

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

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ISR, developments, limitations and solutions



1950s - 1960s

Discovering ISR

ISR was developed independently in the former Soviet Union (Ukraine, 1959; Uzbekistan, 1960s) and the U.S.A. (Wyoming, 1958) using similar engineering and technological approaches

1970s - 1980s

Development ISR, discovering of new type deposits for ISR

ISR mining ramp up the USSR (Uzbekistan, Kazakhstan) and USA (Wyoming, Texas)

New ISR mines in Bulgaria, Czechoslovakia and China

Period of major sandstone type deposits (uranium deposits most suitable for ISR) discoveries worldwide

1990s

Stagnation

Stagnation period in uranium industry

New small ISR projects in Russia and Australia

ISR production at existing mines in Kazakhstan and Uzbekistan

ISR mines closure in the USA, Europe

2000s

Wide development ISR, the displacement of conventional mines

ISR mining boom in Kazakhstan (8 new mines)

New ISR mines in Uzbekistan, USA, Russia, Australia

2010s

New ISR mines in Kazakhstan, USA, Australia, Russia, Uzbekistan

ISR production share increased to 51% of World uranium production in 2015.

The capacity of ISR mines reached to conventional mines capacity

1970s - 1980s

Discovering ISR for Cu, Au Pilot test for leaching by-products at the uranium Mines

Test for ISR the following elements as by-products at the uranium Mines: Sc, Re, REE, Y, Mo, V, Se

First ISR tests and mines for Cu in USA (Arizona) and Australia, Au in Canada

1990s

Developing ISR at the new types of deposits including new commodities (Ni, Zn)

Closing the first ISR copper mines in USA, Australia.

Developing ISR Mines for Au, Cu in the new regions including Russia

Identification of chemical reagents for most effective leaching of Au, Cu

Wide development of heap leaching in the gold industry

2000s

Development ISR for new commodities (Ni, Zn)

Development ISR to new types Cu, Au deposits including tailings

2010-2015

Development ISR, discovering of new type deposits for ISR, development of new methodologies

ISR is spread locally by enthusiasts for Au, Cu, Ni

Development technologies for leaching and extraction metals from pregnant solutions

Return to test for ISR of Sc, REE, Y as by-products at the uranium mines

2016-2020

Wide development ISR, the displacement of conventional mines

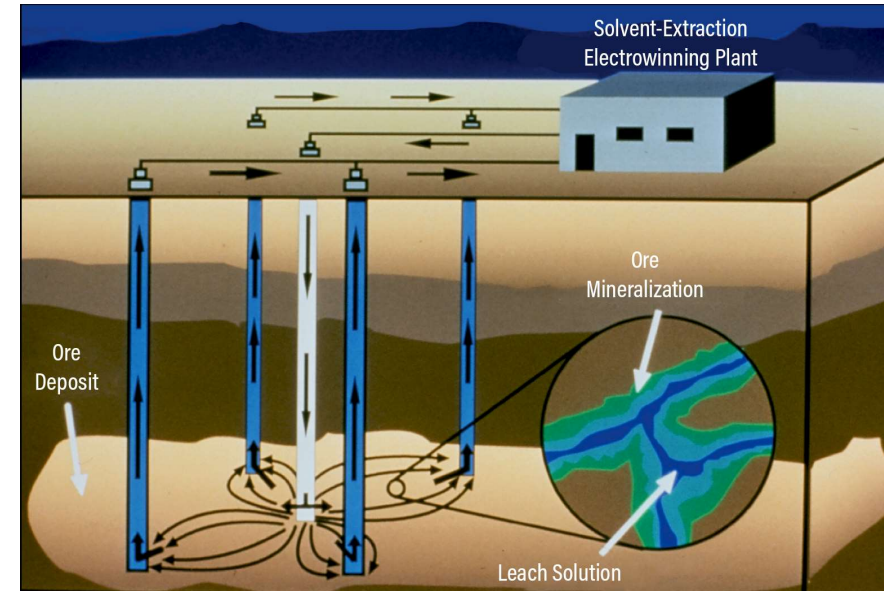
Definition of approaches for exploration, modelling and estimation deposits for ISR

Definition and discovering of types of deposits which can be operated by ISR

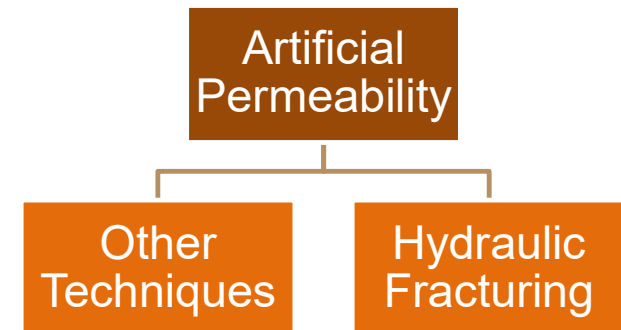
More wide distribution of ISR tests and small Mines, especially for technogenic and depleted deposits

Extraction REE, Y, Sc as by-products at the uranium Mines

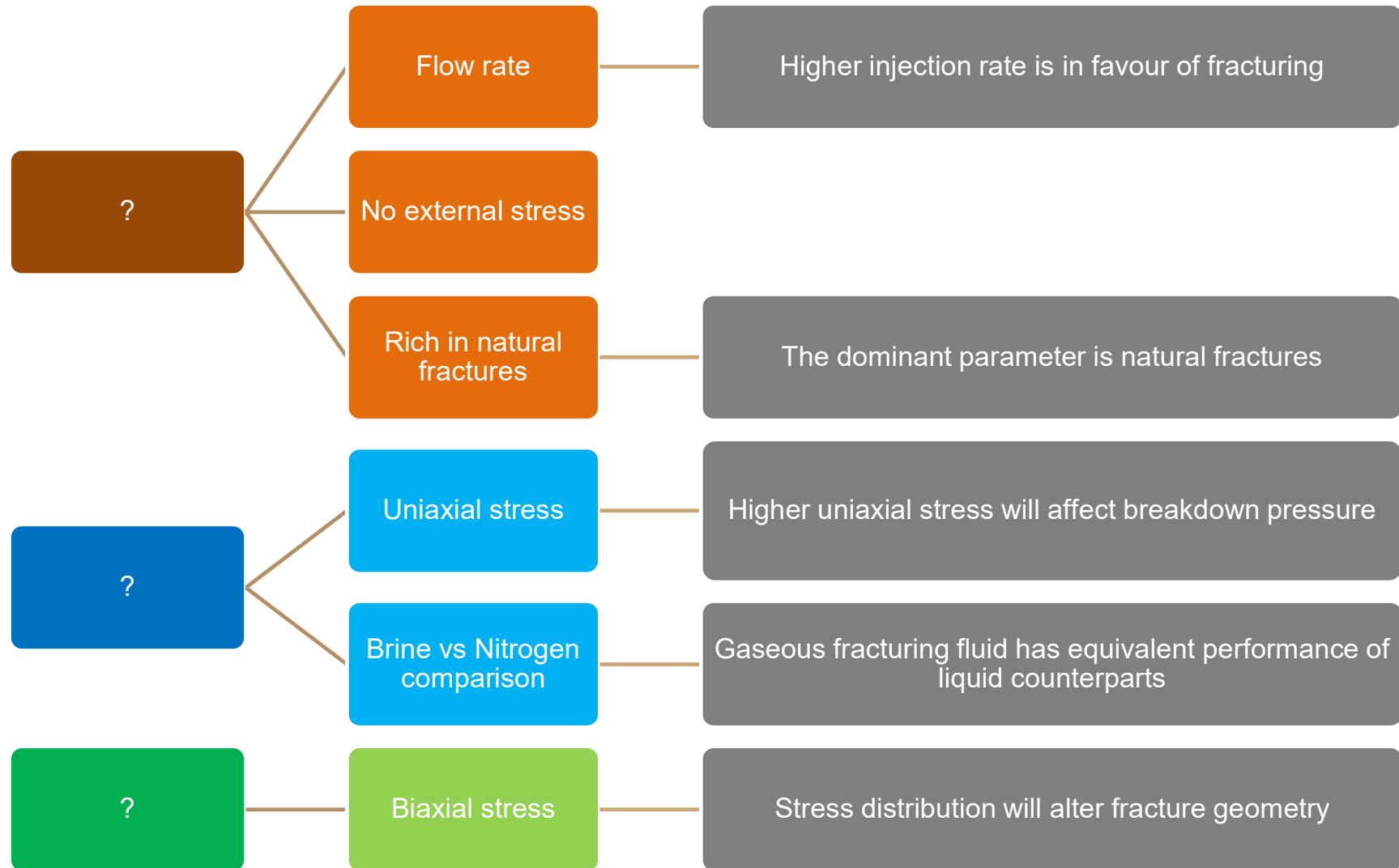
2020s



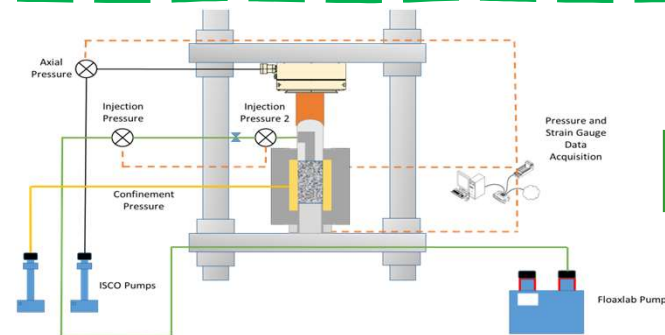
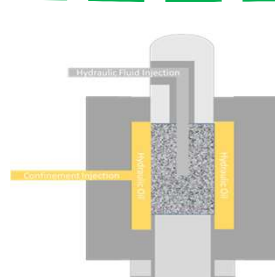
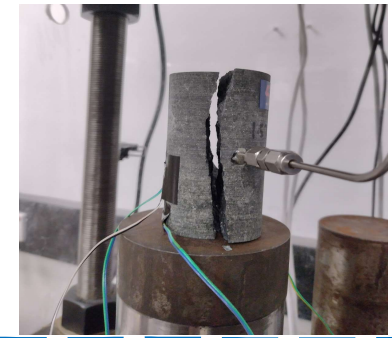
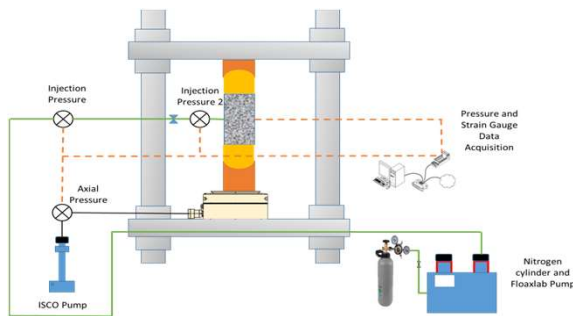
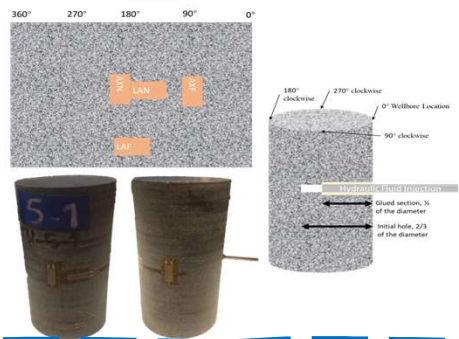
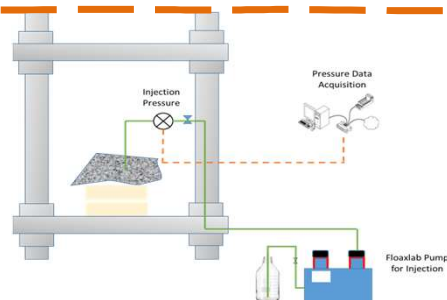
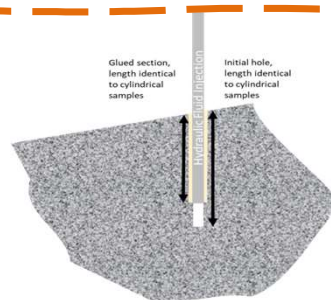
(D. Earley III. 2020)



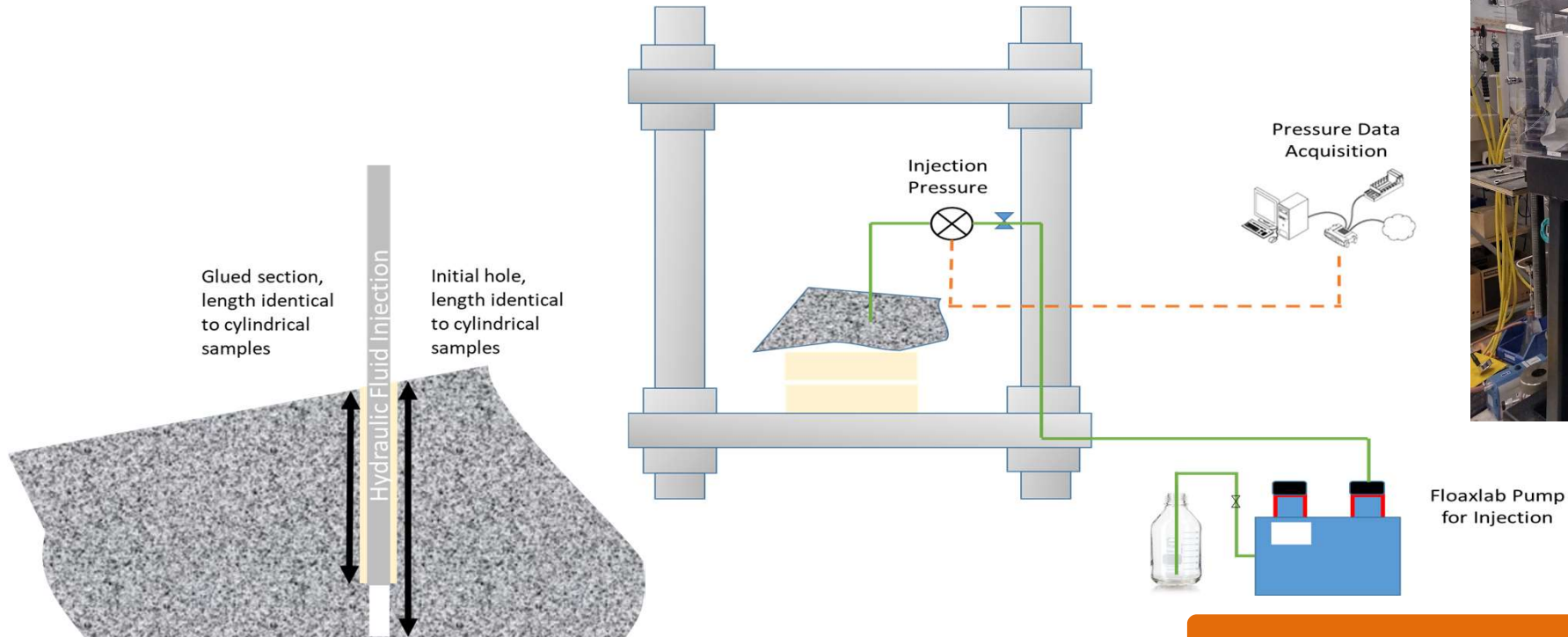
Experimental goals



Free-standing, Uniaxial, and Biaxial HF experiments



Free-standing HF experiments



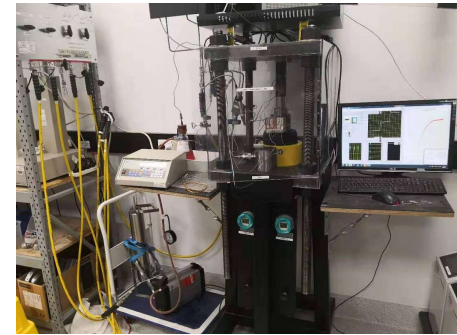
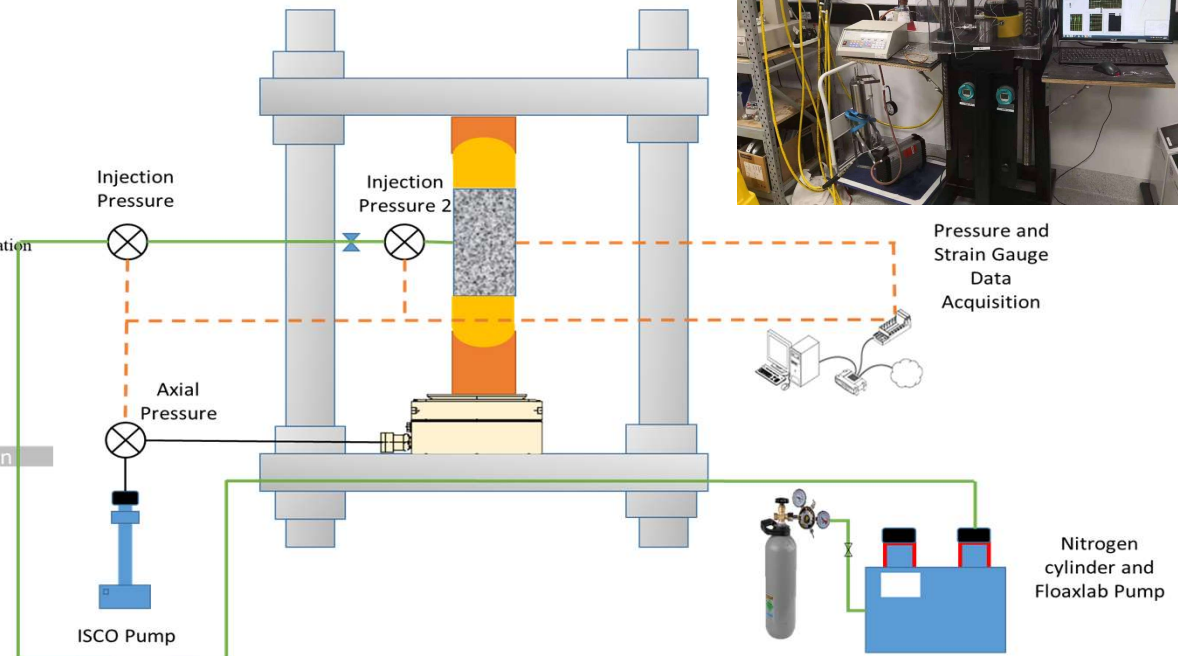
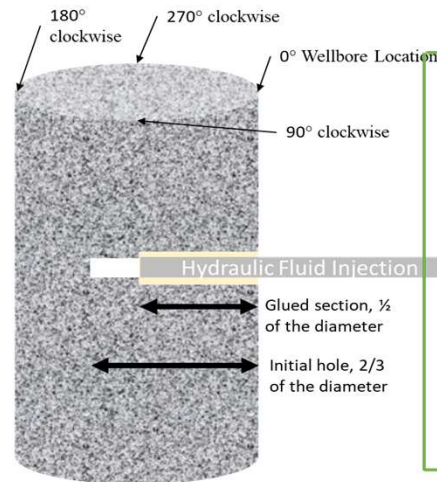
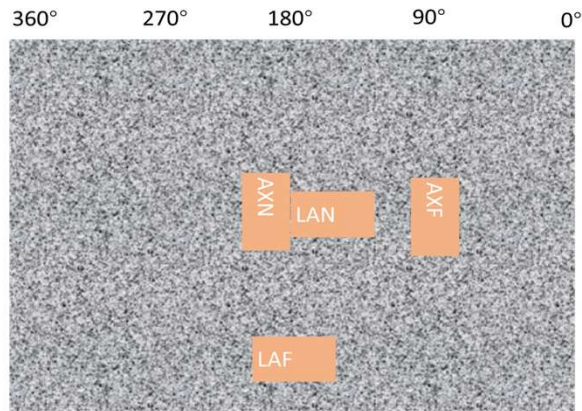
Free-standing

Flow rate

No external stress

Rich in natural fractures

Uniaxial HF experiments

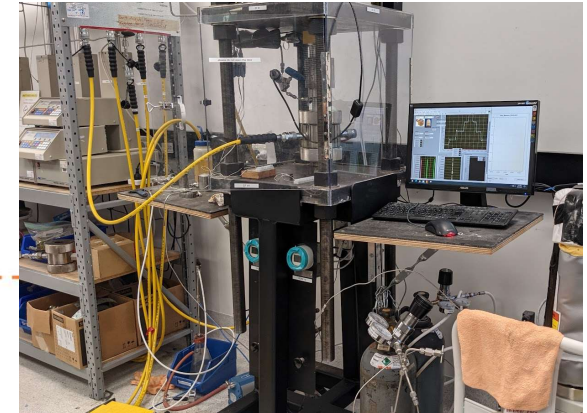
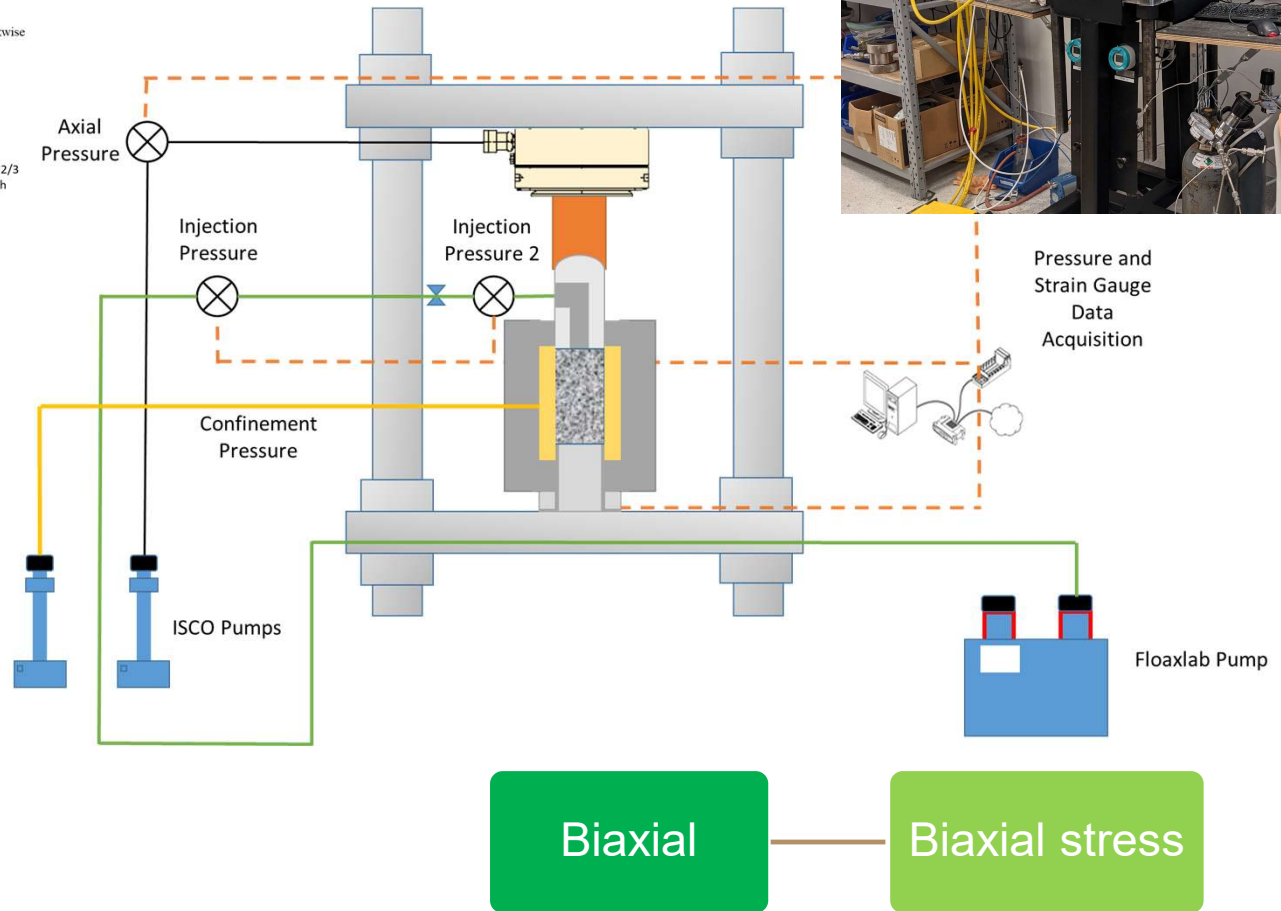
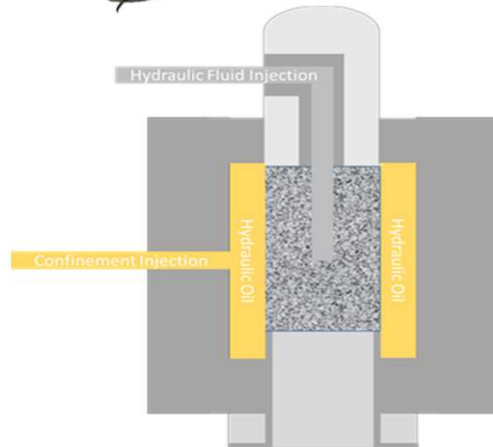
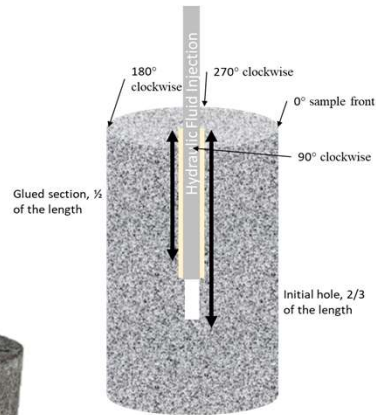
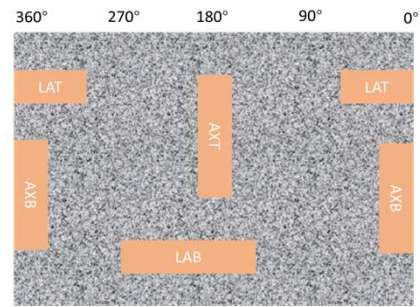


Uniaxial

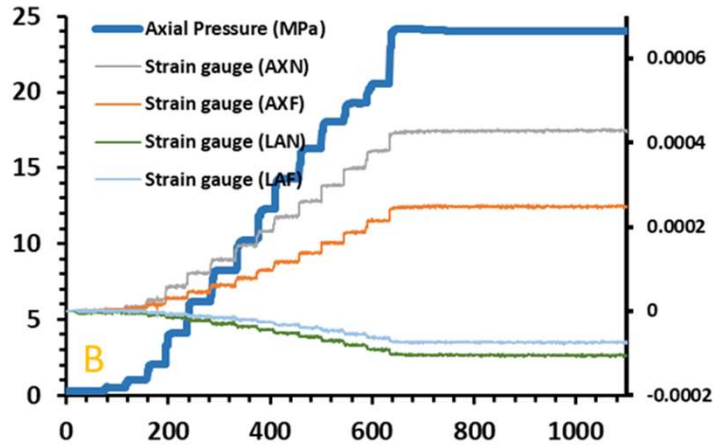
Uniaxial stress

Brine vs Nitrogen
comparison

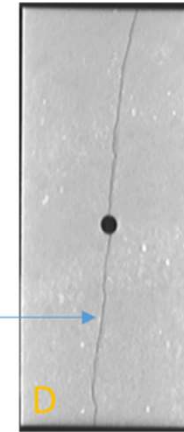
Biaxial HF experiments



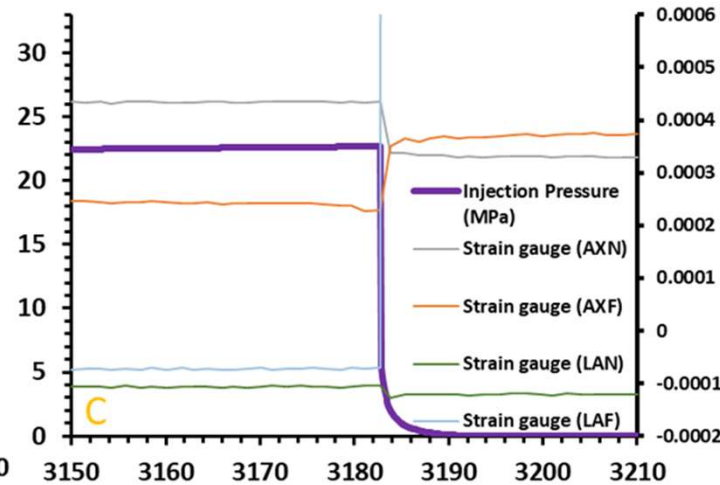
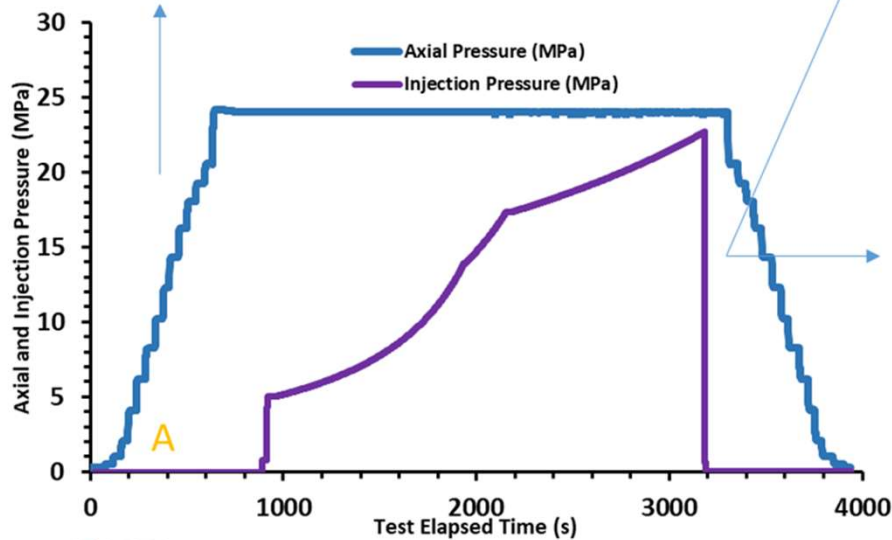
Datasets collected from experiments



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.



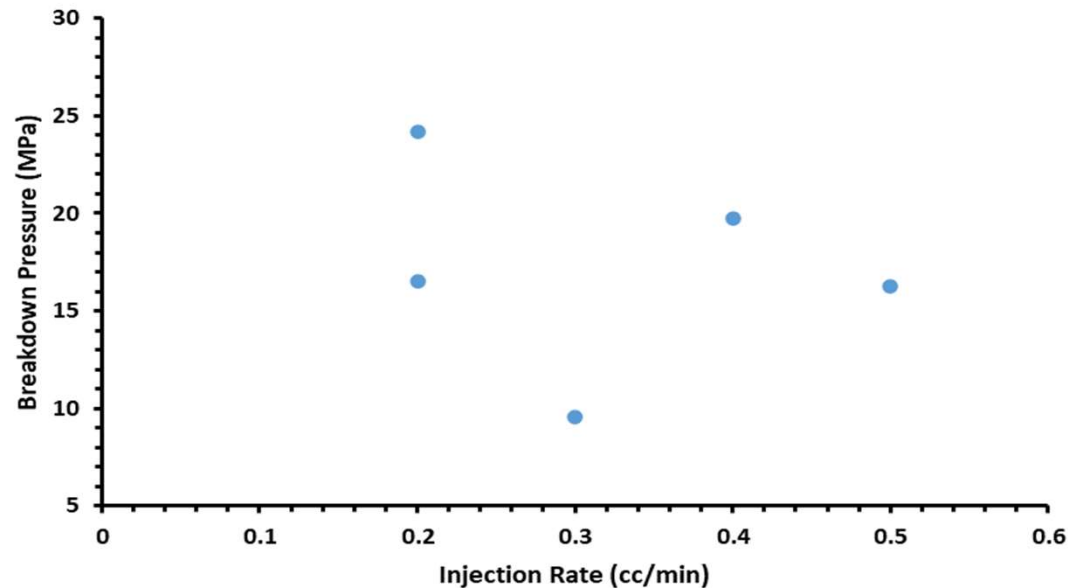
Fracture geometry



Breakdown pressure

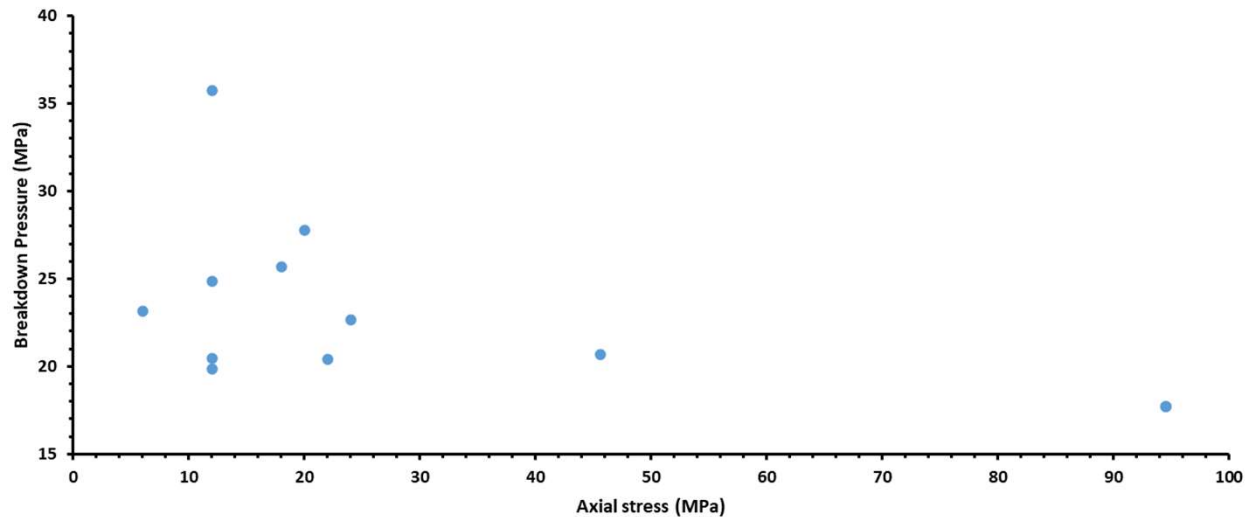
Breakdown pressure comparison (1)

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



Breakdown pressure comparison (2)

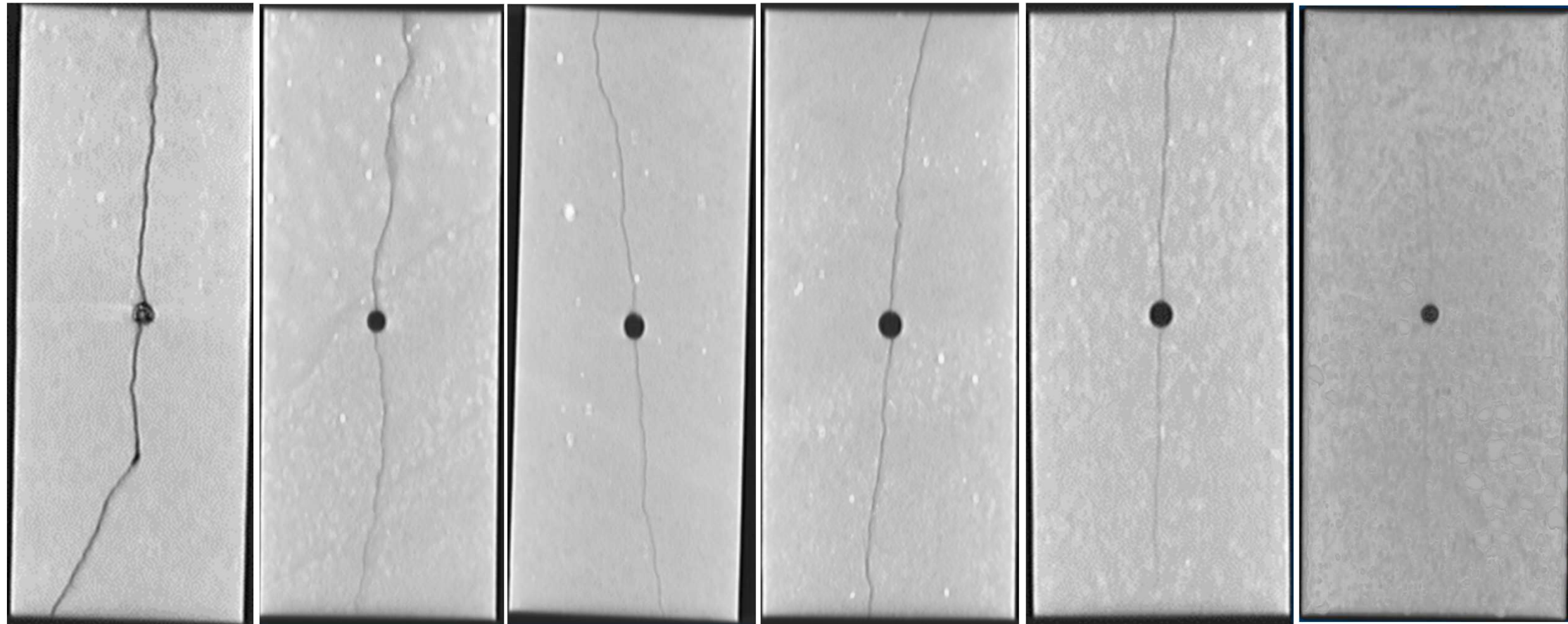
Sample No.	Axial Stress(MPa)	Conf. Stress(MPa)	Fracture Fluid	Flow Rate(cc/min)	Bd Pressure(MPa)	Fracture outcome
152-7-3	6	0	Nitrogen	1	23.13	Clear Frac
152-5-6	12	0	Nitrogen	1	24.84	Clear Frac
152-2-1	12	0	Nitrogen	1	20.46	Clear Frac
153-5-2	12	0	Nitrogen	1	19.88	Clear Frac
153-5-4	12	0	Nitrogen	1	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



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

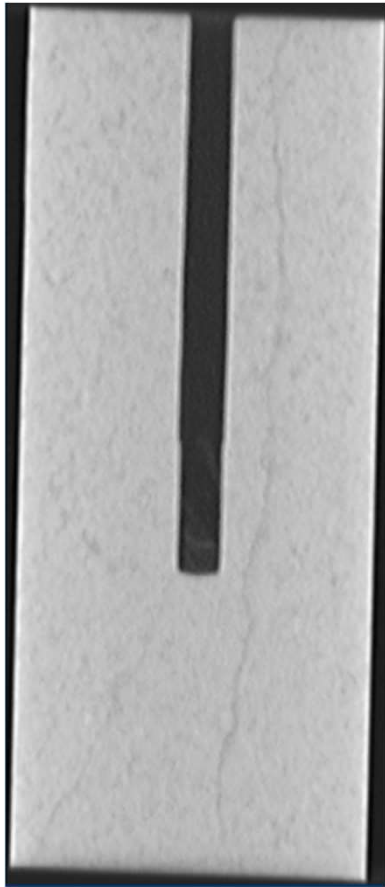
153-3-1
22MPa

153-4-1
24MPa

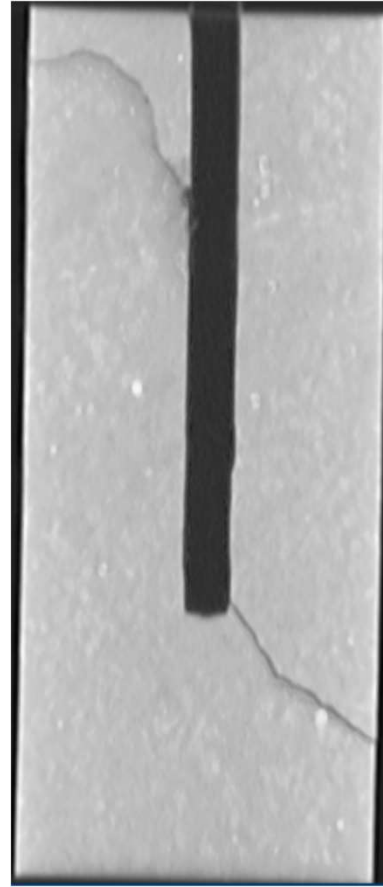
153-6-2
45.61MPa

31-6-1
94.55MPa

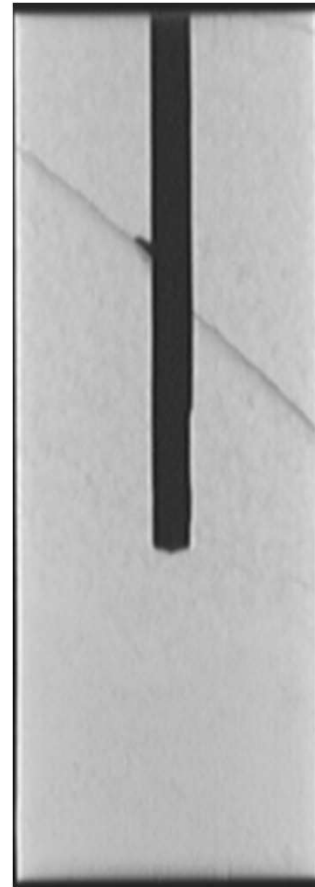
Fracture geometry results comparison (2)



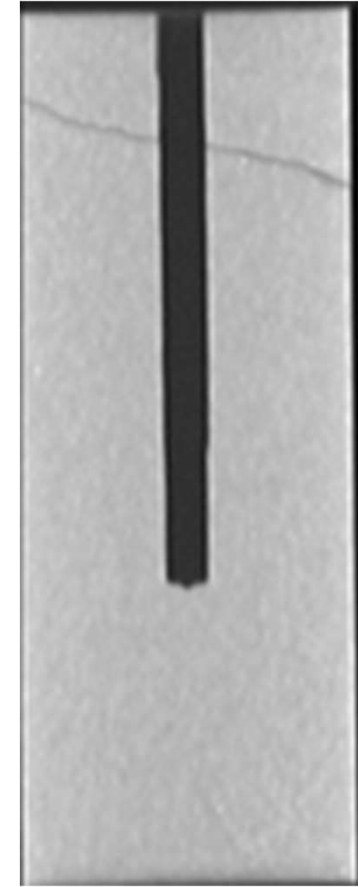
30-4-4
 $V:H = 4:1$
 $V = 12 \text{ MPa}, H = 3 \text{ MPa}$



153-4-7
 $V:H = 1:1$
 $V = 15 \text{ MPa}, H = 15 \text{ MPa}$

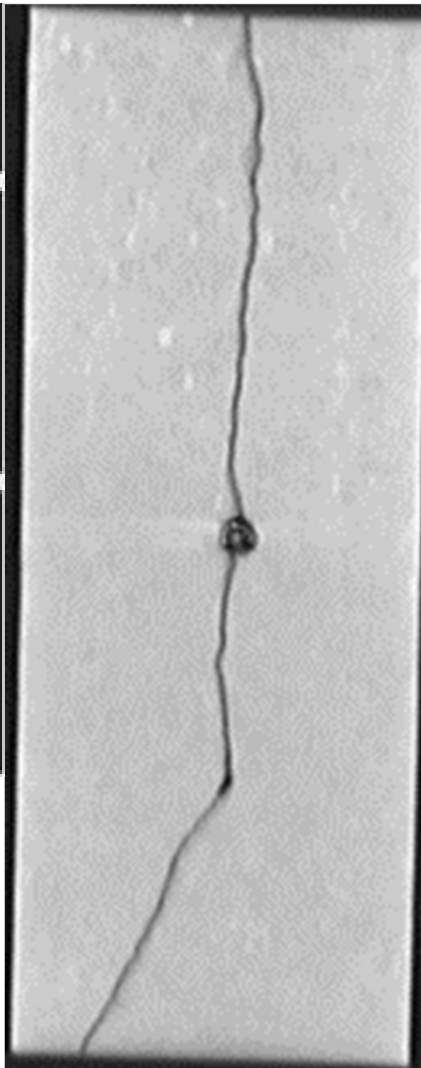
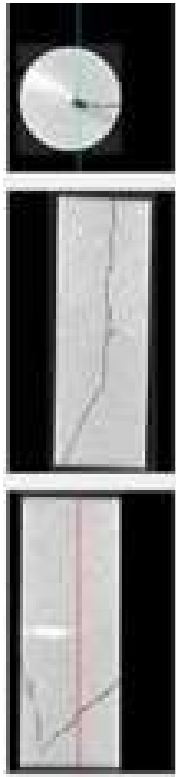
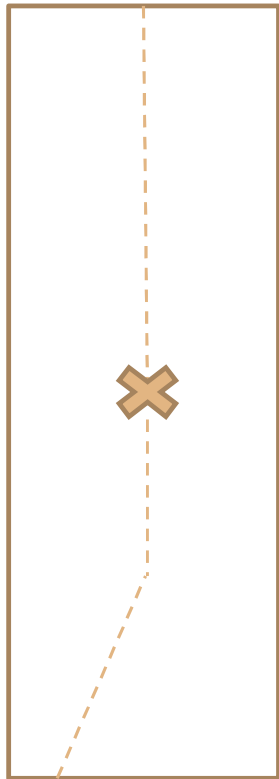


153-6-7
 $V:H = 1:3$
 $V = 1 \text{ MPa}, H = 3 \text{ MPa}$

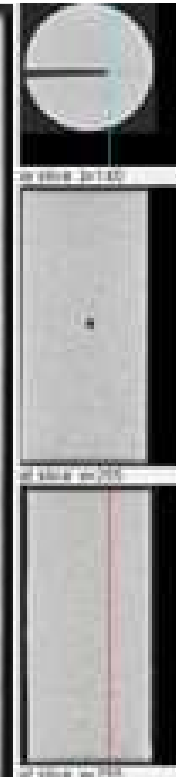
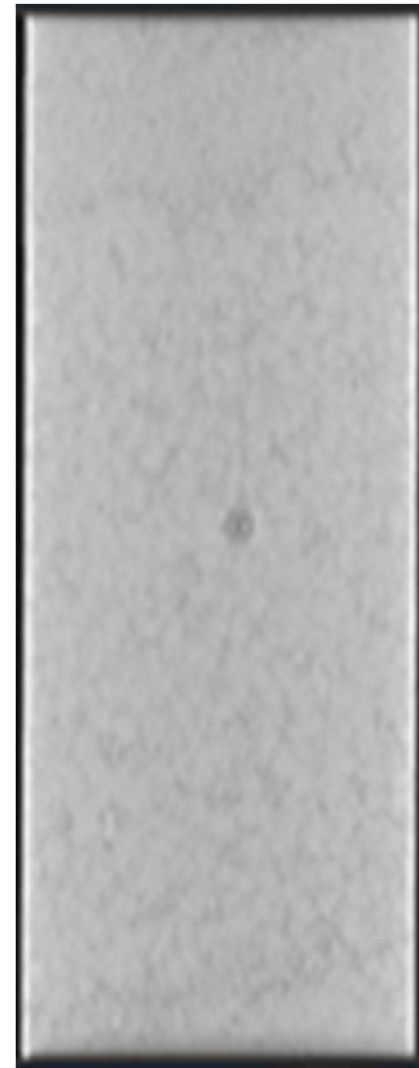


152-7-7
 $V:H = 1:6$
 $V = 0.5 \text{ MPa}, H = 3 \text{ MPa}$

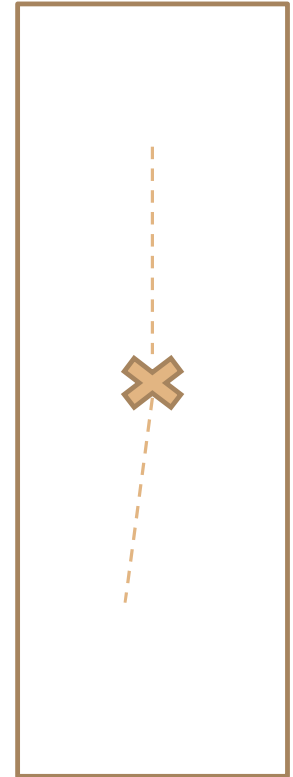
Fracture geometry results comparison (3)



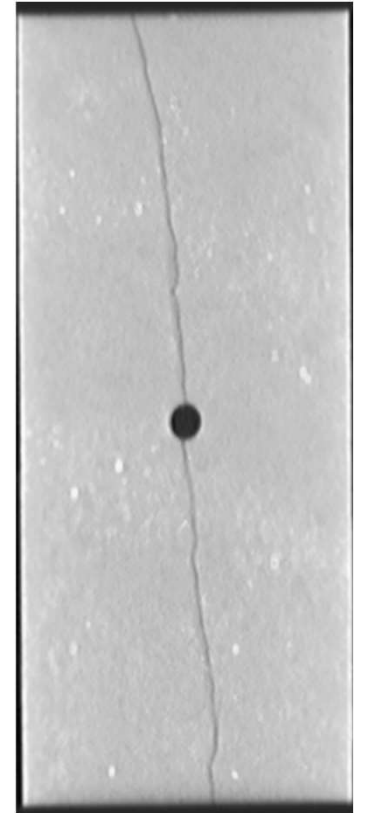
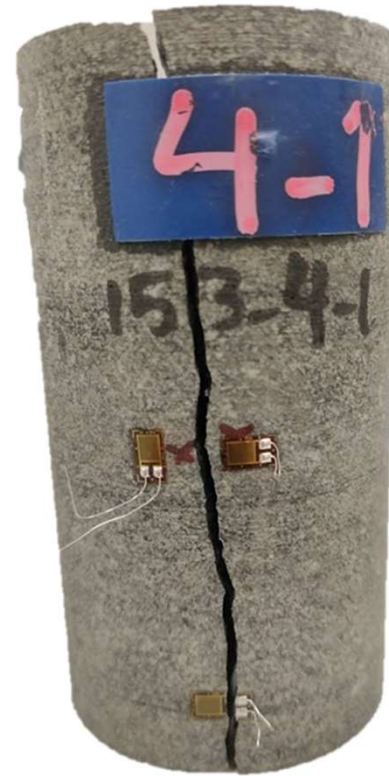
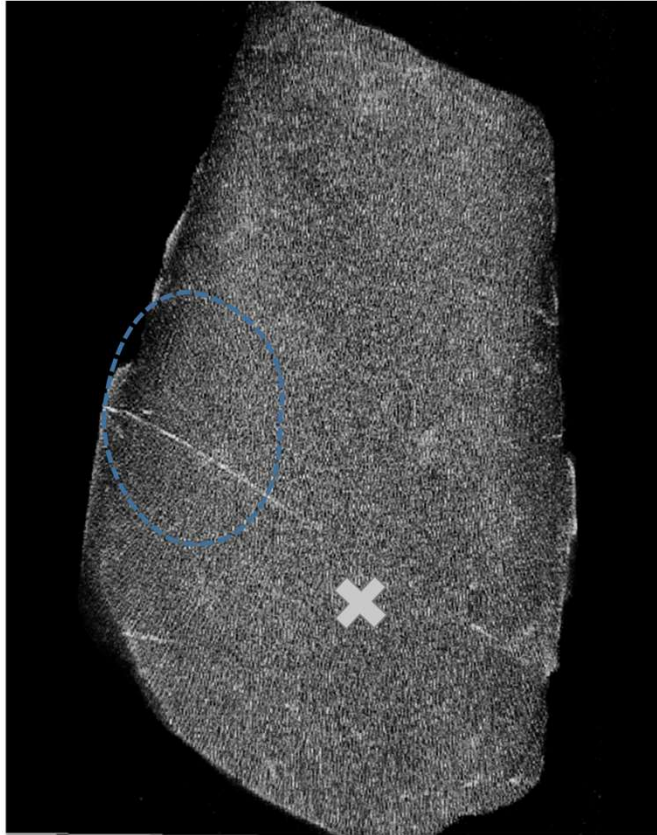
153-5-4
Nitrogen



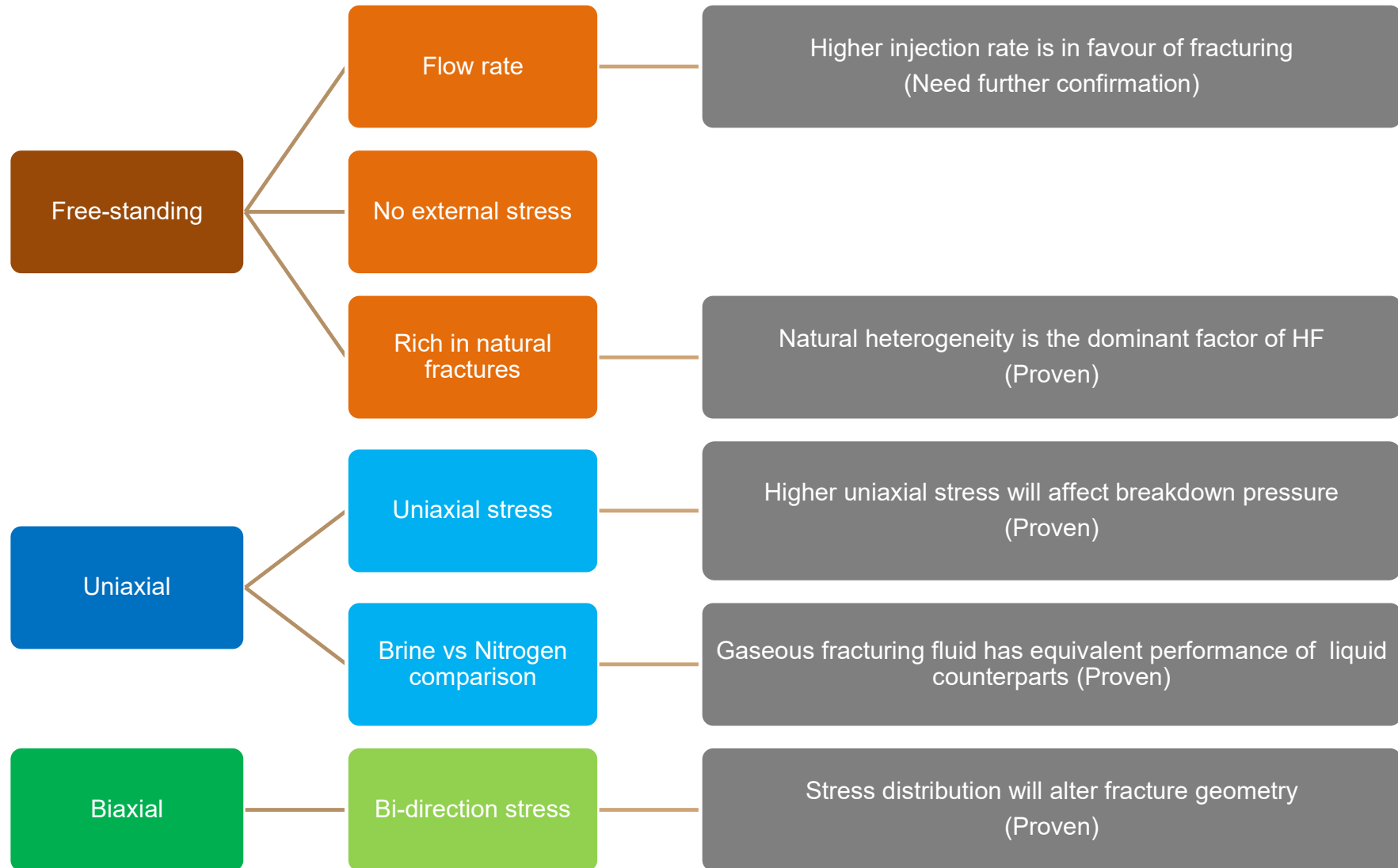
30-6-6
Brine



Fracture geometry results comparison (4)

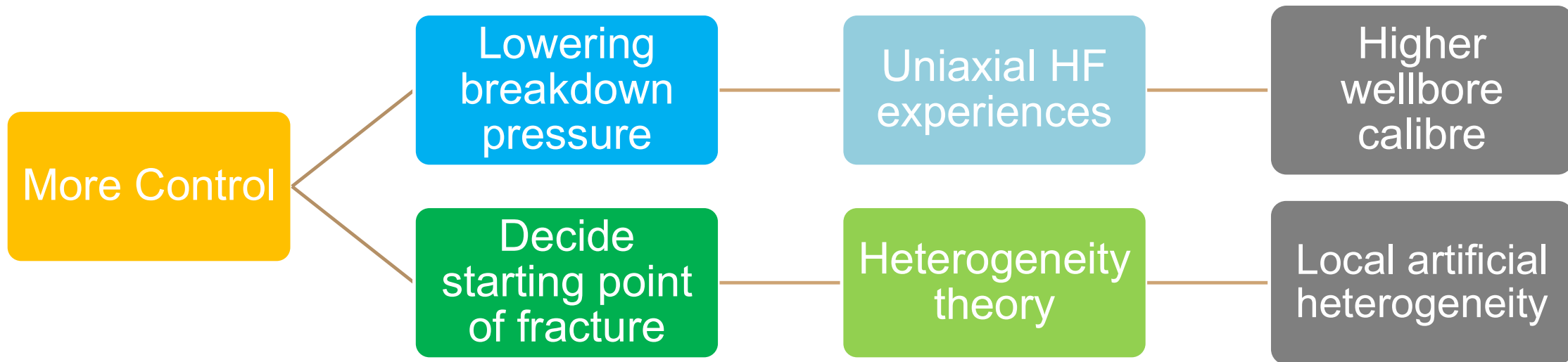


Experimental results

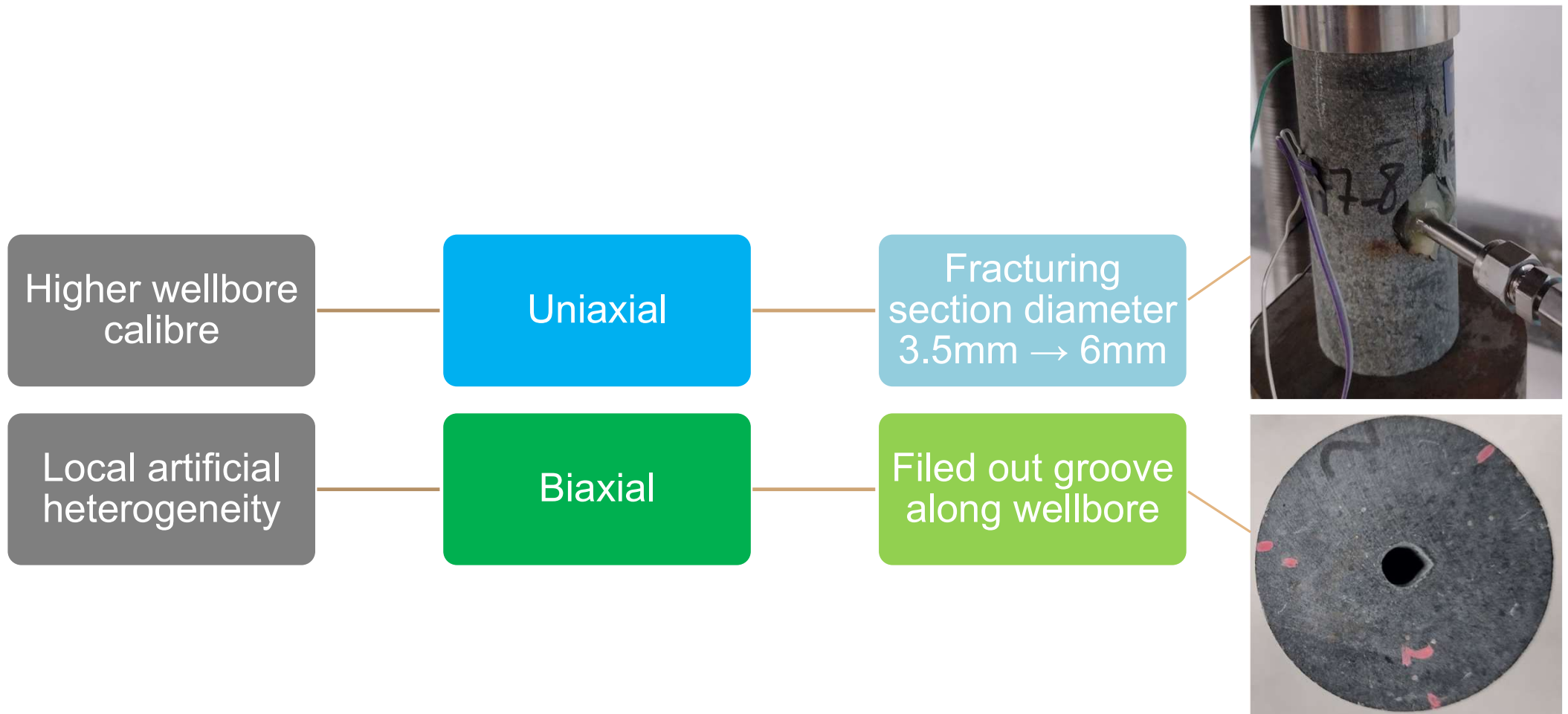


Conclusions(?)

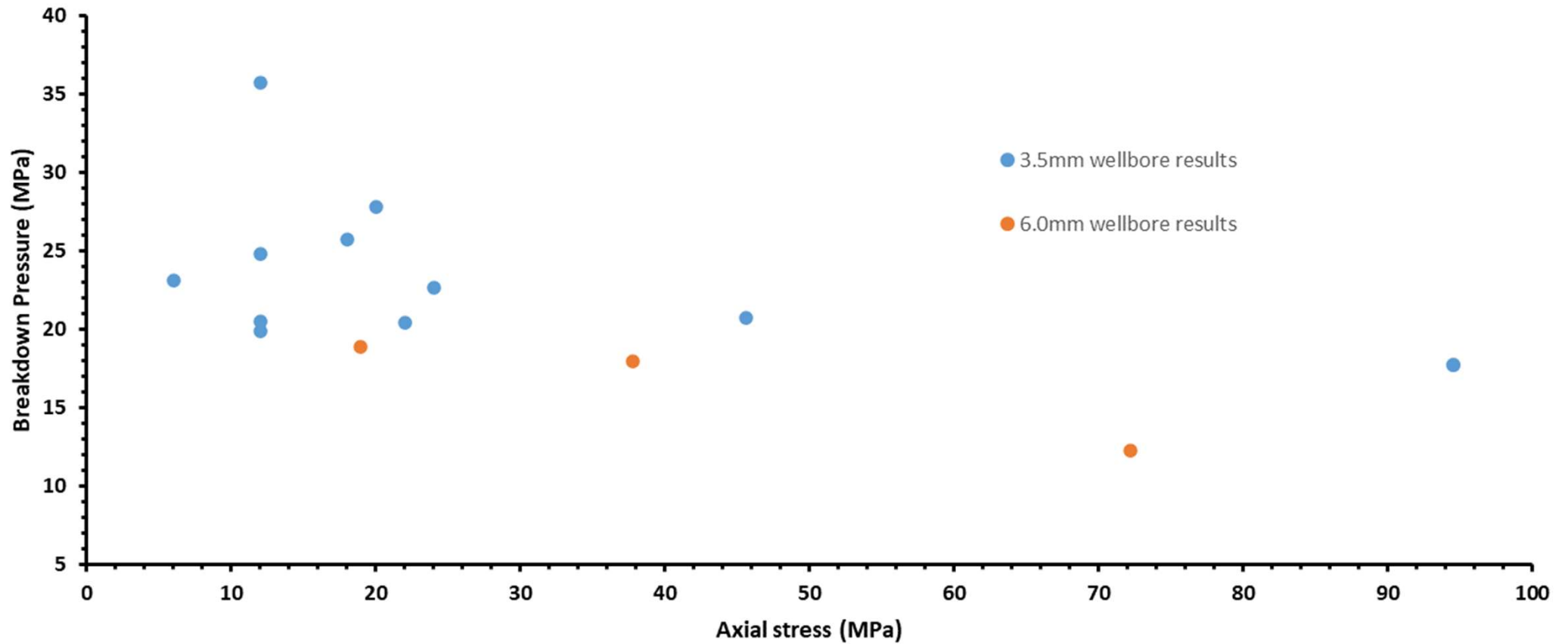
More control over HF



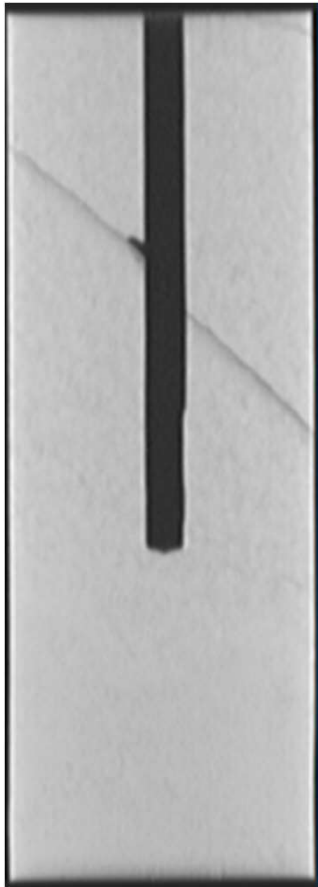
Experimental approach for more control over HF



Breakdown pressure comparison (4)



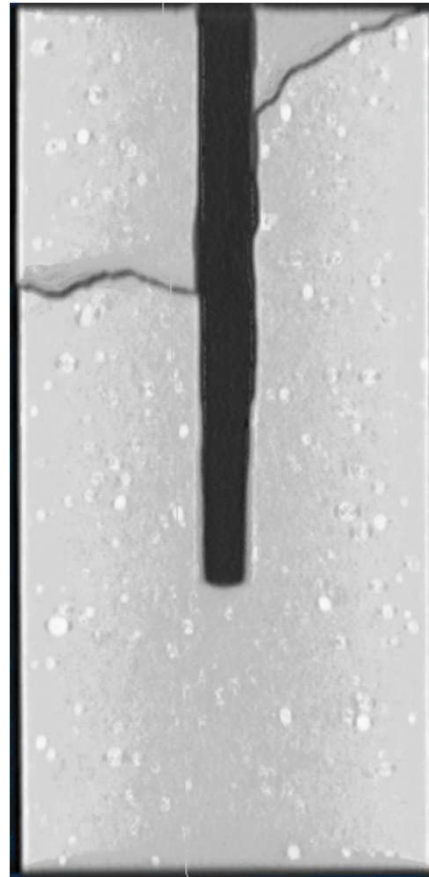
Fracture geometry results comparison (5)



153-6-7

V:H = 1:3

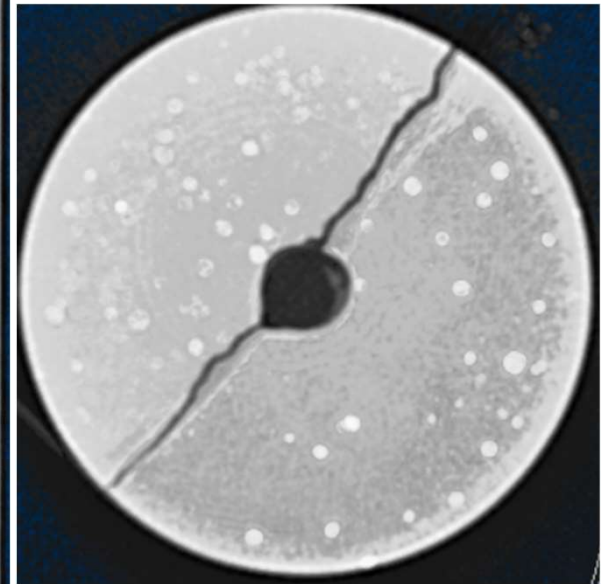
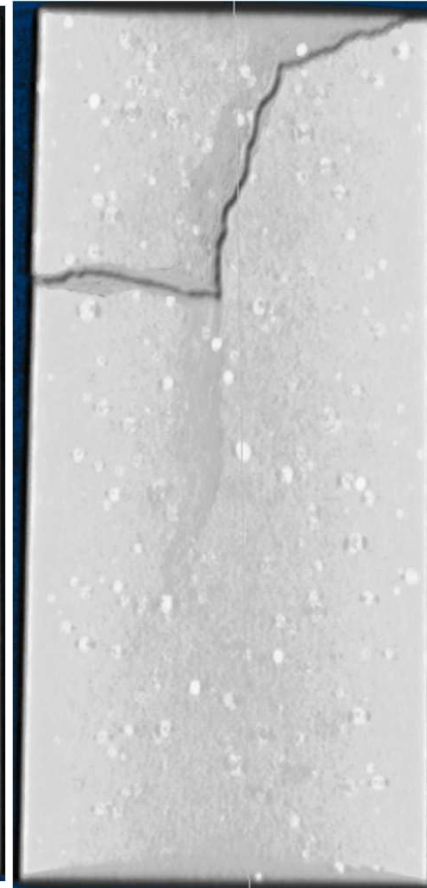
V = 1 MPa, H = 3 MPa



153-3-2

V:H = 1:3

V = 1 MPa, H = 3 MPa



Control methods proven

More Control

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graph LR; A[More Control] --> B[Lowering breakdown pressure]; A --> C[Decide starting point of fracture]; B --> D[Higher wellbore calibre (proven)]; C --> E[Local artificial heterogeneity (proven)];
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The diagram is a flowchart illustrating control methods for fracture treatment. It starts with a yellow box on the left labeled 'More Control'. Two lines branch out from this box to two intermediate boxes: a blue box labeled 'Lowering breakdown pressure' and a green box labeled 'Decide starting point of fracture'. From the blue box, a line leads to a grey box labeled 'Higher wellbore calibre (proven)'. From the green box, a line leads to a grey box labeled 'Local artificial heterogeneity (proven)'.

Lowering
breakdown
pressure

Higher wellbore
calibre (proven)

Decide starting
point of fracture

Local artificial
heterogeneity
(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

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Thank you

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