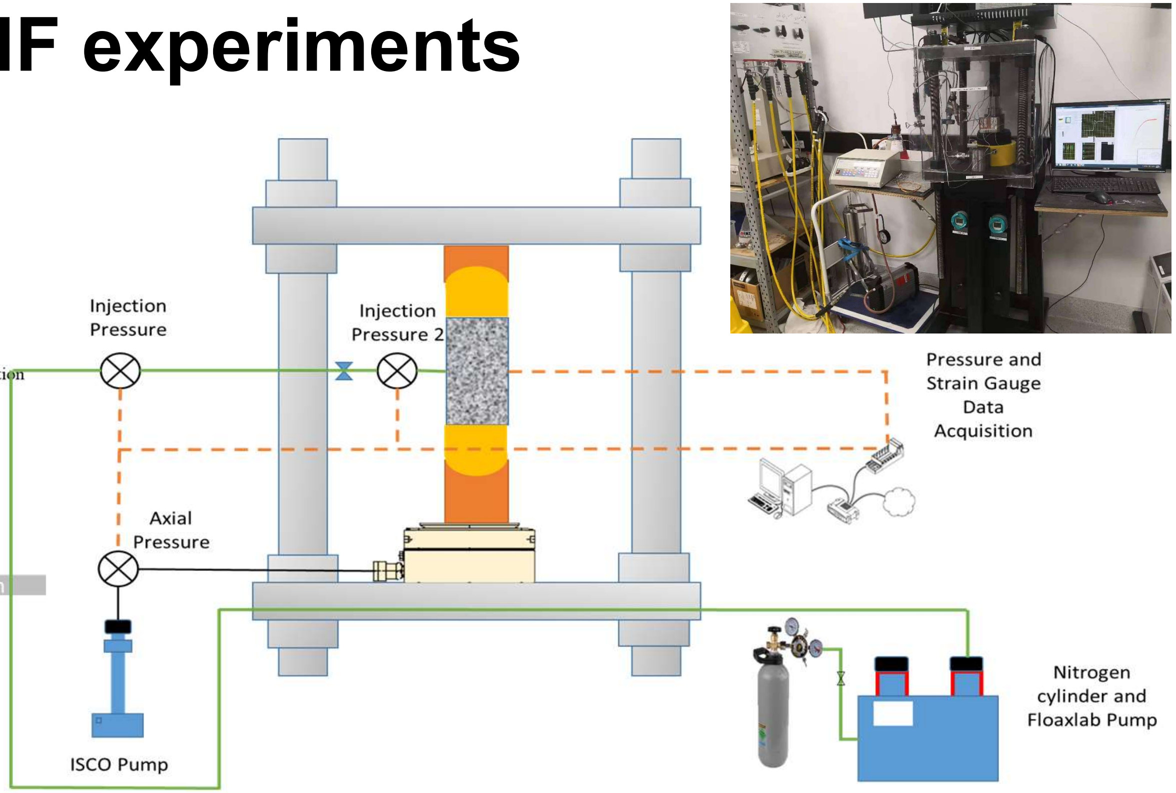
Free-standing

- Flow rate
- No external stress
- Rich in natural fractures

Uniaxial HF experiments







Uniaxial

- Unaxial stress
- Brine vs Nitrogen comparison

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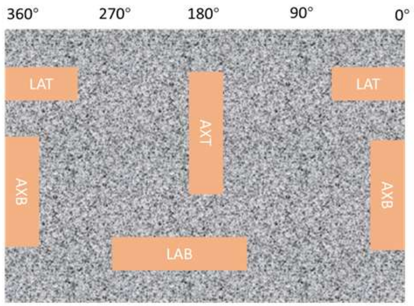
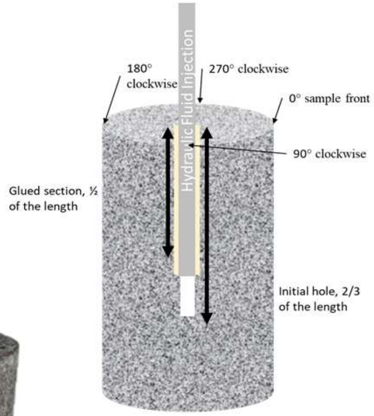
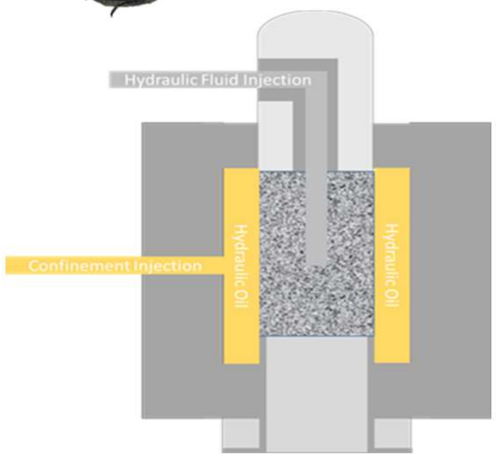
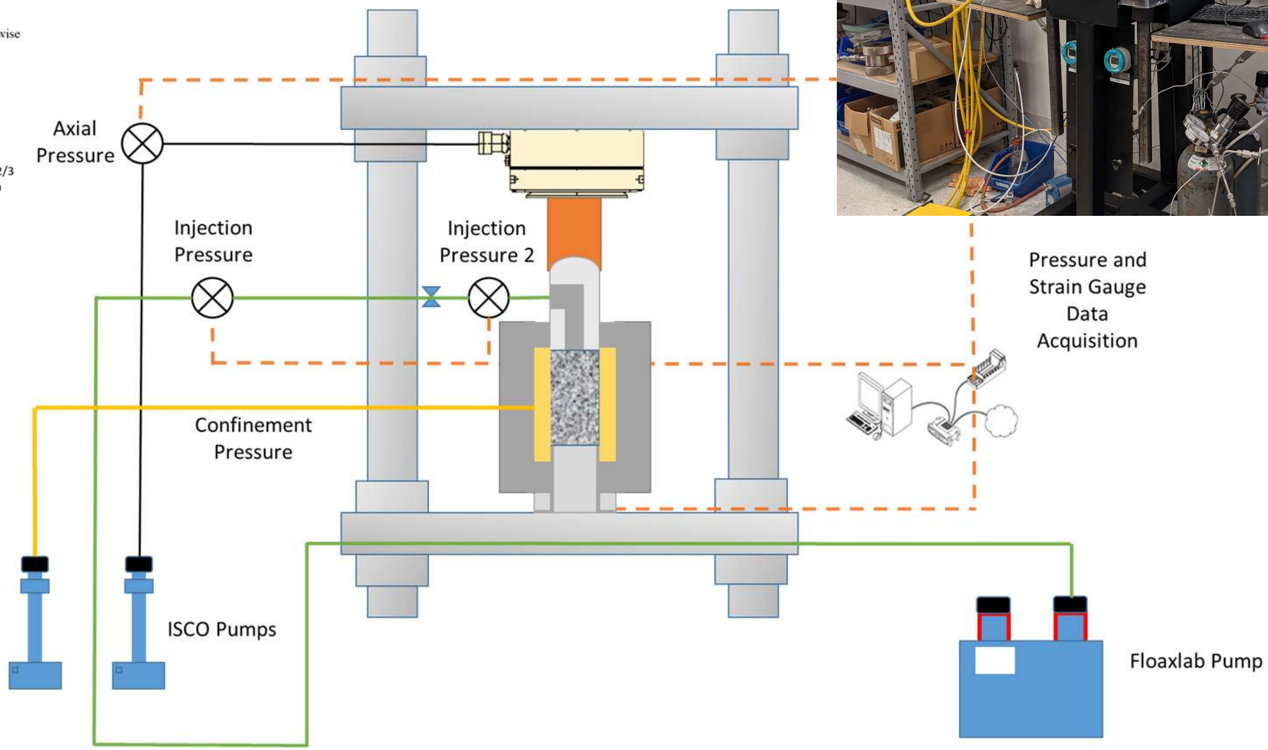
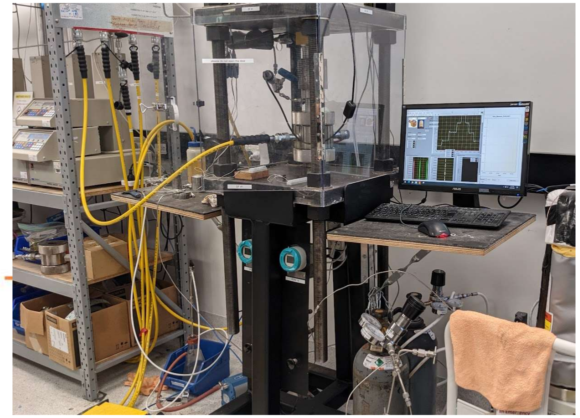
Biaxial HF experiments





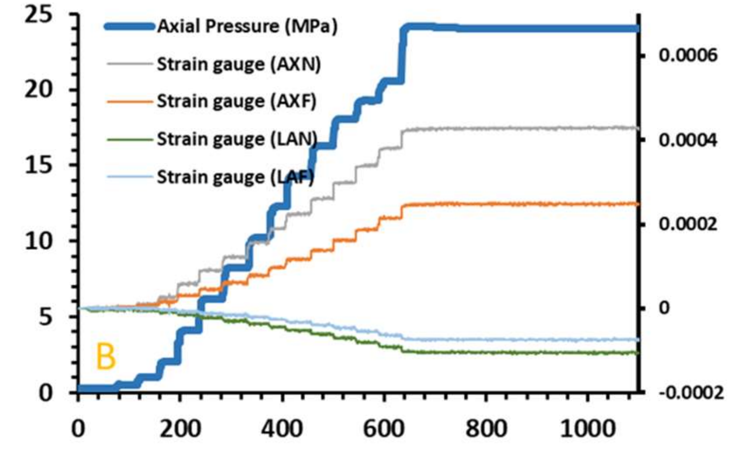




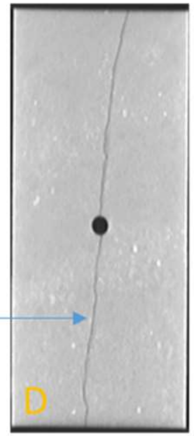


Biaxial — Biaxial stress

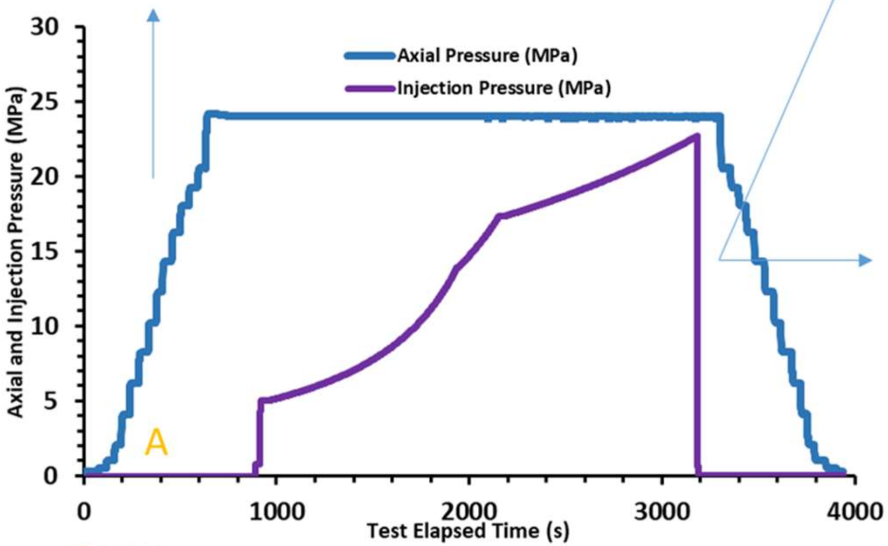
Datasets collected from experiments

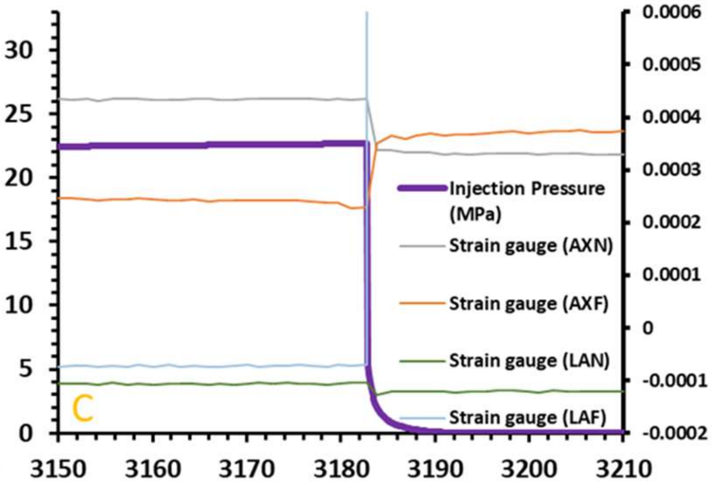


Sample 153-4-1 was fractured with 24 MPa axial stress, at **22.68** MPa injection pressure.
CT scanning image had shown that the fracture geometry is a slightly inclined vertical clear brittle fracture.



Fracture geometry

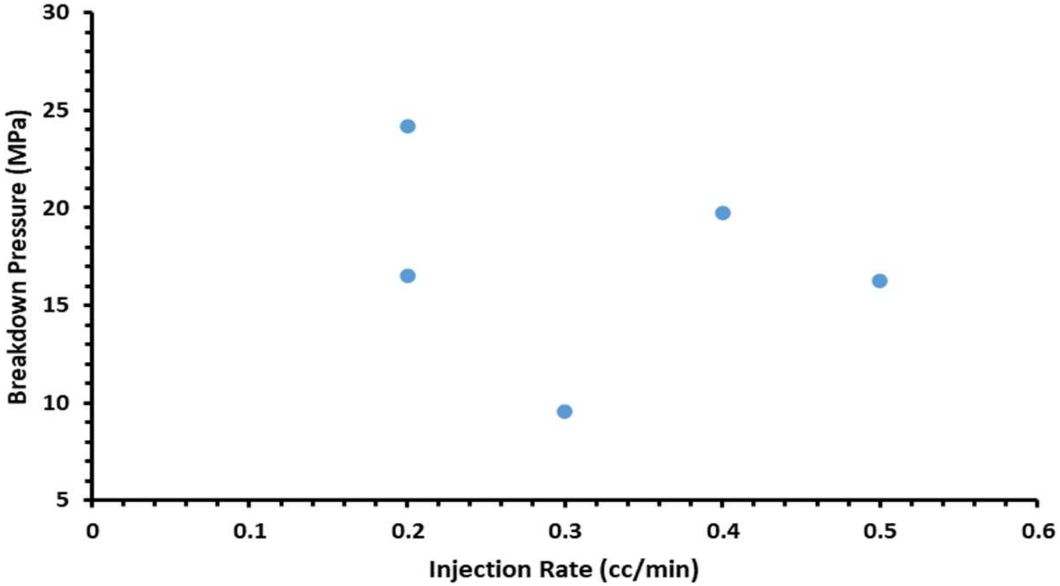




Breakdown pressure

Breakdown pressure comparison (1)

Sample No.	Fracture Fluid	Flow Rate(cc/min)	Bd Pressure(MPa)	Fracture outcome
Crusher1A	Water	0.2	16.5	Fractured
Crusher1B	Water	0.2	24.19	Fractured
Crusher2	Water	0.4	19.71	Fractured
Crusher7	Water	0.3	9.56	Connected Natural
Crusher8	Water	0.5	16.23	Fractured



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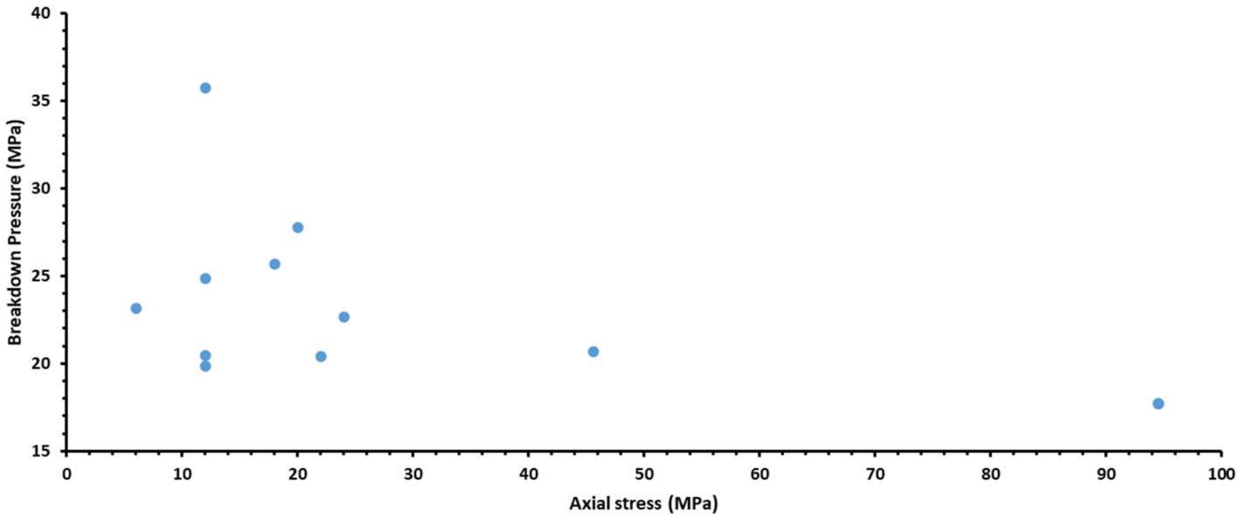
Breakdown pressure comparison (2)

Sample No.	Axial Stress(MPa)	Conf. Stress(MPa)	Fracture Fluid	Flow Rate(cc/min)	Bd Pressure(MPa)	Fracture outcome
152-7-3	6	0	Nitrogen	1	23.13	Clear Frac
152-5-6	12	0	Nitrogen	1	24.84	Clear Frac
152-2-1	12	0	Nitrogen	1	20.46	Clear Frac
153-5-2	12	0	Nitrogen	1	19.88	Clear Frac
153-5-4	12	0	Nitrogen	1	35.76	Clear Frac
153-4-9	18	0	Nitrogen	1	25.71	Clear Frac
153-4-4	20	0	Nitrogen	1	27.8	Clear Frac
153-3-1	22	0	Nitrogen	1	20.42	Clear Frac
153-4-1	24	0	Nitrogen	1	22.68	Clear Frac
153-6-2	45.61	0	Nitrogen	1	20.7	Clear Frac
31-6-1	94.55	0	Nitrogen	1	17.68	Frac not visble



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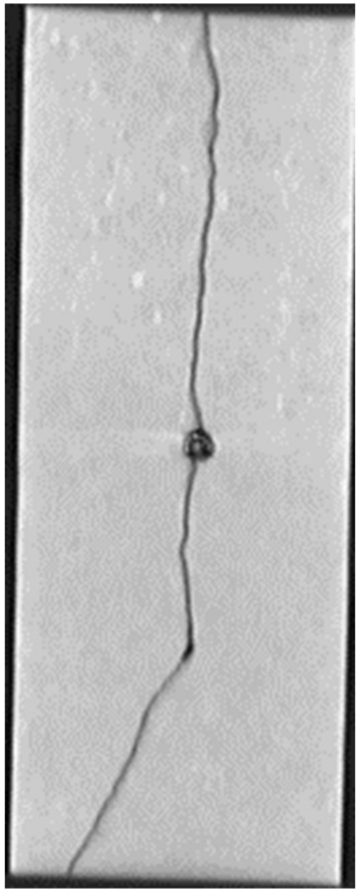
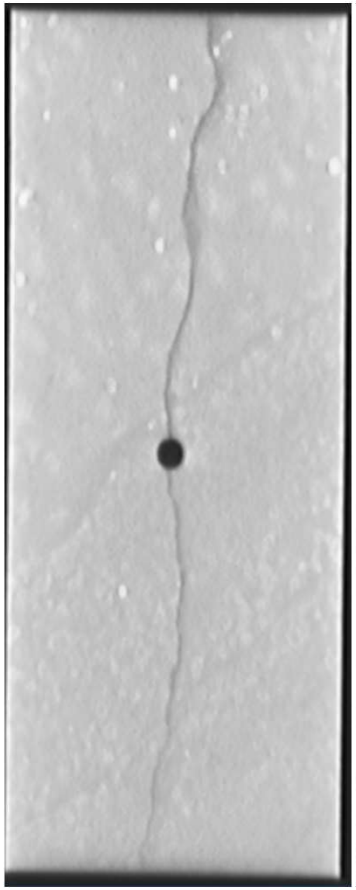
Breakdown pressure comparison (3)

Sample No.	Axial Stress(MPa)	Conf. Stress(MPa)	Fracture Fluid	Flow Rate(cc/min)	Bd Pressure(MPa)	Fracture outcome
152-1-3	12	0	Brine	0.4	29.05	Frac
30-6-6	12	0	Brine	0.2	28	Frac
152-5-6	12	0	Nitrogen	1	24.56	Clear Frac
152-2-1	12	0	Nitrogen	1	20.46	Clear Frac

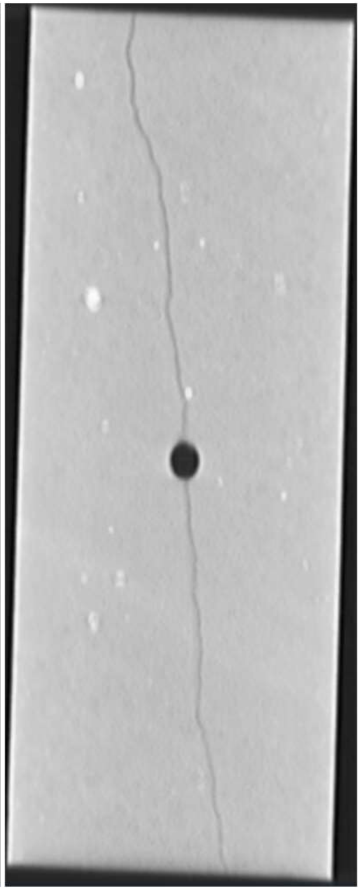
Fracture geometry results comparison (1)



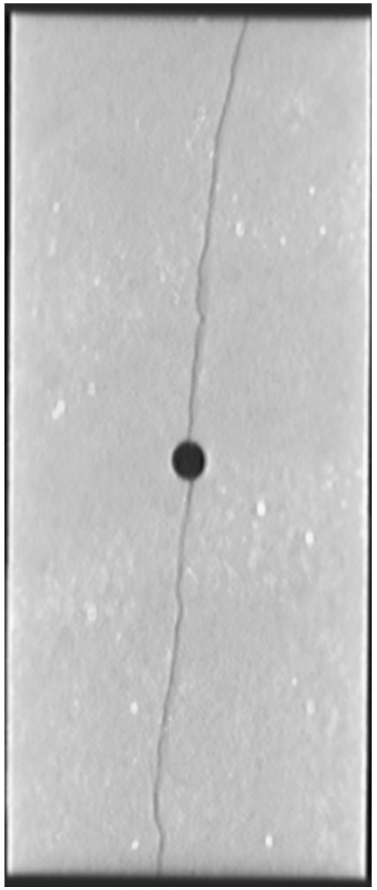
153-5-4
12MPa



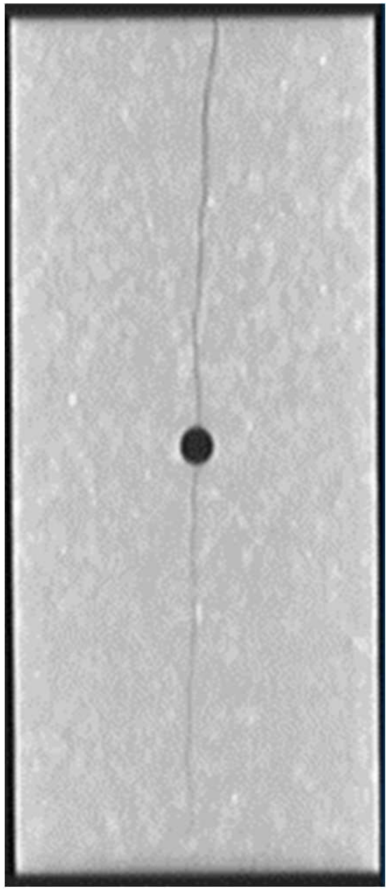
153-4-4
20MPa



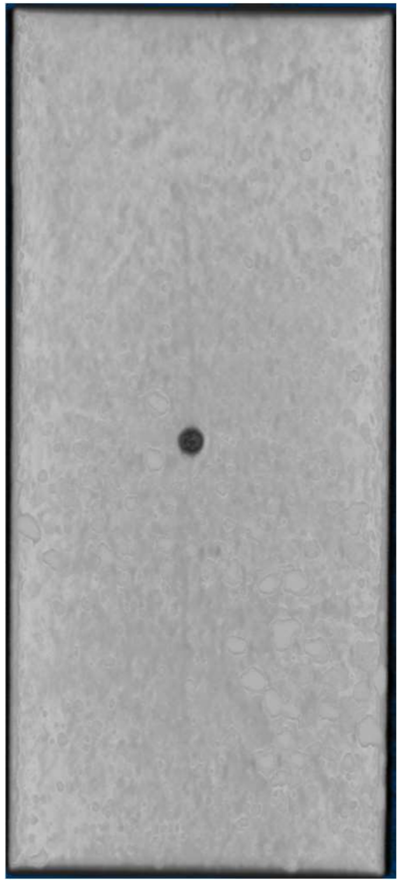
153-3-1
22MPa



153-4-1
24MPa

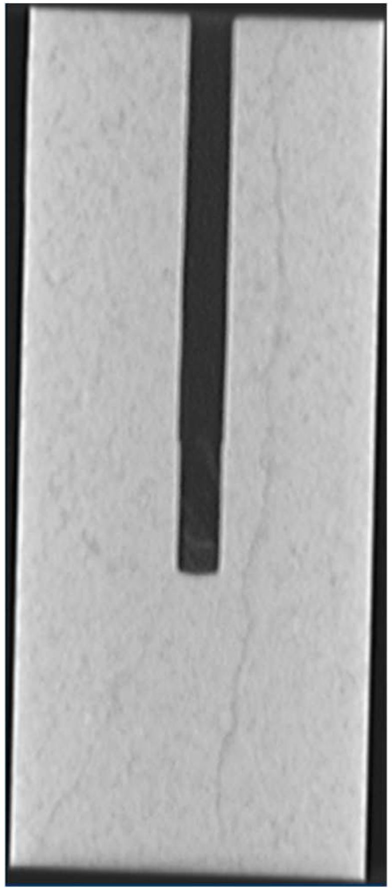


153-6-2
45.61MPa

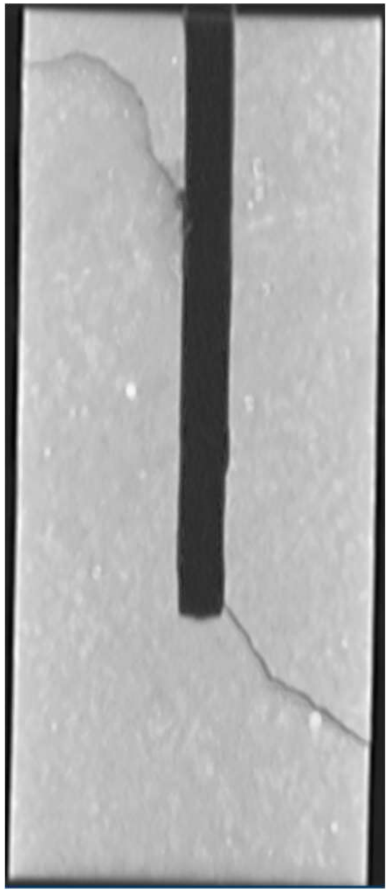


31-6-1
94.55MPa

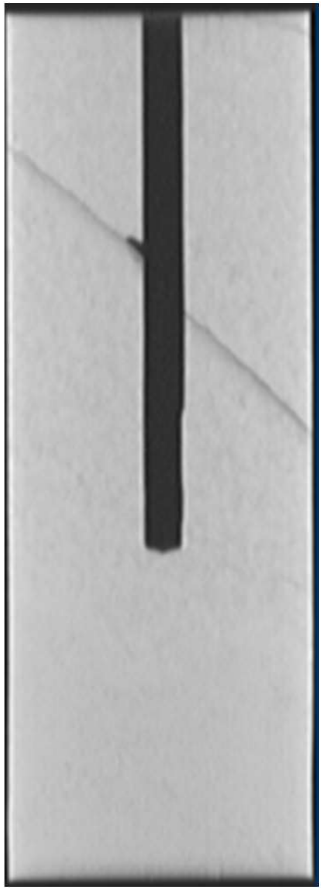
Fracture geometry results comparison (2)



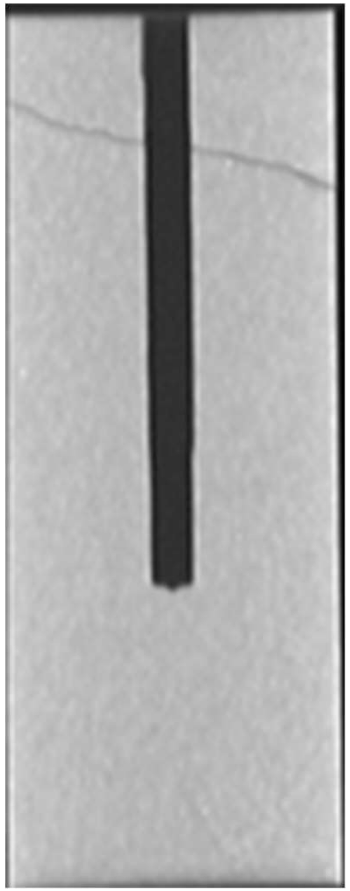
30-4-4
V:H = 4:1
V = 12 MPa, H = 3 MPa



153-4-7
V:H = 1:1
V = 15 MPa, H = 15 MPa

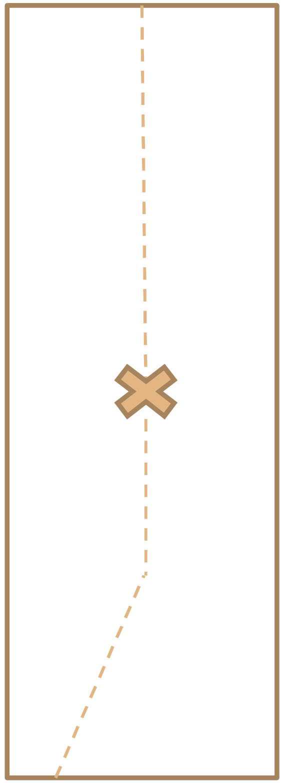


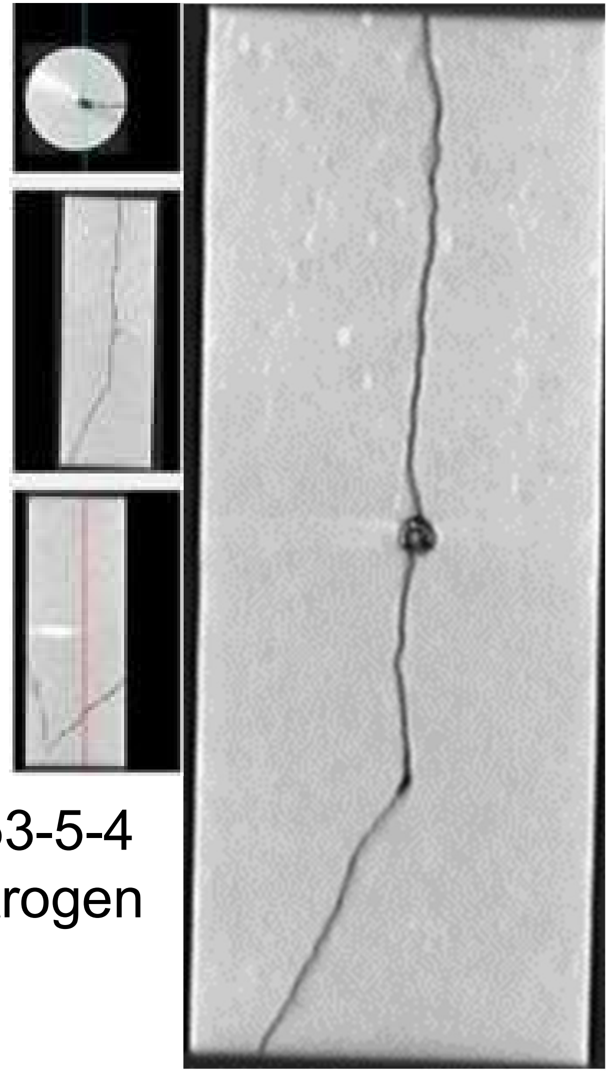
153-6-7
V:H = 1:3
V = 1 MPa, H = 3 MPa



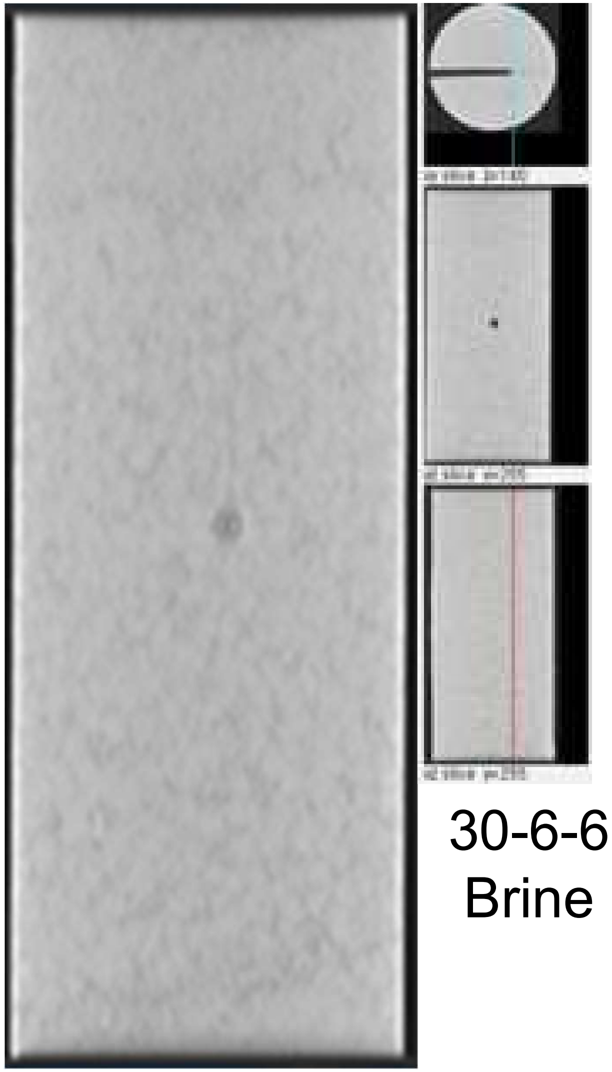
152-7-7
V:H = 1:6
V = 0.5 MPa, H = 3 MPa

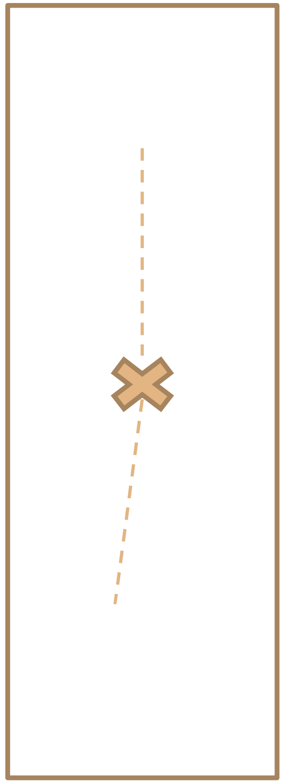
Fracture geometry results comparison (3)





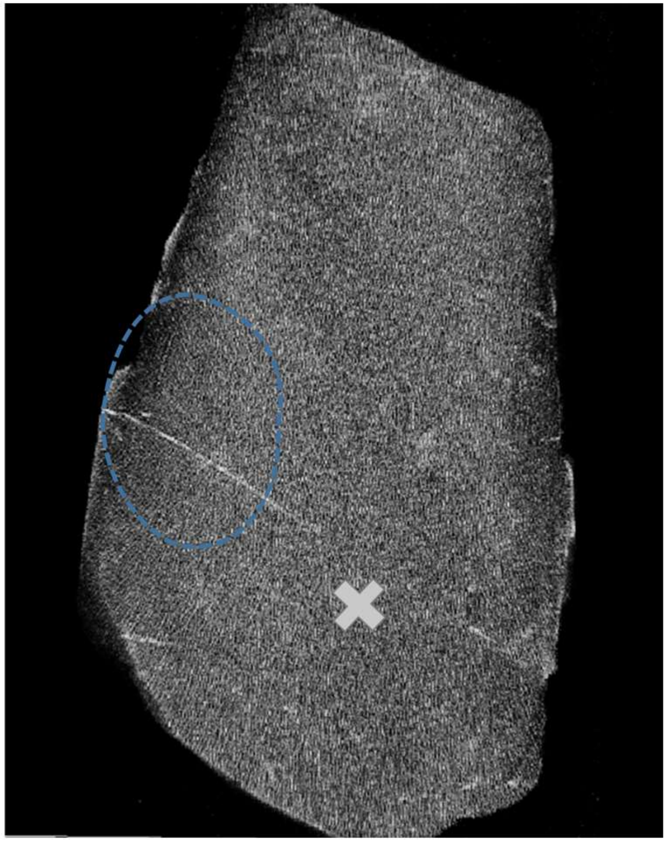
153-5-4
Nitrogen

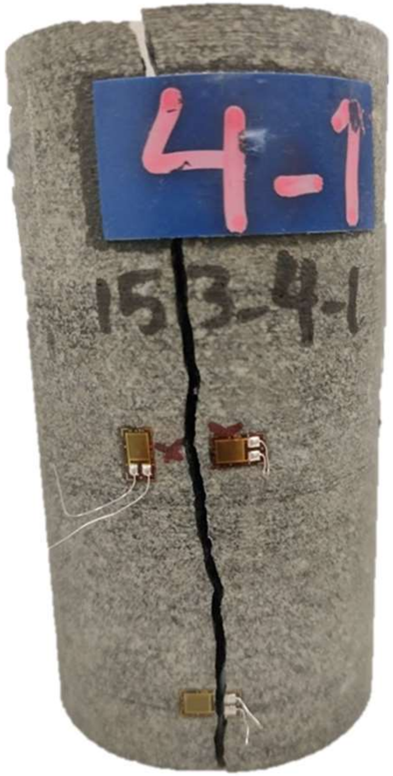


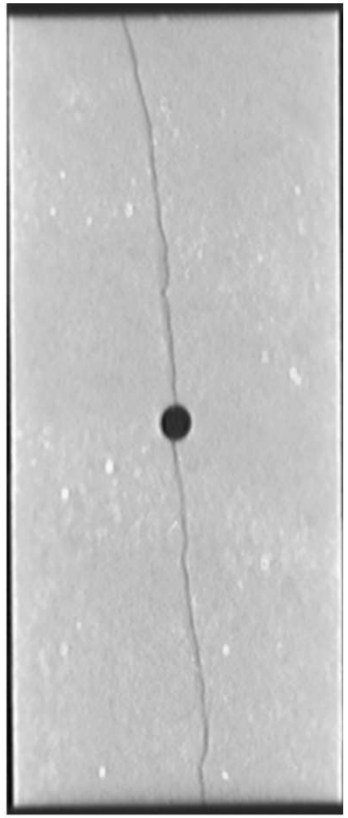


30-6-6
Brine

Fracture geometry results comparison (4)





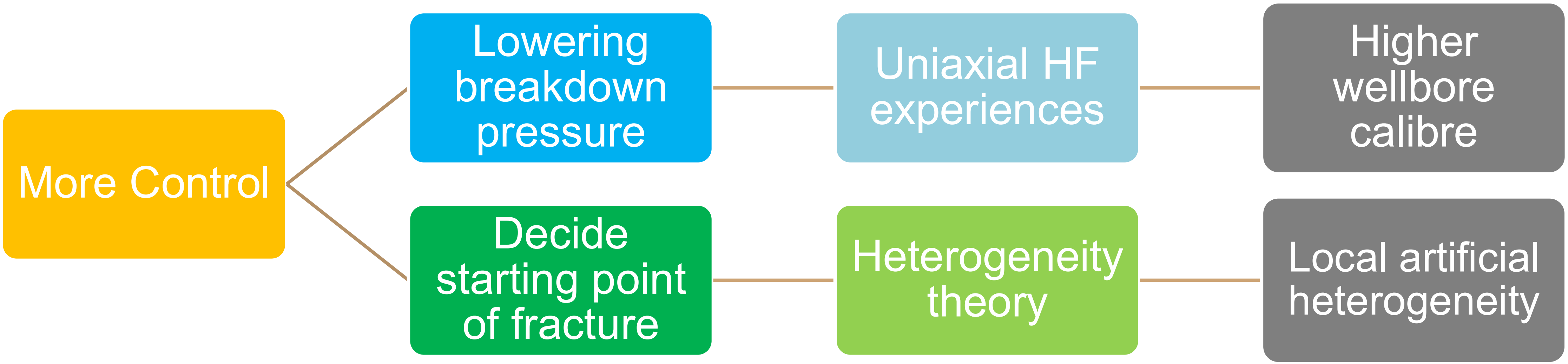


Experimental results

- Free-standing
  - Flow rate — Higher injection rate is in favour of fracturing (Need further confirmation)
  - No external stress
  - Rich in natural fractures — Natural heterogeneity is the dominant factor of HF (Proven)
- Uniaxial
  - Uniaxial stress — Higher uniaxial stress will affect breakdown pressure (Proven)
  - Brine vs Nitrogen comparison — Gaseous fracturing fluid has equivalent performance of liquid counterparts (Proven)
- Biaxial
  - Bi-direction stress — Stress distribution will alter fracture geometry (Proven)

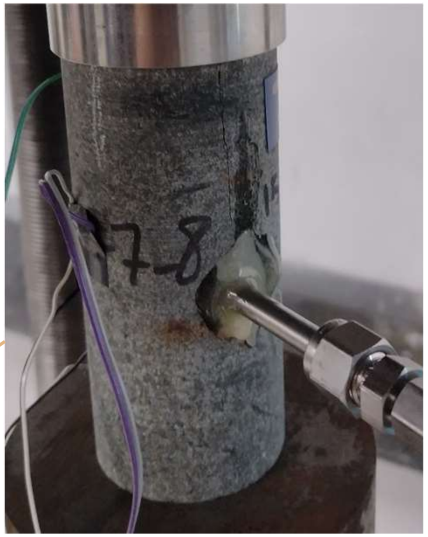
Conclusions(?)

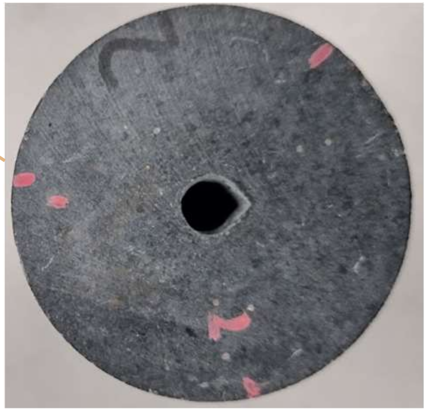
More control over HF



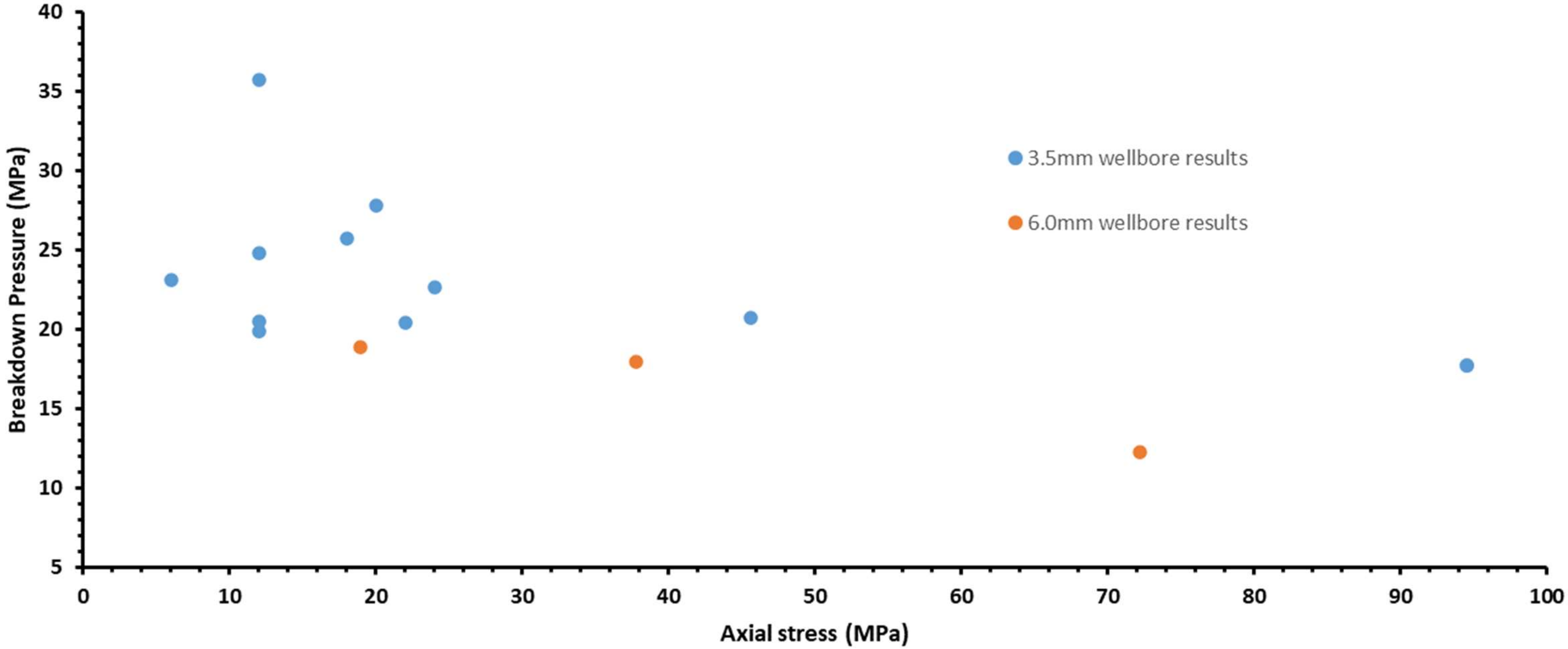
Experimental approach for more control over HF

Higher wellbore calibre	Uniaxial	Fracturing section diameter 3.5mm → 6mm
Local artificial heterogeneity	Biaxial	Filed out groove along wellbore





Breakdown pressure comparison (4)



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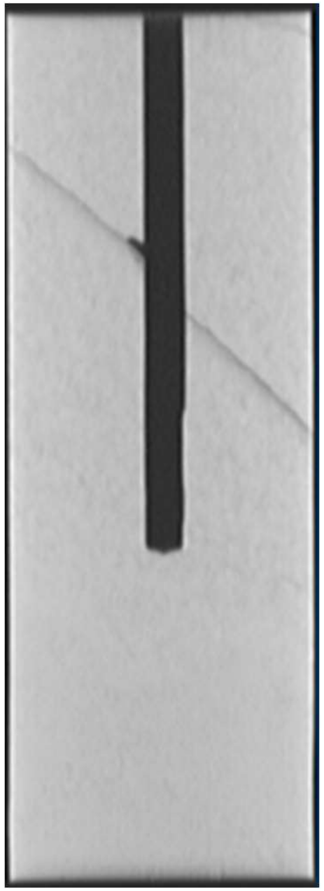
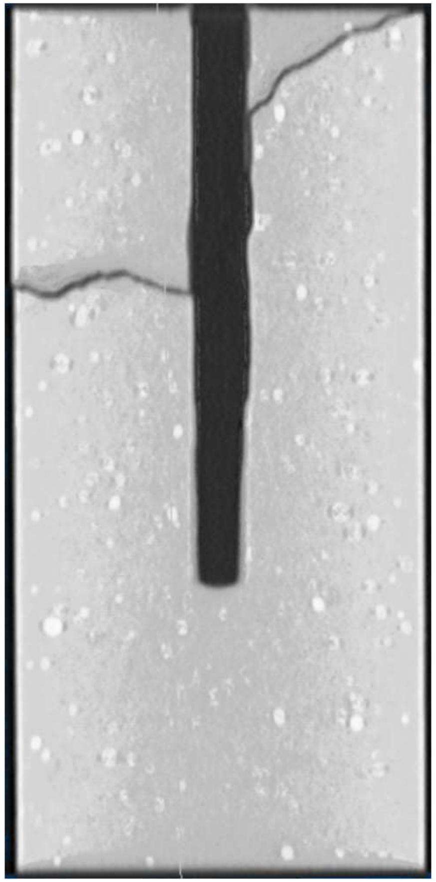
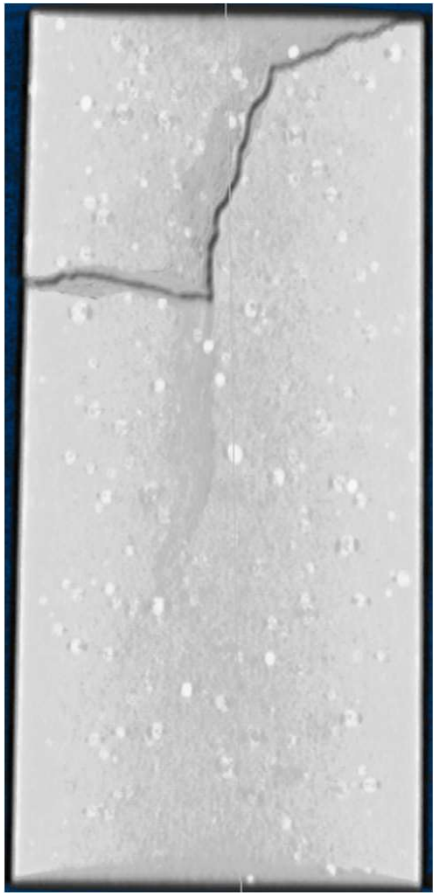
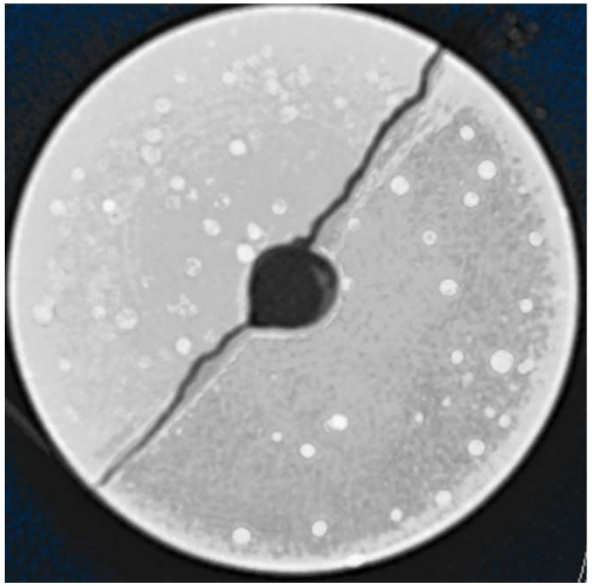
Fracture geometry results comparison (5)



153-6-7
V:H = 1:3
V = 1 MPa, H = 3 MPa

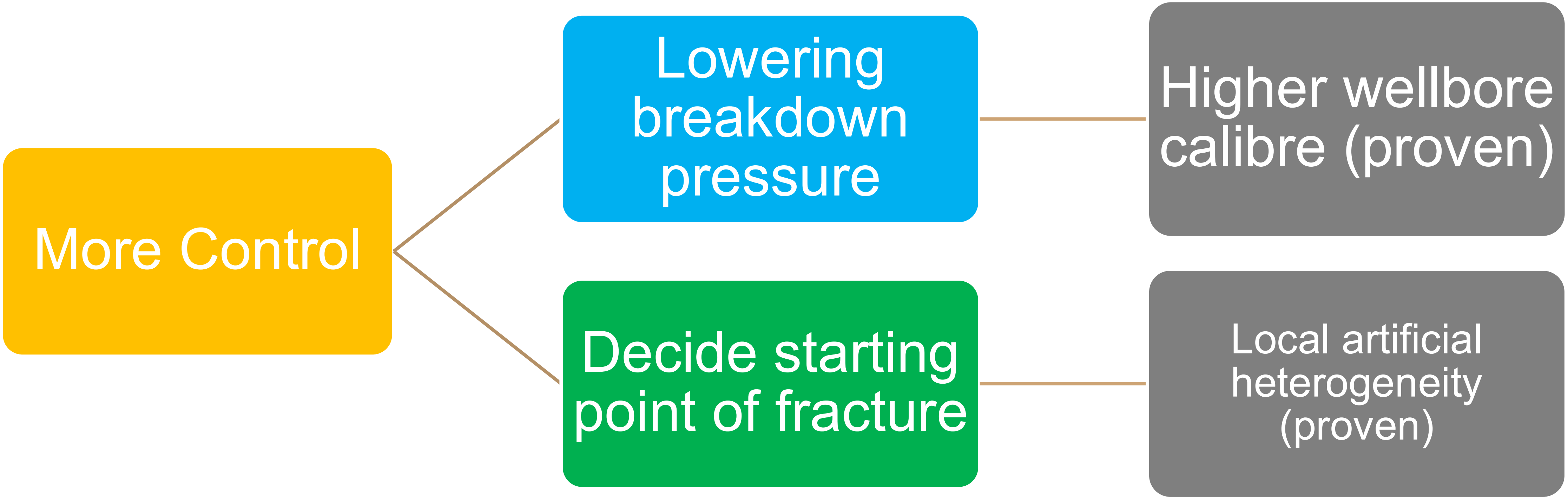






153-3-2
V:H = 1:3
V = 1 MPa, H = 3 MPa

Control methods proven



Conclusions & Implications

- Hydraulic fracturing can be applied to create fractures in hard rock deposits
- Heterogeneities (i.e., faults, mineral veins) in hard rock dominates the fracture starting point, thus can be exploited for designating fracture starting point and further propagation direction guidance
- In-situ stress distribution ratio in hard rock will guide fracture propagation direction regardless of absolute stress values, especially when fracture point is locally intact
- High deviance in in-situ stress distribution tend to create smooth fractures without branches, thus it is recommended to apply more control over fracture process for optimum fracturing volume in hard rock deposit
- Environmental benign fluids (i.e., nitrogen) and larger wellbore diameter can be applied in HF-ISR enhancement with potentially lower breakdown pressure requirement

Acknowledgements

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Thank you

References

1, Maxim Seredkin, Alexander Zabolotsky, Graham Jeffress, *In situ recovery, an alternative to conventional methods of mining: Exploration, resource estimation, environmental issues, project evaluation and economics*, Ore Geology Reviews, Volume 79,2016,Pages 500-514,ISSN 0169-1368,https://doi.org/10.1016/j.oregeorev.2016.06.016.

2, Drummond Earley III, *In Situ Recovery and Remediation of Metals*, Society for Mining, Metallurgy & Exploration, Incorporated, 2020. ISBN: 9780873354868

3, Gregory Zuckerman, *The Frackers: The Outrageous Inside Story of the New Energy Revolution*, Penguin, 2013. ISBN:1591847095