Post-Fracturing Rock-Fluid Reactions in Sub-Surface Caney Shale of Southern Oklahoma

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OFFICE OF OIL & NATURAL GAS

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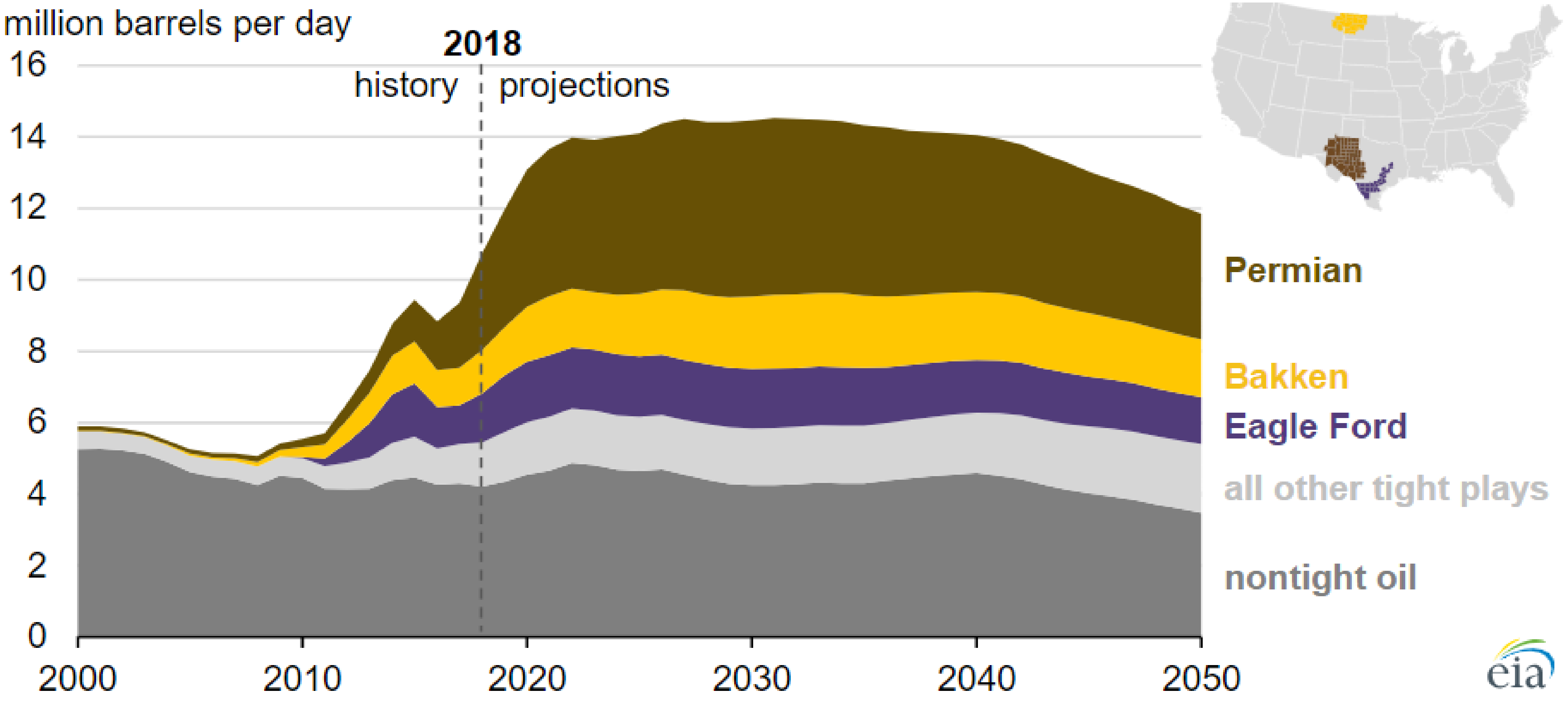
PRESENTATION OUTLINE

- ❑ Overview
- ❑ Problem
- ❑ Objectives
- ❑ Materials and Methodology
- ❑ Results and Discussions
- ❑ Conclusions
- ❑ Plans Going Forward

OVERVIEW – Conventional versus Unconventional



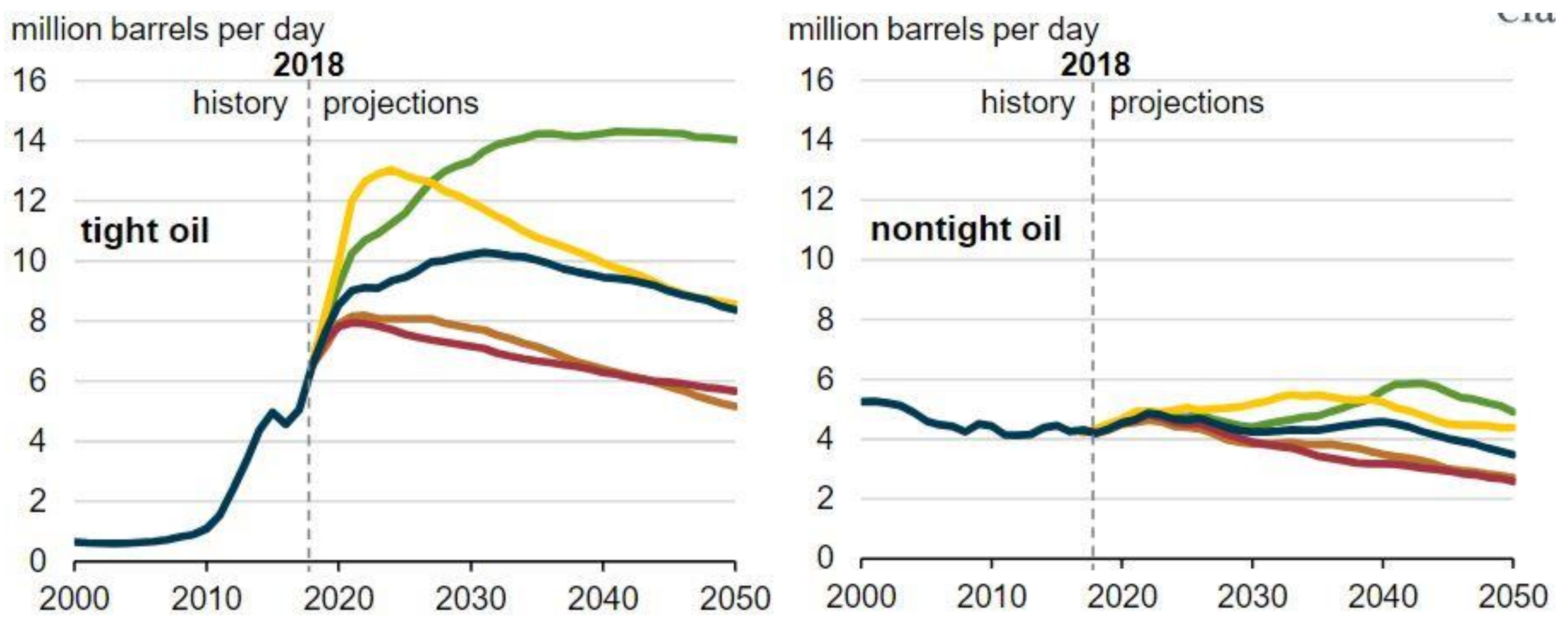
Contributions from conventional and unconventional sources to total hydrocarbon production in USA

Source: US Energy Information Administration

OVERVIEW - PROJECTIONS

Contribution of unconventional hydrocarbon sources to total production is projected to increase

Graphs below show contributions for various scenarios



High Technology Development

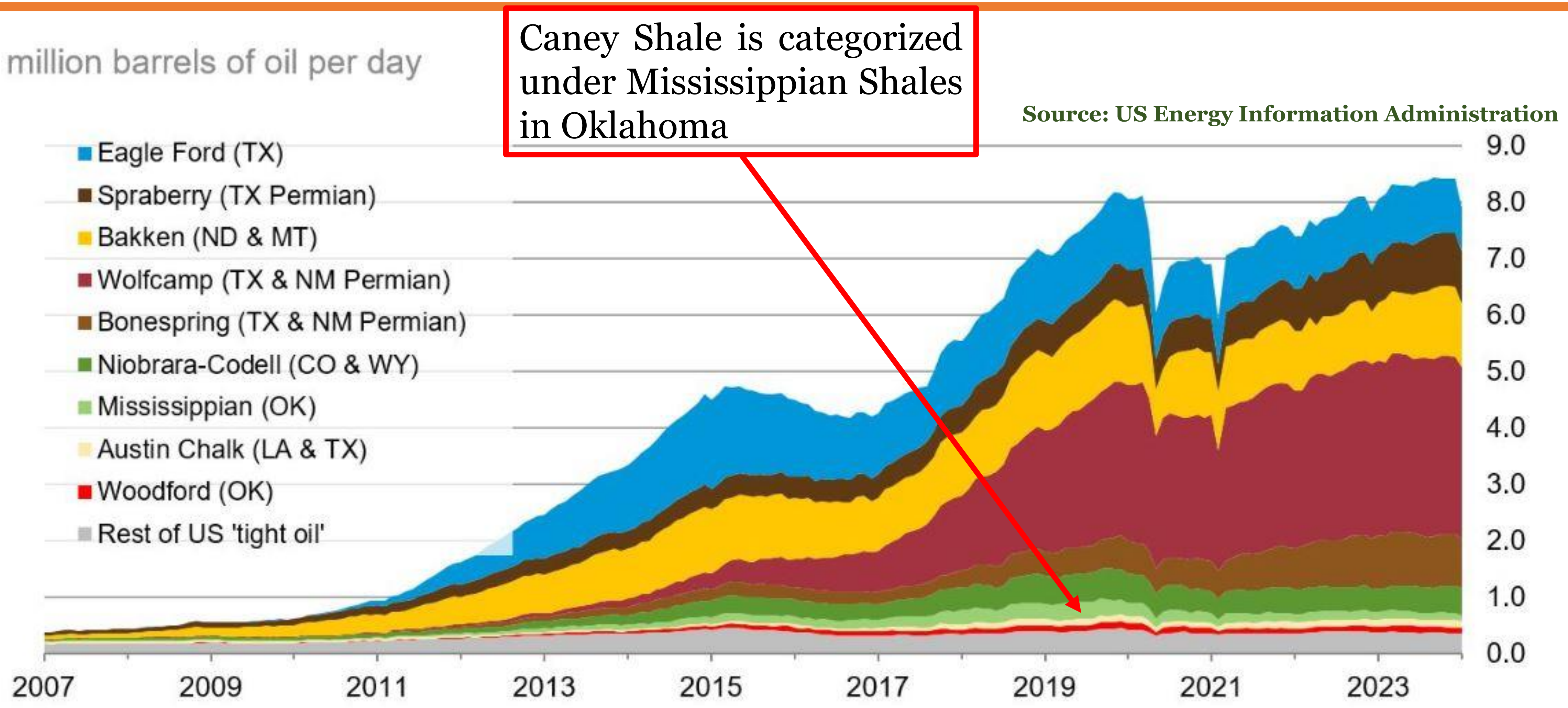
Low Technology Development

High Petroleum Prices

Low Petroleum Prices

Source: US Energy Information Administration

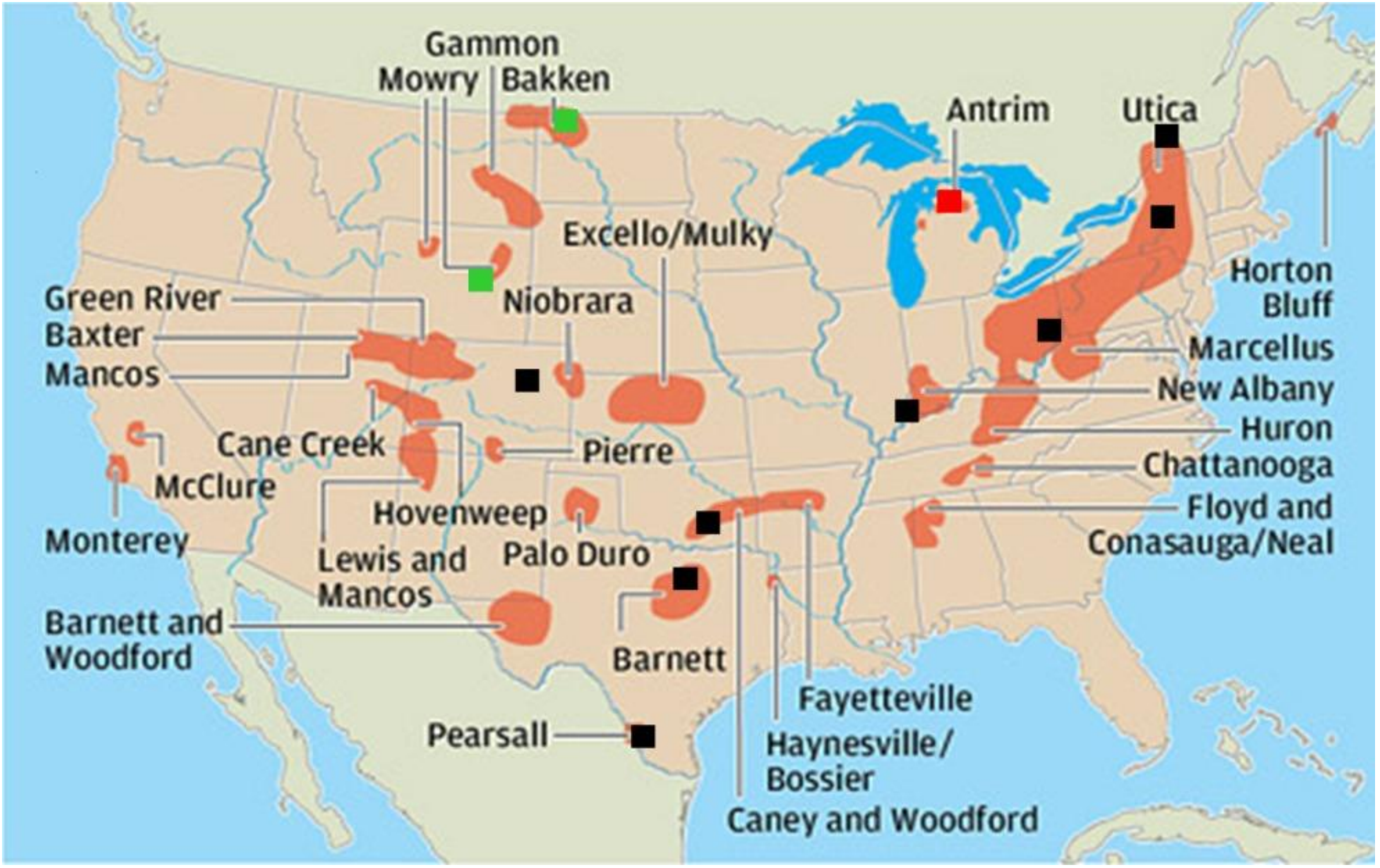
OVERVIEW – Caney Shale Contribution



Contributions from various unconventional sources to total unconventional production in USA

PROBLEM

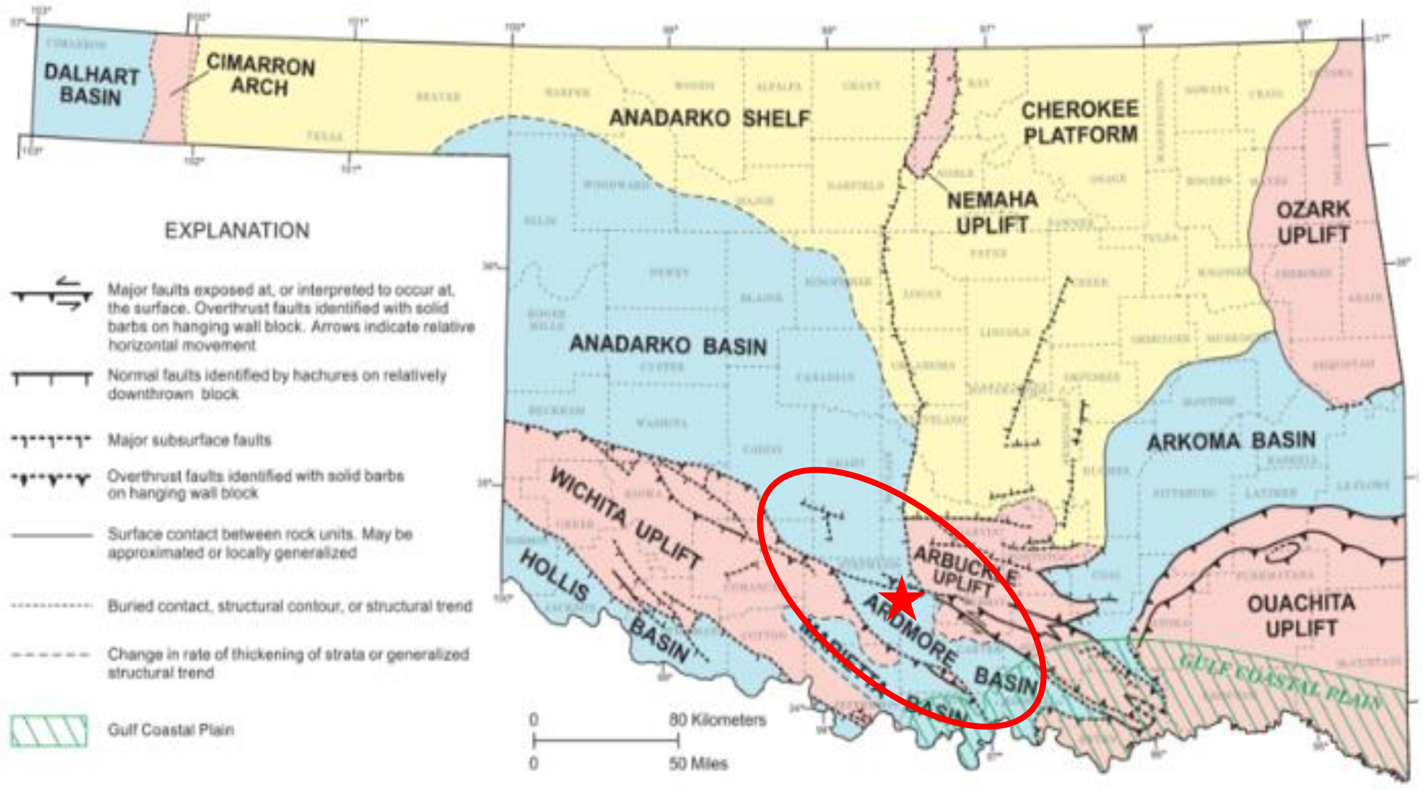
- Recent statistics of unconventional shale reserves in the USA are estimated at approximately, 6 trillion barrels of oil and 495 trillion cubic feet of gas (Farrokhrouz et al., 2022)
- Complex mineralogy and ultra-low permeability of shale reservoir makes development and production of these reservoirs challenging (Swami et al., 2012)
- Current recovery from shale reservoirs is just about 10% of original hydrocarbons in place (Mukhina et al., 2021)
- Current research aims to understand these reservoirs to help create technologies that will enhance recovery



Locations of unconventional hydrocarbon deposits in the United States of America (https://www.ireservoir.com/case_shale.html, accessed on May 12, 2023)

PROBLEM – Specific Area

- The Caney Shale is located in the Ardmore Basin of South-Central Oklahoma Oil Province (SCOOP)
- It overlies the better-known Woodford Shale which has been the main target of drilling in the area over the years
- The Caney Shale, though replete with hydrocarbons, is characterized by high clay content, complex mineralogy, and ultra-low permeability
- This makes hydraulic fracturing the most viable option in producing from this shale



Geological map of Oklahoma, showing SCOOP area (red ellipsoid) and well locations (red star) (*after Johnson, 2008*)

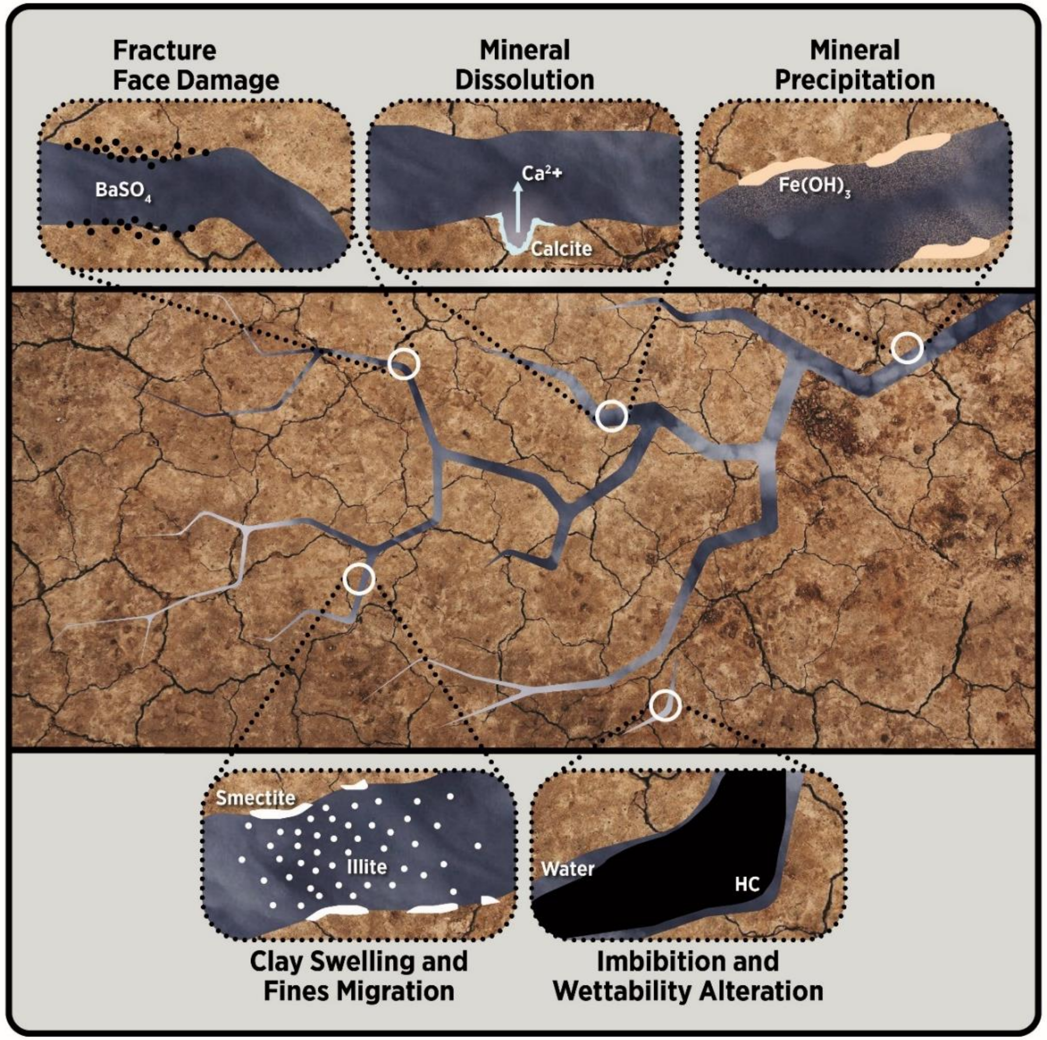
- This study characterizes the long-term geochemical responses of the Caney Shale after hydraulic fracturing

OBJECTIVES

This work is designed to investigate the impact of geochemical rock-fluid reactions on permeability of Caney Shale

The following sub-objectives culminate in achieving this objective:

1. Evaluating the mineralogy of Caney Shale in South Central Oklahoma Province (SCOOP)
2. Understanding the microstructural configuration and spatial heterogeneity of the Caney Shale
3. To evaluate potential geochemical rock-fluid interactions in Caney Shale
4. To identify the mechanisms controlling geochemical rock-fluid interaction in the Caney Shale and the factors that enhance or reduce these mechanisms
5. To assess the impact of rock-fluid interactions on evolution of petrophysical (permeability and porosity) and mechanical properties of Caney Shale



Fracture and near-fracture Rock-Fluid Interaction following hydraulic fracturing of reservoir formation

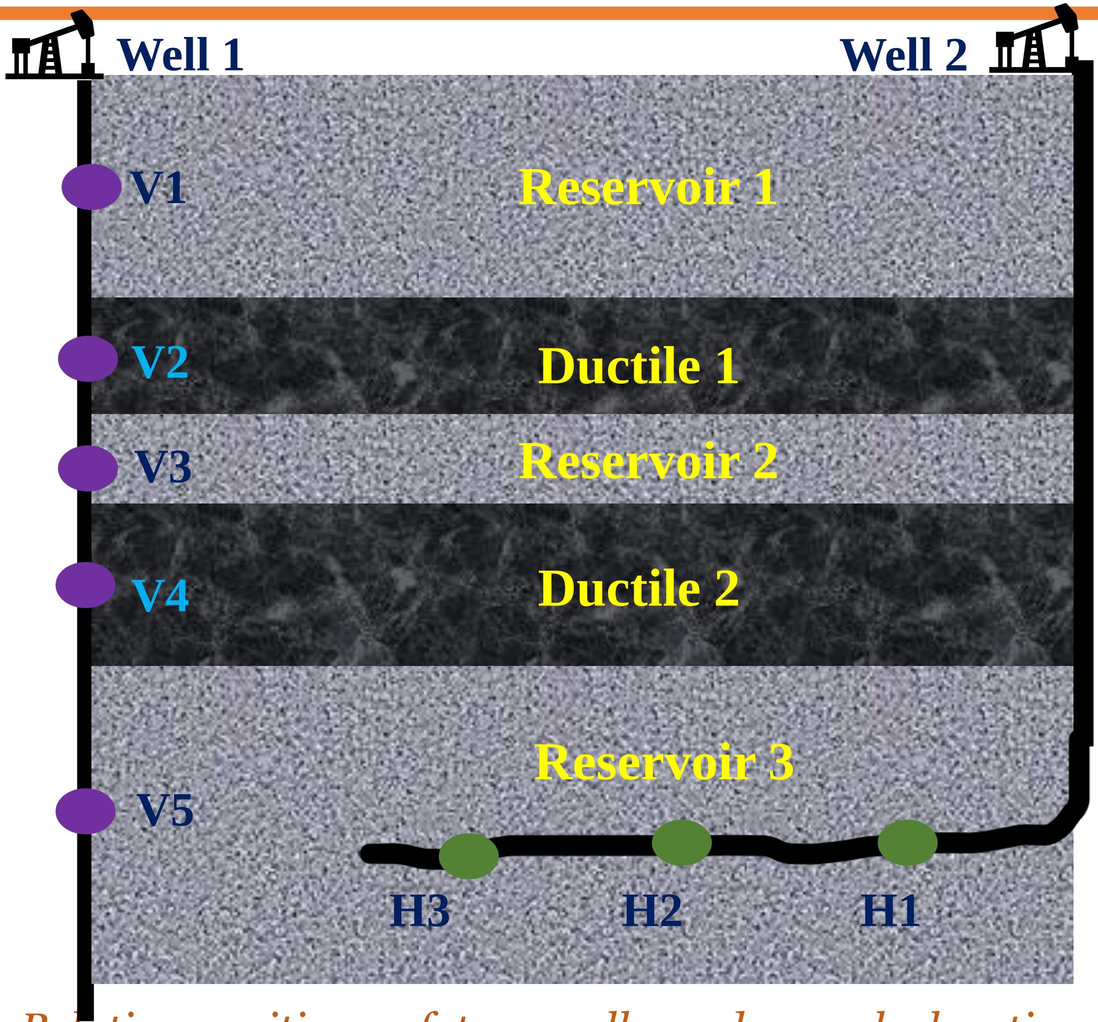
MATERIALS AND METHODLOGY

Rock samples used for this experiment are recovered from two different wells as follows:

- Well 1:
  - Vertical well across entire Caney Shale
  - Samples are recovered as cored-rock
- Well 2:
  - Horizontal well drilled within Reservoir 3
  - Samples are recovered as rock-cuttings at 1000ft intervals

Rock samples are prepared and ground into powders with average particle size of 30μm

Field Fracturing Fluid and Field Produced Brines recovered from Caney Shale were the main reacting fluids. Deionized water was used as a standard for comparison



Relative positions of two wells and sample locations: Samples V1 to V5 are cored-rocks from five (5) zones of the formation. H1 to H3 are rock cuttings spaced 1000ft horizontally at approximately the same vertical depth (Schematic not drawn to scale)

MATERIALS AND METHODLOGY

SAMPLE PREPARATION AND STATIC BATCH REACTOR EXPERIMENT

Rock Powder

Vertical Well (Cored-Rock)
Horizontal Well (Rock-Cuttings)

+

Fluids

Exp 1: Synthetic Fracturing Fluids
Exp 2: Field Fracturing Fluid
Exp 3: Field Produced Fluid
Standard: Deionized Water

Oven

Conditions: 95°C (203°F), 14.7psi
(200mL:1g) Avg ps =30µm
Exp 2 & 3: 7 and 30 days
(150mL:1g) Avg ps =30µm

LABORATORY TECHNIQUES AND DATA ACQUISITION

Before → After

- Scanning Electron Microscopy (SEM)
- Energy Dispersive Spectroscopy (EDS)
- X-ray Diffraction (XRD)
- Inductively Coupled Plasma Mass Spectroscopy (ICPMS)

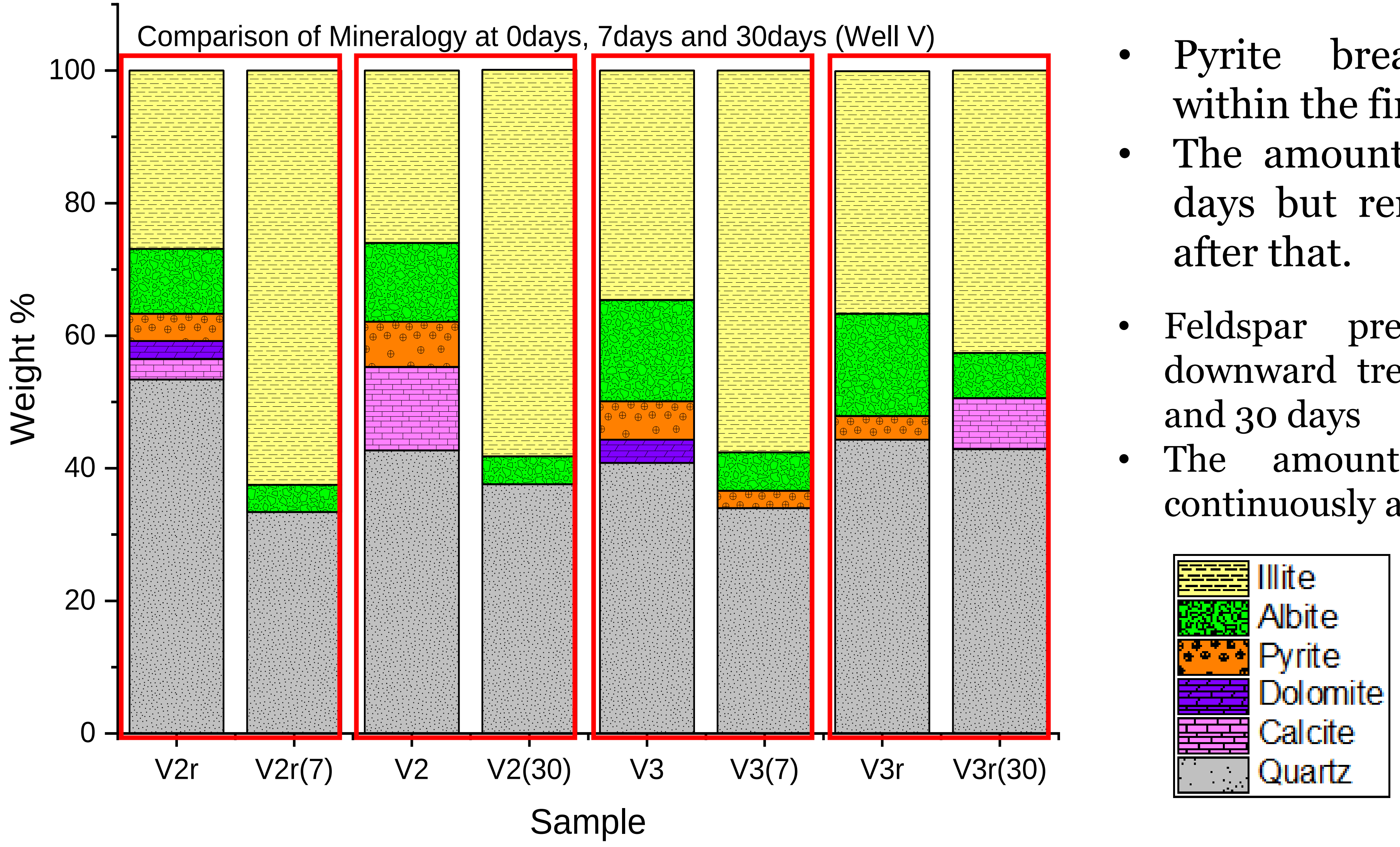
DATA ANALYSES, INTEGRATION AND INTERPRETATION

Microstructure
+
Chemical Compositions
+
Mineralogical Compositions
+
Effluent Chemistry

Characterization of Alterations caused by Geochemical Reaction

Flow chart of materials and methodology used in preliminary experiments, data acquisition and interpretation

RESULTS – Mineralogical Alterations of Caney Shale Powders in Field Fracturing Fluids (HF)-XRD analysis



- Pyrite breakdown occurs mostly within the first 7 days of reaction
- The amount of quartz drops after 7 days but remains relatively constant after that.

- Feldspar presence generally shows a downward trend after reaction at both 7 and 30 days
- The amount of illite is increasing continuously at 7 and 30 days.

V – Vertical Well

(7) – 7days reaction

(30) – 30days reaction

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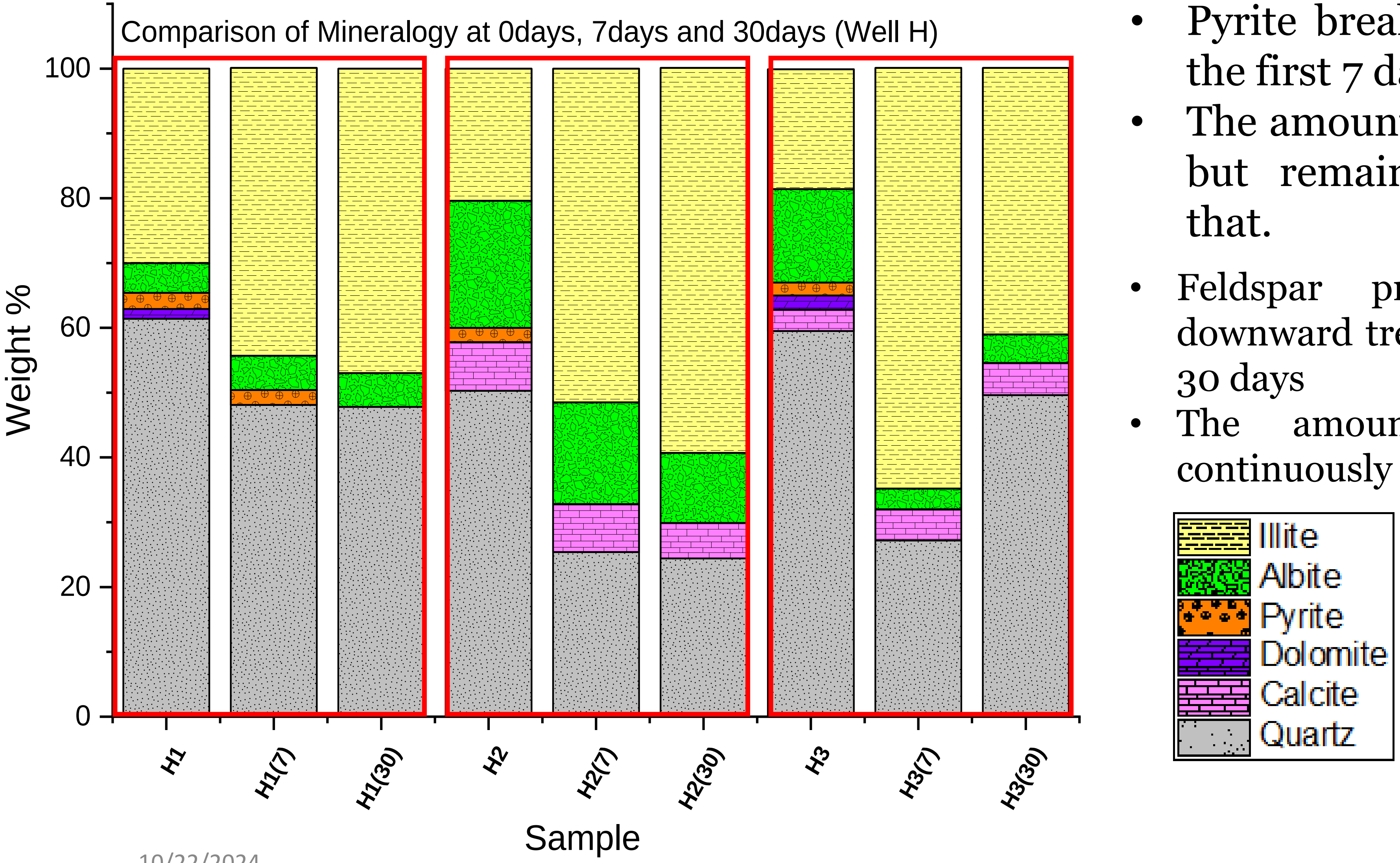

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H – Horizontal Well

(7) – 7days reaction

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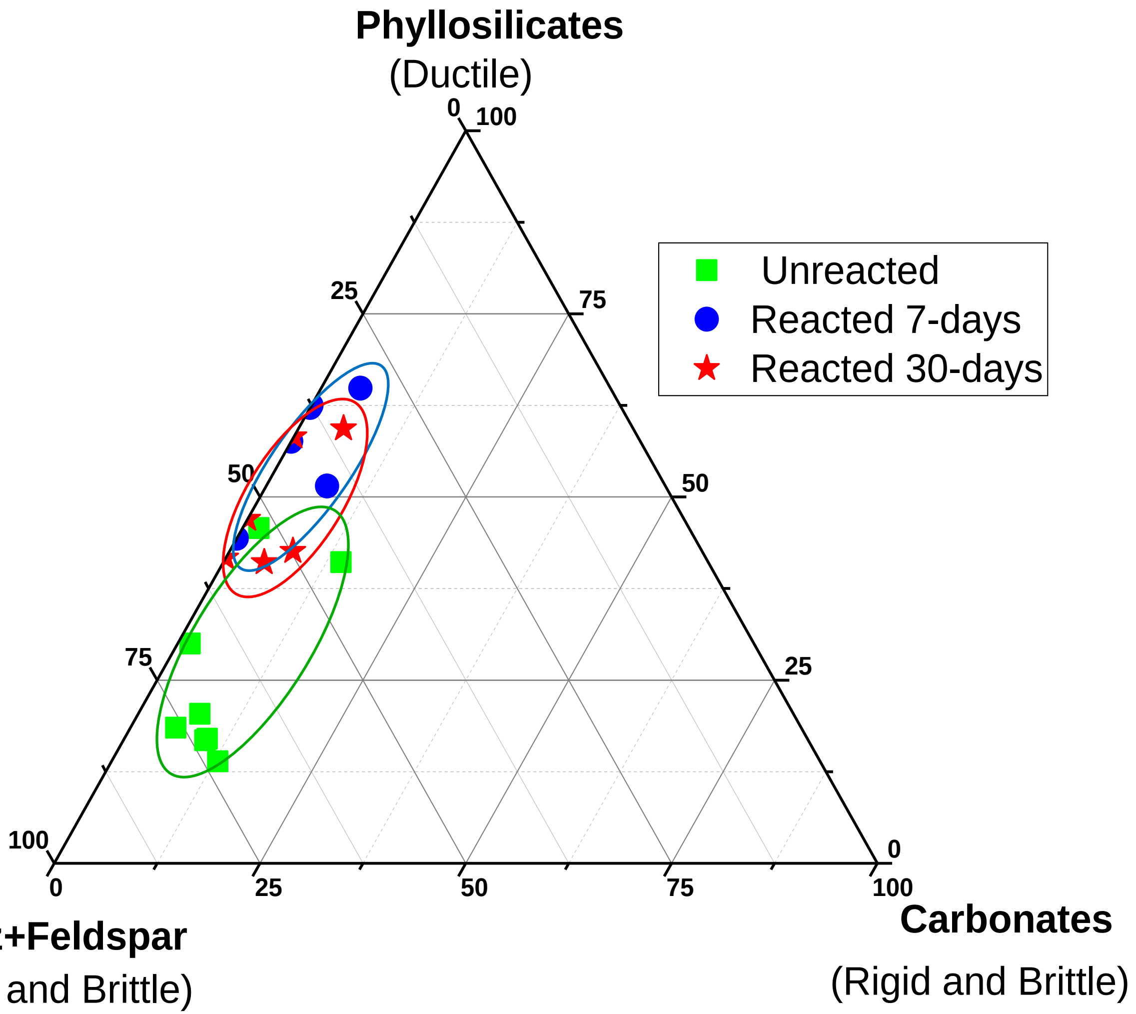
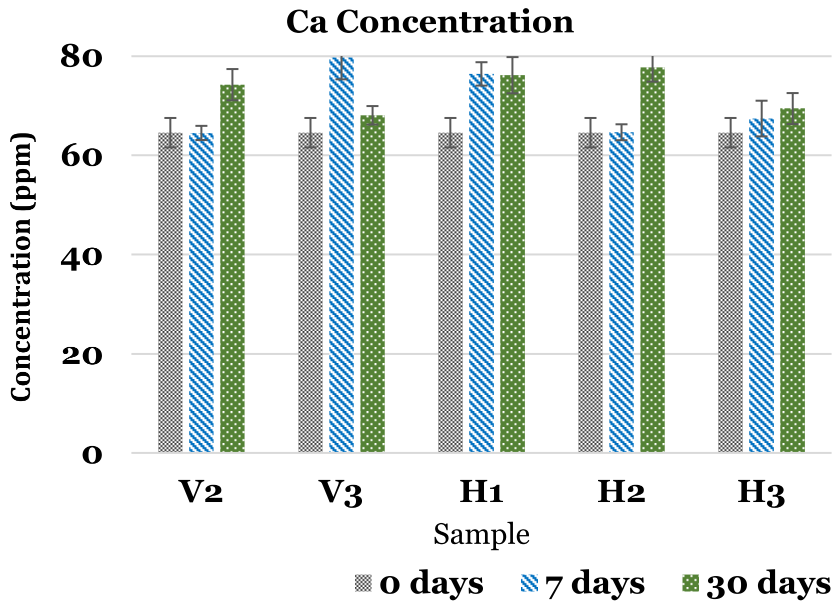
RESULTS – Big Picture

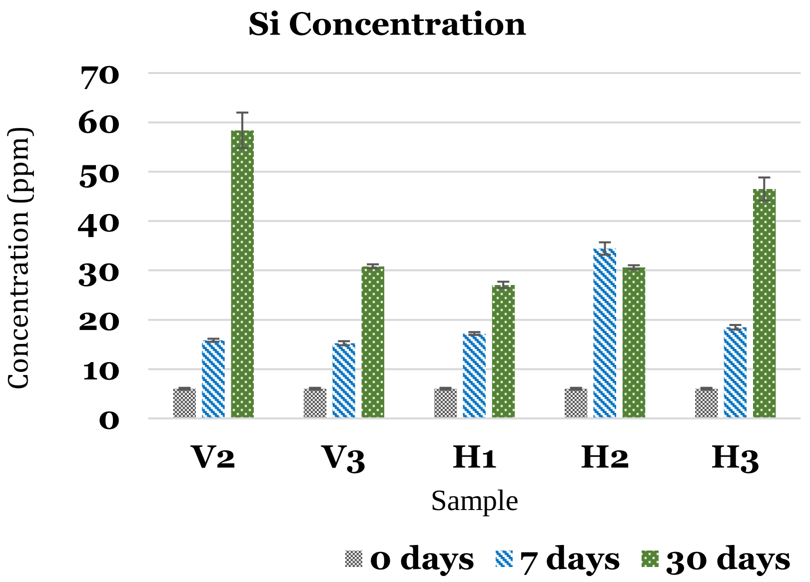


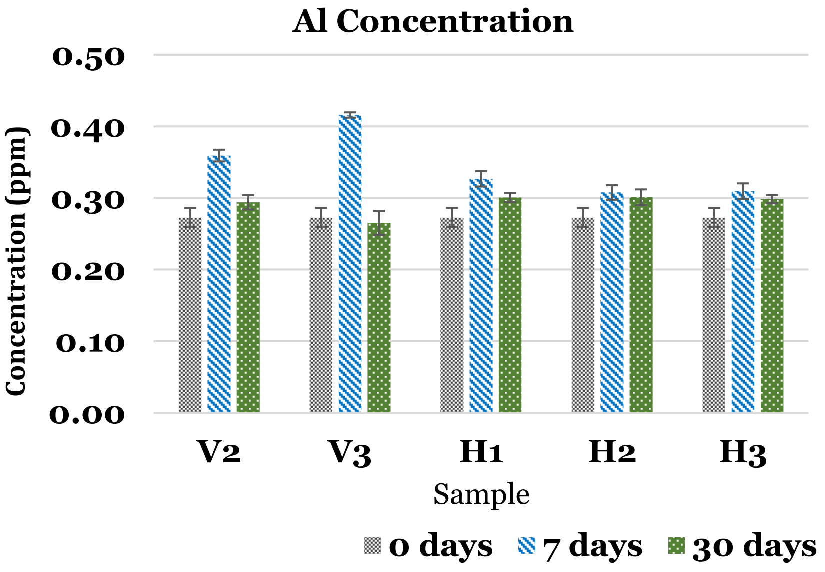
Ternary diagram showing Comparison of unreacted samples to 7 days and 30 days reacted samples – Hydraulic Fracturing Fluids

- The ternary diagram shows the changes in mineralogy that occurred due to geochemical rock fluid interactions
- Mineralogy of rocks are originally closer to quartz, feldspar field which represents the brittle component of the formation
- The breakdown of feldspar, pyrite and carbonates after 7days of reaction shifts the mineralogy towards phyllosilicates
- After 30days of reaction, the mineralogy shifts moderately towards quartz-feldspar field but not enough to regain the original rigid and brittle characteristics
- Shift towards phyllosilicates introduces a ductile character into the rocks

RESULTS - Elemental Composition of Caney-HF Fluid after Experiment (ICPMS)





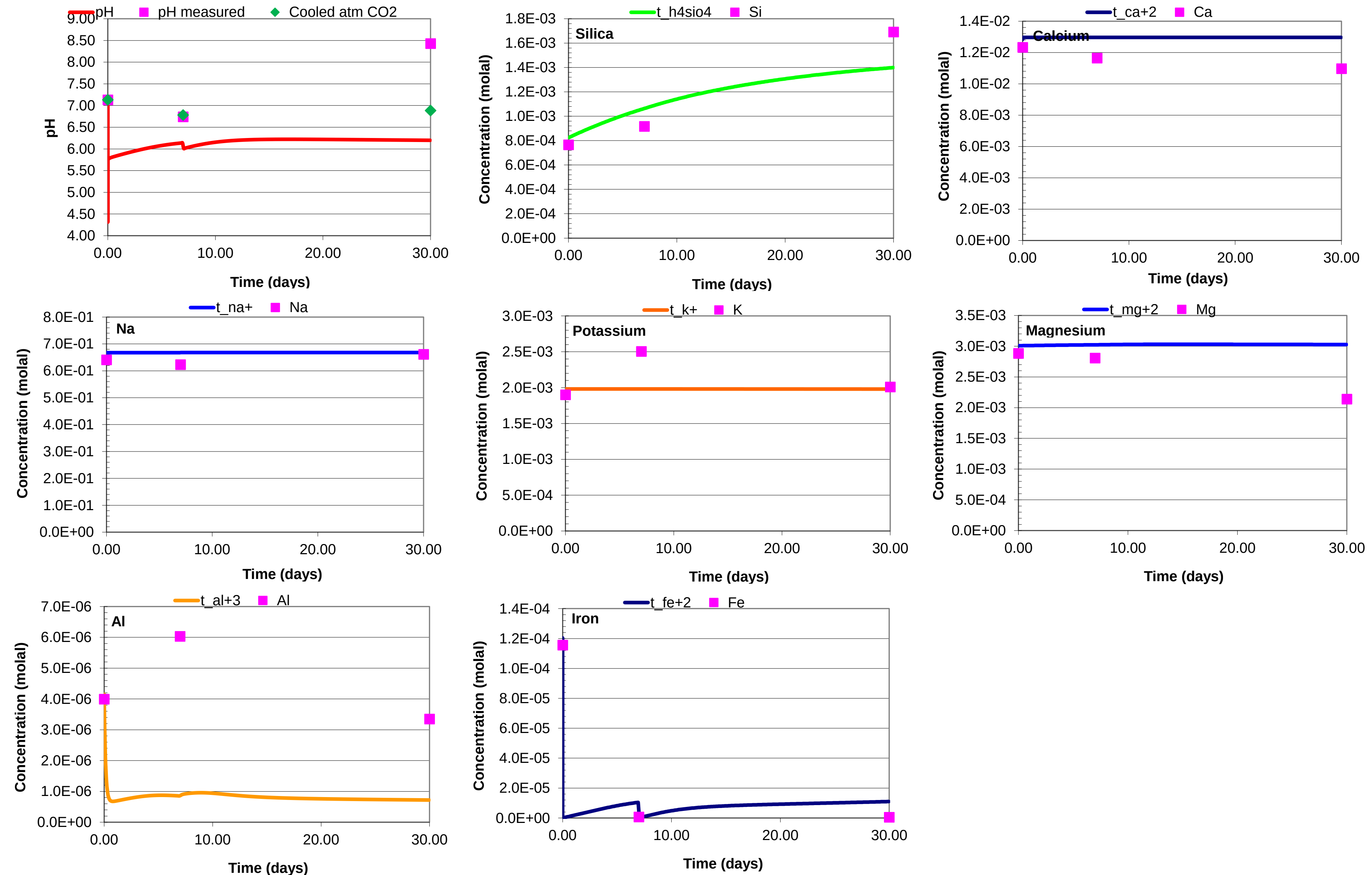


- Ca concentrations relatively stable because, fracturing fluid used for experiment had a circumneutral pH
- Dissolution of pyrite causes transient acidity which initiates dissolution of carbonates
- Cation exchange in clay sites also causes Ca concentration in effluent

- High concentrations of Si observed on the graphs cannot be explained by quartz dissolution at the given conditions
- Dissolution of feldspar contributes to Si concentration in effluent
- Dissolution of biogenic silica could explain high Si concentrations

- Al is mainly from the dissolution of feldspars
- Al entering solution is precipitated at a fast rate – Clays and Al-based minerals
- Similar trends observed for Mg and Fe

RESULTS – Model of Experiment (TOUGHREACT Simulator with Thermodderm Thermodynamic Database) by LBNL



Modeling of experiment shows most elemental concentrations in effluent matching with ICP-MS results

Due to limitations in complete characterization of rock and fluids, some assumptions were made in the model

These assumptions and limitations of model are captured in the next slide

RESULTS – Model of Experiment

The following uncertainties and limitations are worth noting about modeling of experiment:

Thermodynamic data/models

Modeled minerals of mixed composition (e.g. clays) may not have the same composition as in the rock formation

Fluid salinity may exceed the validity range of the implemented ion activity model (extended Debye-Hückel)

Reconstruction of the Fracturing compositions

Anion concentrations computed from assumptions

Organic compounds besides acetate were neglected (unknown potential effects on experimental results)

Rock formation mineralogy

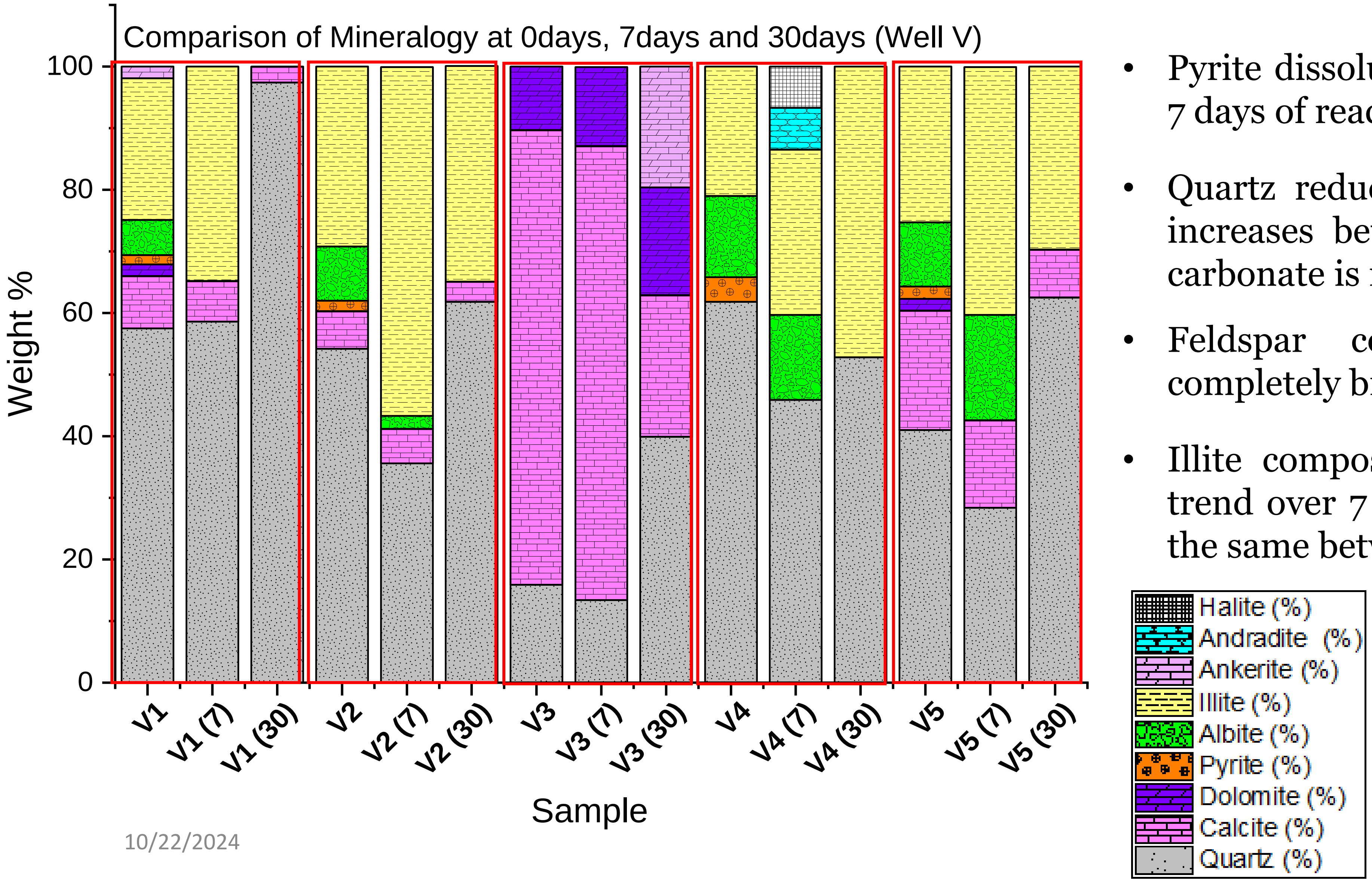
Trace or amorphous minerals (undetected by XRD) impact the system geochemistry – amounts and types were assumed

Sampling effects

Interactions with atmosphere (O_2, CO_2 impact pH and redox)

Mineral reaction rates (kinetic constants, surface area)

RESULTS - Mineralogical Alterations in Vertical Well Samples



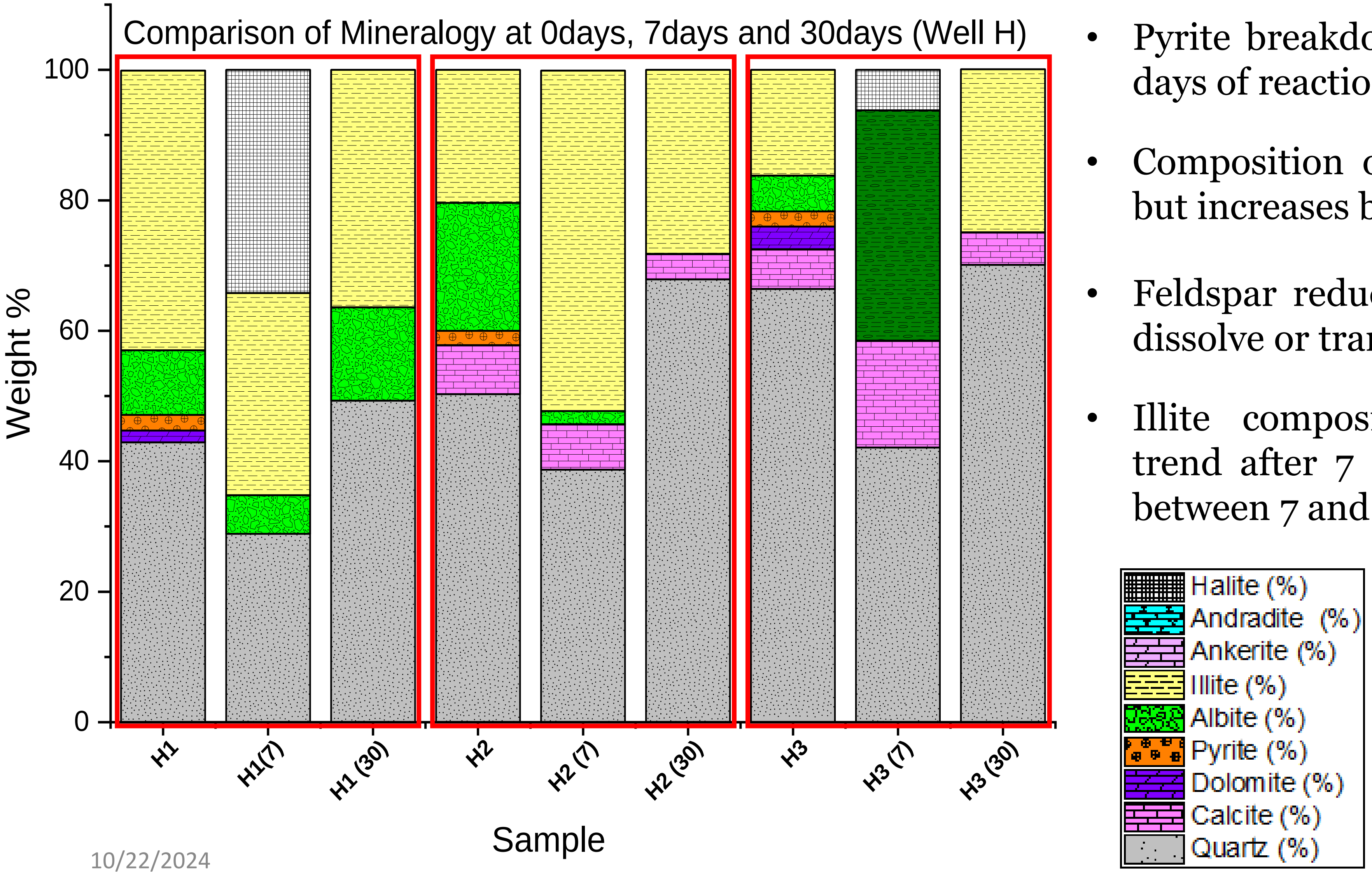
- Pyrite dissolution occurs within the first 7 days of reaction
- Quartz reduces in the first 7 days but increases between 7 to 30 days whilst carbonate is relatively stable
- Feldspar composition reduces and completely breakdown after 30 days
- Illite composition shows an increasing trend over 7 days but remains relatively the same between 7 days and 30 days

V – Vertical Well

(7) – 7 days reaction

(30) – 30 days reaction

RESULTS - Mineralogical Alterations in Horizontal Well Samples



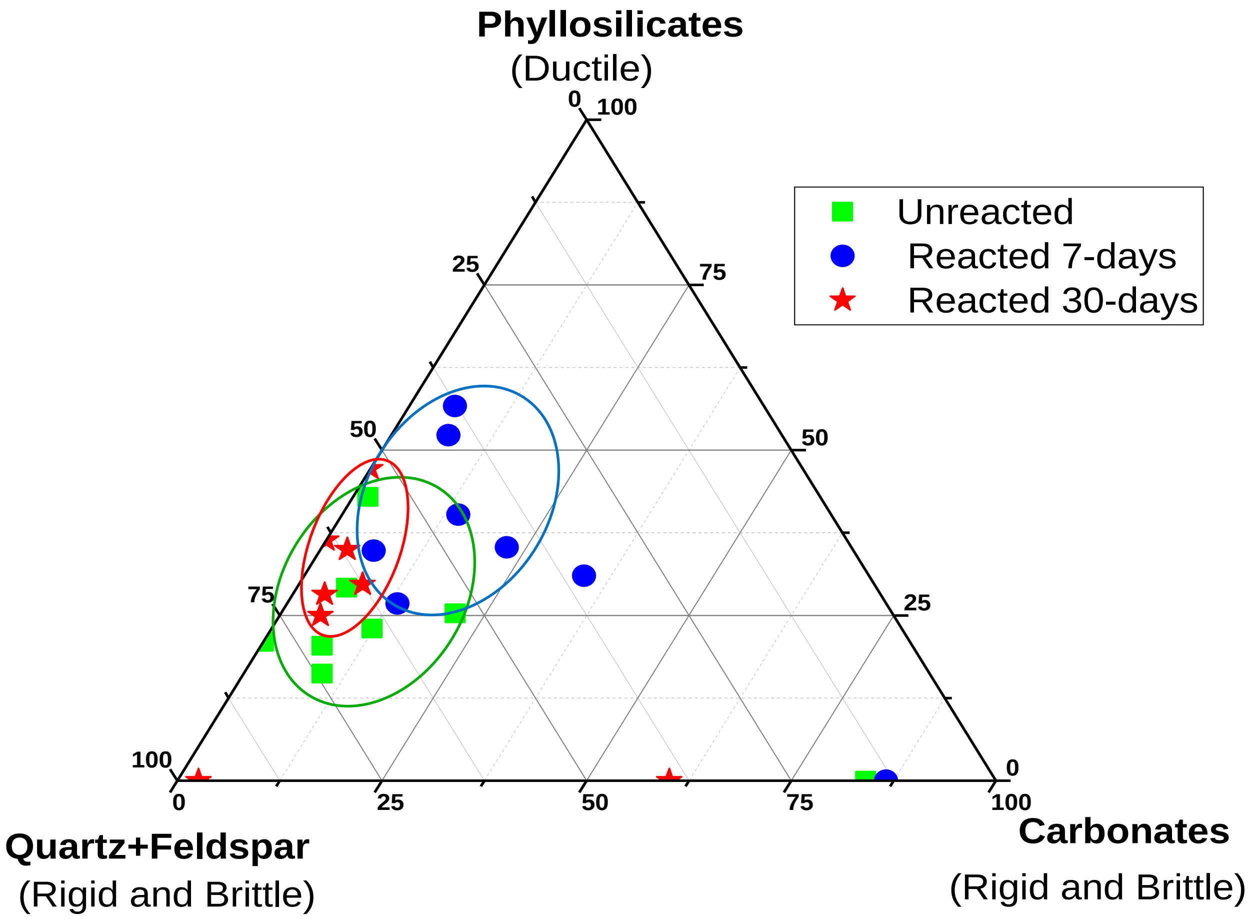
- Pyrite breakdown occurs within the first 7 days of reaction
- Composition of quartz drops after 7 days but increases between 7 to 30 days
- Feldspar reduces continuously and mostly dissolve or transform by 30 days
- Illite composition shows an increasing trend after 7 days reaction and decreases between 7 and 30 days

H – Horizontal Well

(7) – 7 days reaction

(30) – 30 days reaction

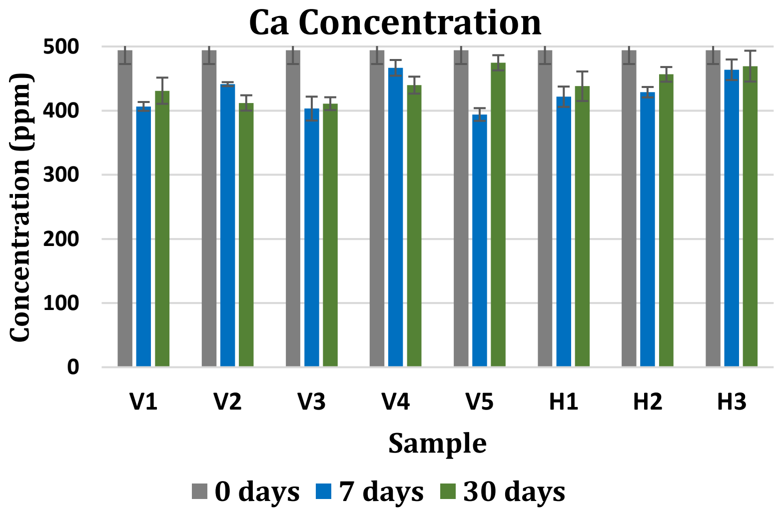
RESULTS – Big Picture

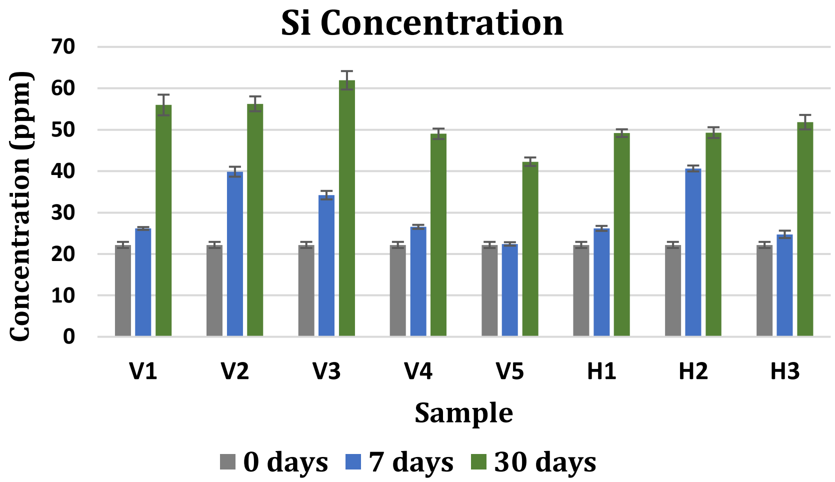


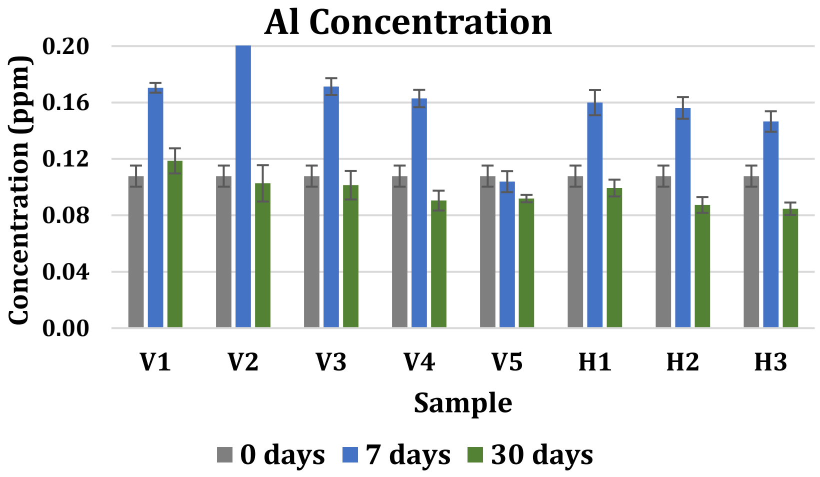
Comparison of unreacted samples to 7 days and 30 days reacted samples – Produced Fluids

- The ternary diagram gives a big picture of impacts of mineralogical changes on rock properties
- Mineralogy of rocks are originally closer to quartz and pyrite, indicating brittleness
- Rock-fluid reaction shifts the samples to phyllosilicate zone, indicating ductility
- Ductility promotes fracture healing thus loss of permeability
- Main reactions that promote shift include:
  - Breakdown of pyrite and microcrystalline quartz
  - Breakdown of feldspar and carbonates
  - Formation of illite

RESULTS - Elemental Composition of Caney-Produced Fluids after Experiment (ICPMS)





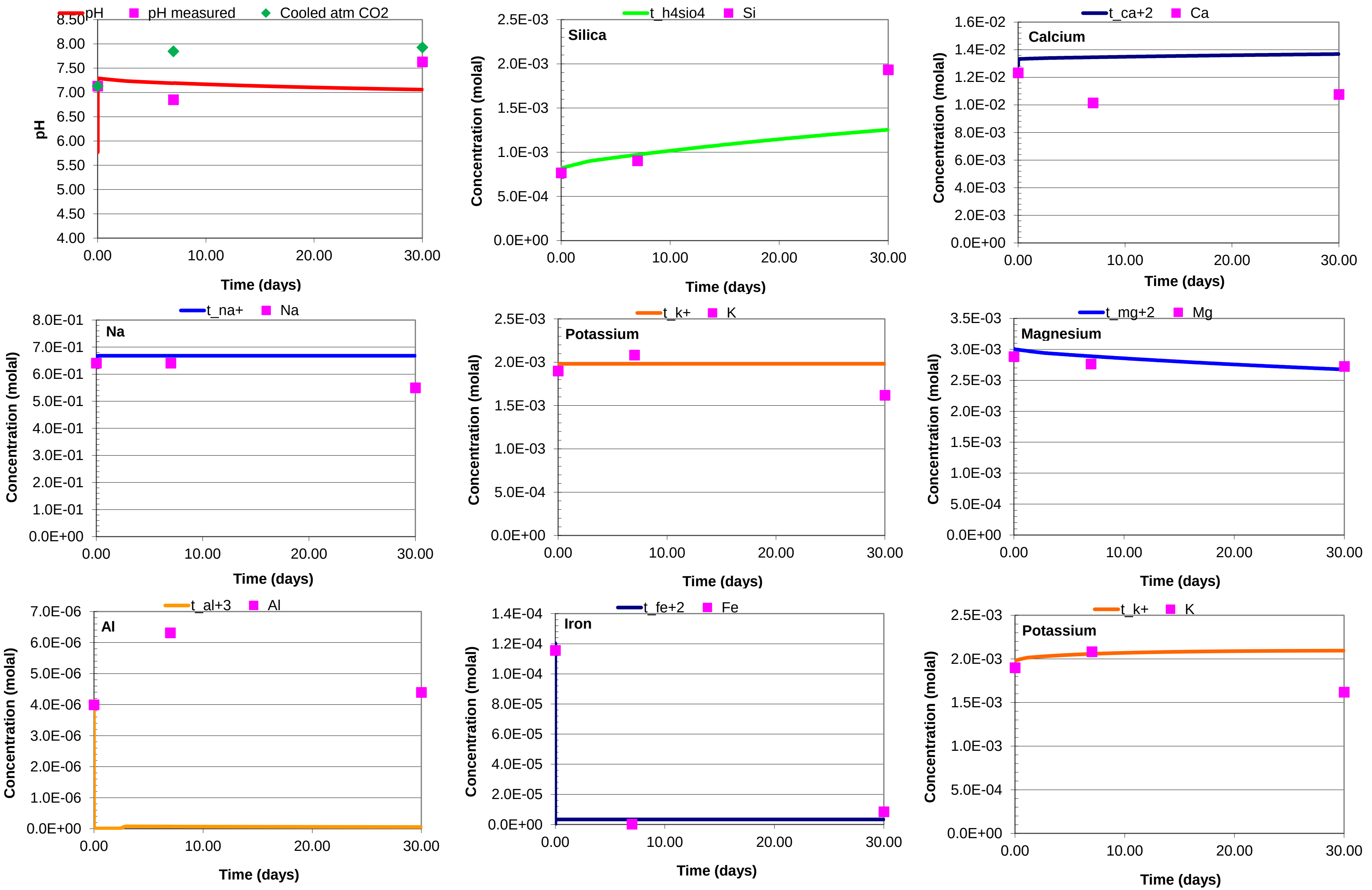


- Due to approximate neutral pH, Ca concentrations relatively stable
- Dissolution of carbonates occur due to transient acidity caused by dissolution of pyrite
- Precipitation or cation exchange in clay sites may lead to Ca uptake from effluent causing decreased Ca concentrations

- The high Si concentrations cannot be explained only by the dissolution of quartz at the experiment conditions
- Dissolved biogenic (microcrystalline quartz) or amorphous silica could explain high silica concentrations
- Dissolution of feldspar contributes to Si concentration in effluent

- Al is mainly from the dissolution of feldspars
- Al concentrations are very low due to uptake from fluid – illite and other Al-based mineral precipitation
- Similar trends observed for Magnesium (Mg) and Iron (Fe)

RESULTS – Model of Experiment (TOUGHREACT Simulator with Thermodderm Thermodynamic Database) by LBNL



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Mineral reaction rates (kinetic constants, surface area)

DISCUSSION

Illitization – Increased illite composition due to breakdown of feldspars which provides the necessary elements for illitization. This phenomenon has been observed in earlier studies such as Guven et al., (1982), where they observed that illitization is favored by high Al concentrations at circum-neutral pH. This is similar to conditions of our experiment

Iron Oxides – The breakdown of pyrite and other iron-bearing minerals release mostly, Fe(II) into solution which is subsequently oxidized to Fe(III) oxyhydroxides that block pores within the formation and lead to permeability losses. The breakdown of pyrite in this study points to high probability of iron oxides formation

Fines Migration – Clay fines migration are occasioned by the deflocculation and dispersal of clay minerals. These subsequently aggregate within flow paths to cause significant permeability losses. High amorphous compositions after reaction observed in this study points to possible clay deflocculation

The cumulative impact of reactions described above is the loss of permeability of formation during long-term post-hydraulic fracturing rock-fluid interactions.

CONCLUSIONS AND RECOMMENDATIONS

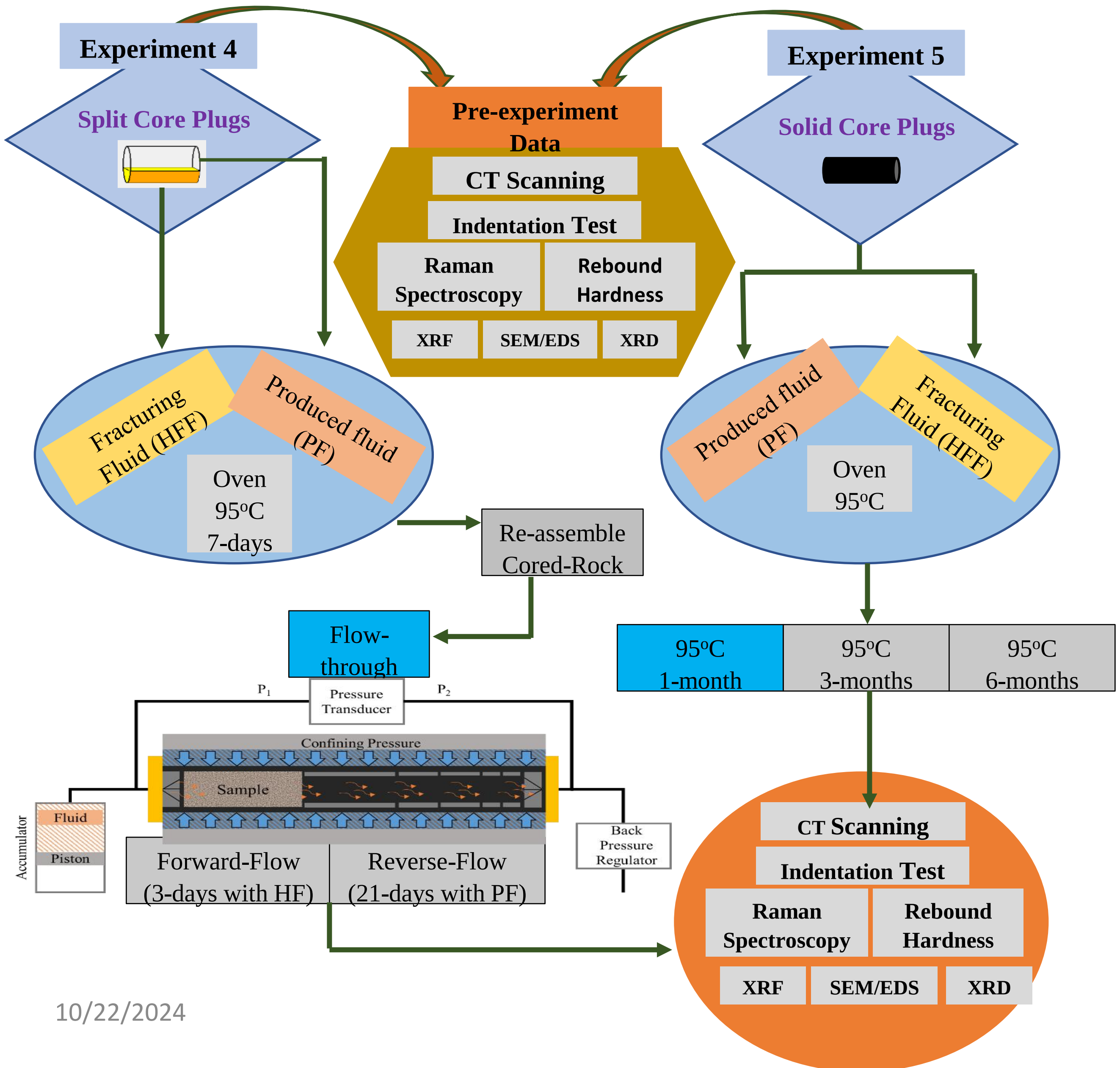
- Carbonates, pyrite, feldspars and clays are susceptible to rapid geochemical reactions
- Oxidation is a major mechanism in rock-fluid interactions, it leads to breakdown of pyrites
- Breakdown of pyrite and other sulfides after exposure to oxygenated fluid leads to generation of acids which cause transient pH reductions, thus catalyzing breakdown of other minerals such as carbonates
- Reactions with fluids lead to increased illite content in rock samples suggesting the shift from initially brittle rock to more ductile rock in the long term
- Deflocculation of clay minerals leads to the generation of fines which can coalesce later within the fracture to cause blockage of pore-throat (Between 7 to 30 days)
- Further work is being done to investigate the cause of illitization observed from XRD measurements

Recommendations:

- Longer periods for experiments to help improve model accuracy
- Experiment with cored rock samples over longer periods for better replication of rock-fluid reactions in the subsurface
- Investigate potential illitization and mechanism that may be responsible

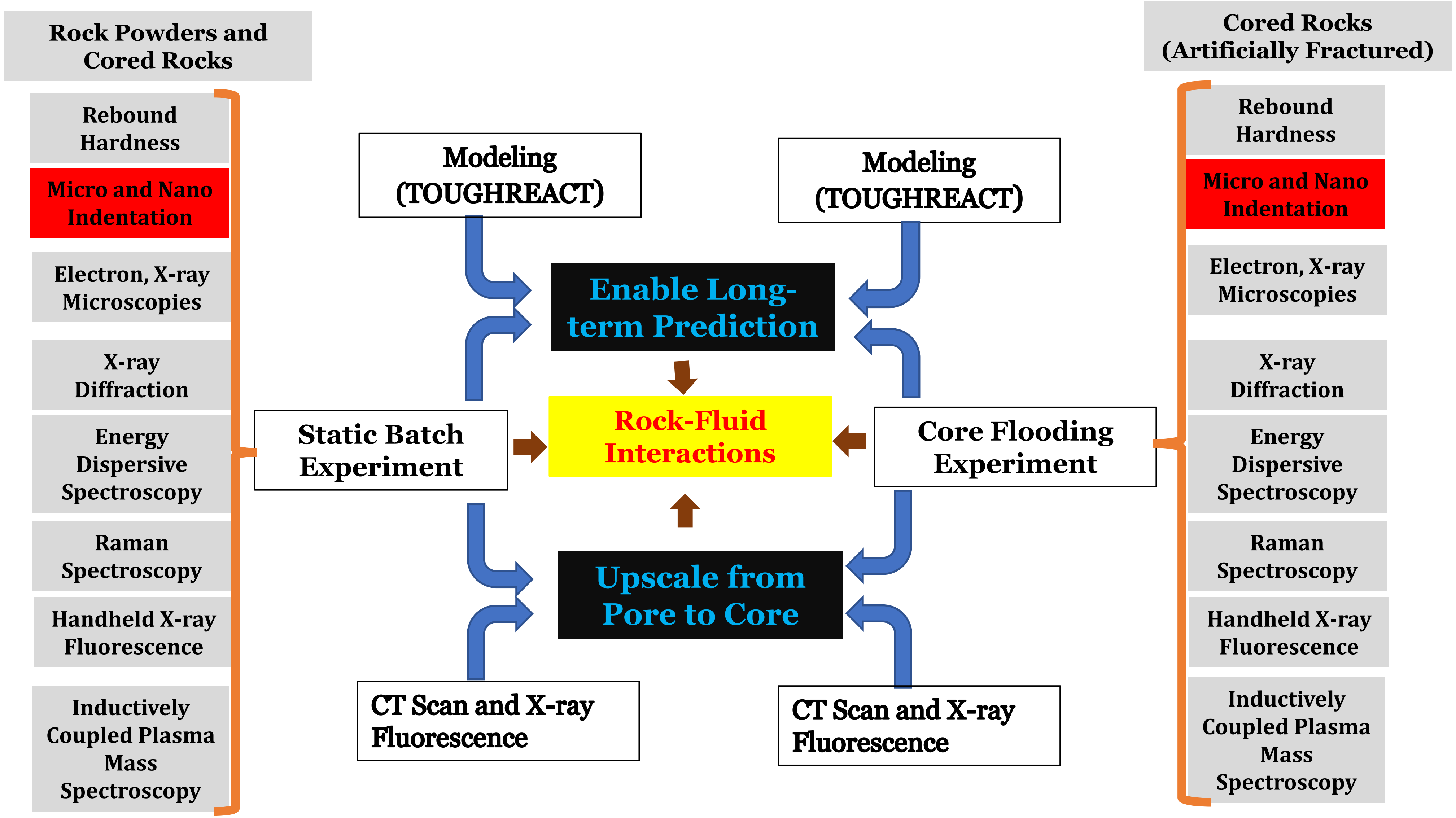
PLANS AND WORK CURRENTLY IN PROGRESS

WORKFLOW FOR THE REMAINING EXPERIMENTS



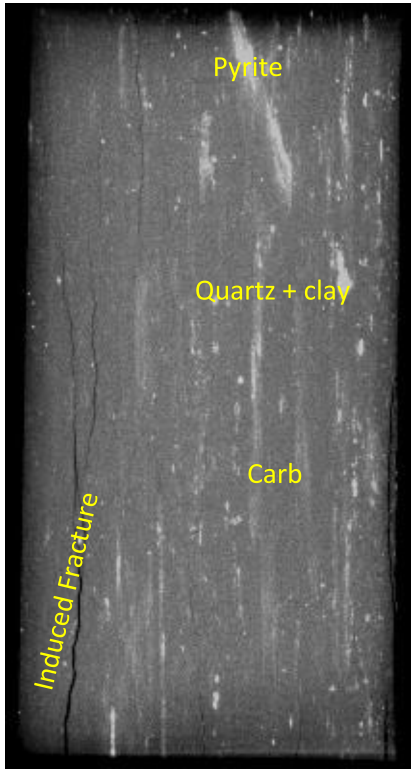
- Experiments designed to complement the initial experiments already undertaken
- Experiments include flow-through experiments and extended static batch reactor experiments with cored rock
- These experiments are designed to be conducted with core-rock samples
- Flow-through experiments will be conducted under dynamic conditions (fluid-flow, temperature, pressure)
- Crucial measurements such as pH will be measured at in-situ temperature and pressure conditions
- These experiments will provide a closer replication of conditions in the subsurface

METHODOLOGY

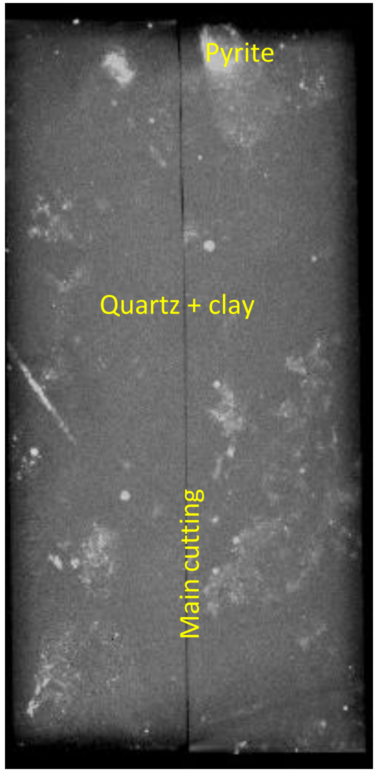


Flow chart of overall project direction and protocols established to achieve objectives

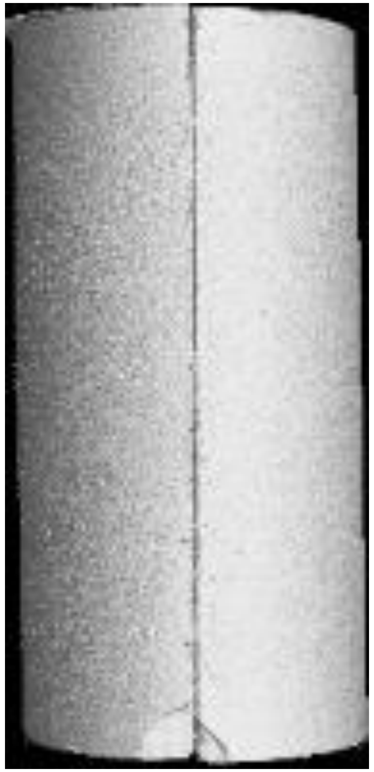
CT-Scan – Sample D2H



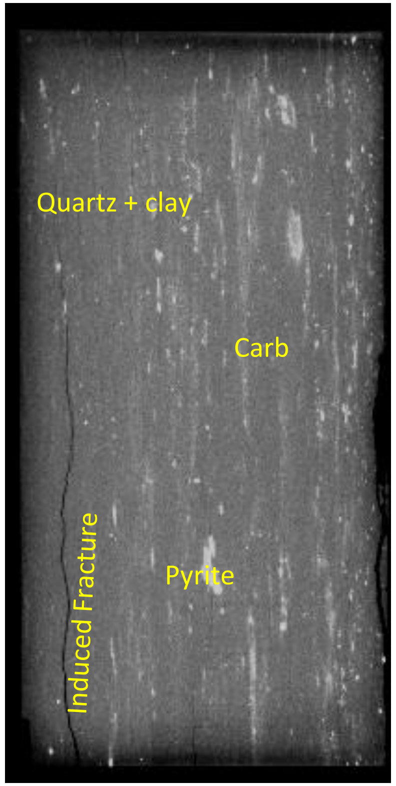
Front View



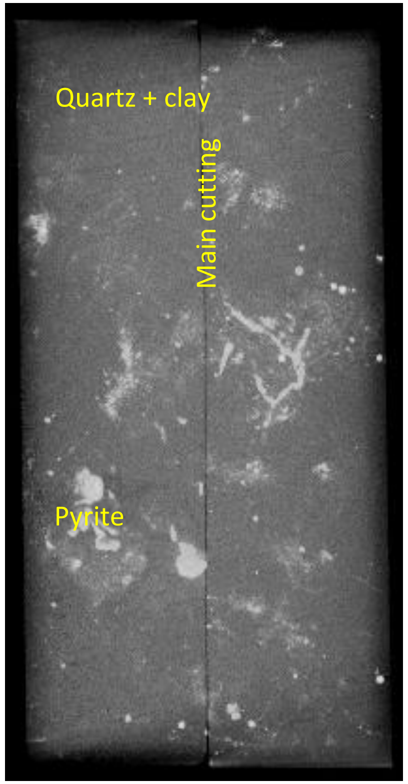
Side View



Solid View



Front View

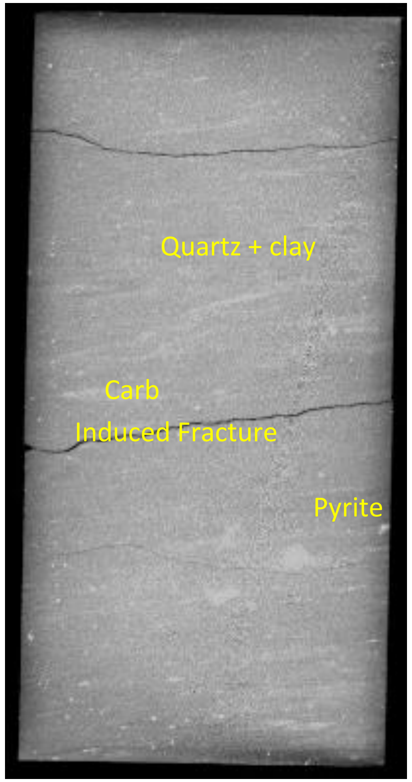


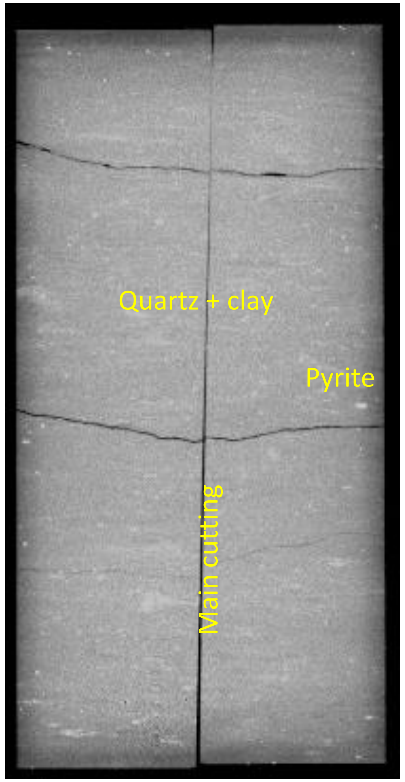
Side View

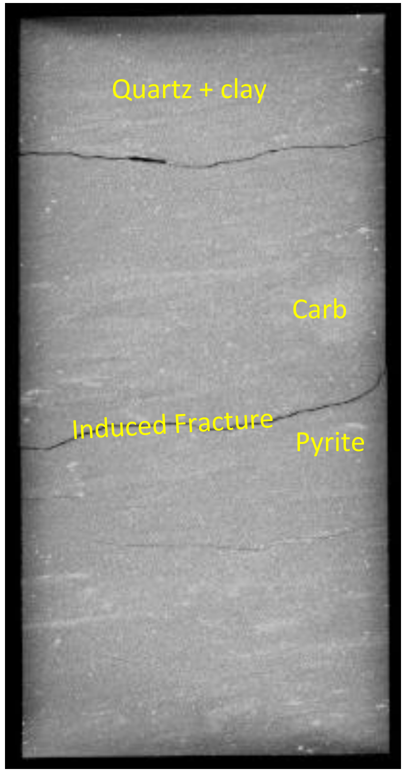
D2H1

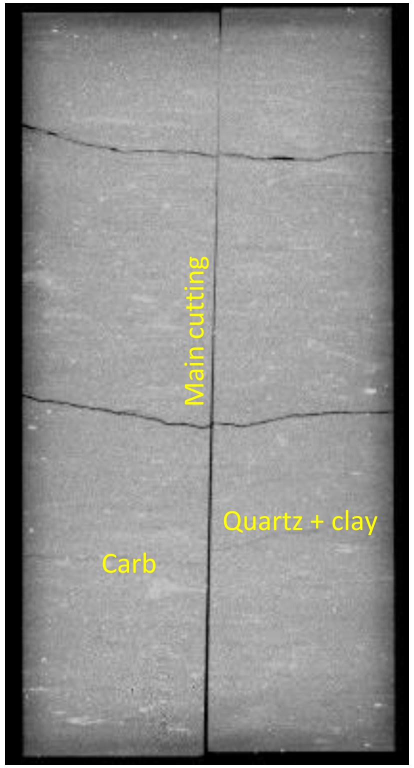
D2H2

CT-Scan – Sample D2V







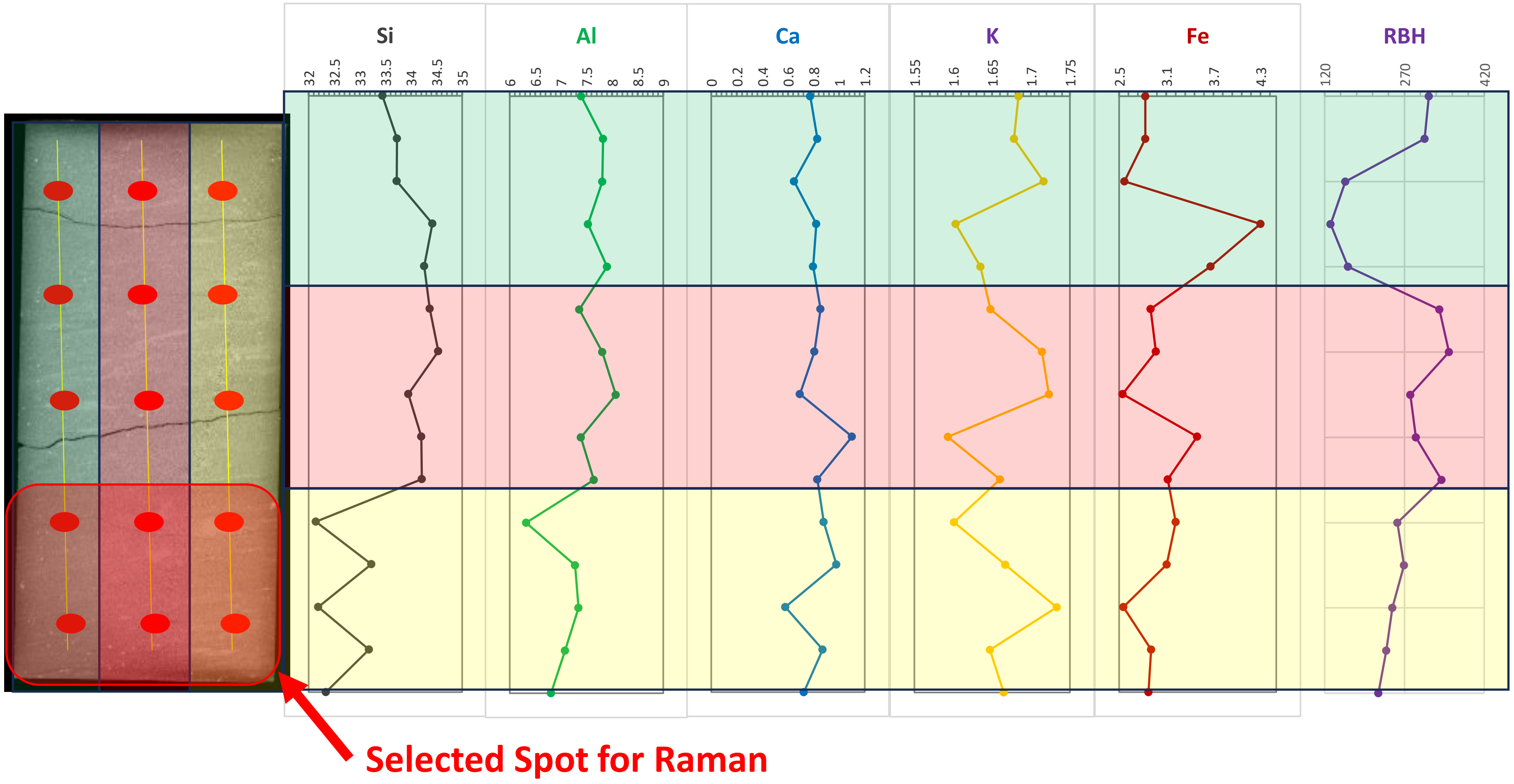


Front View **Side View** **Solid View** **Front View** **Side View**

D2V1 **D2V2**

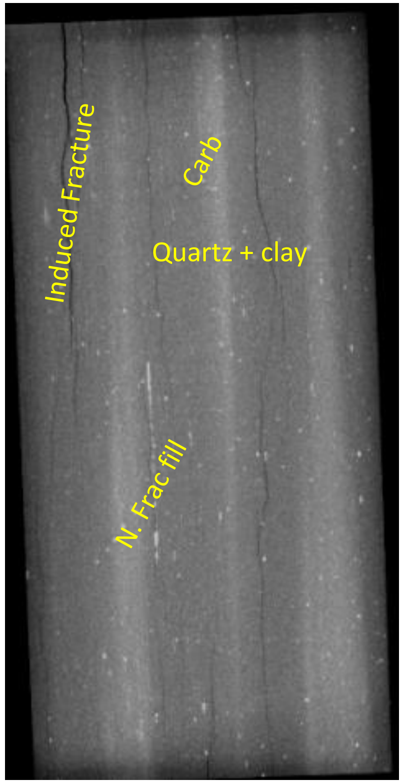
Samples (D2V1)

Combination of CT-Scan, XRF and RBH

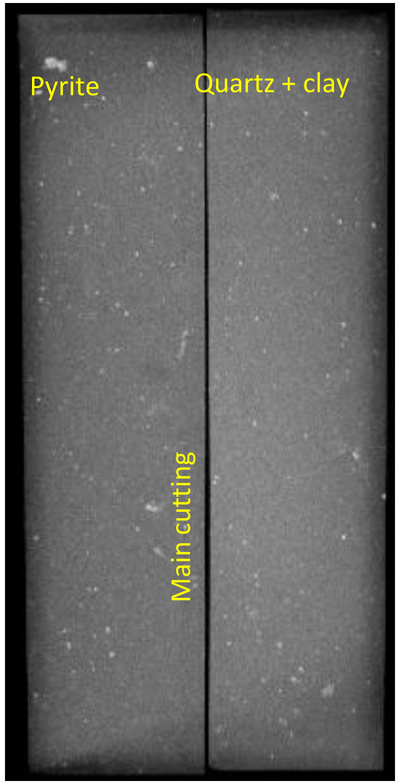


- Low Ca throughout
- Si, and Al constant on left side and middle
- Si drops significantly on the right side
- Ca, Si and Fe drops significantly in middle
- Fe drops in middle and right side
- Generally, ductile and more so in right side
- Highest RBH in the middle

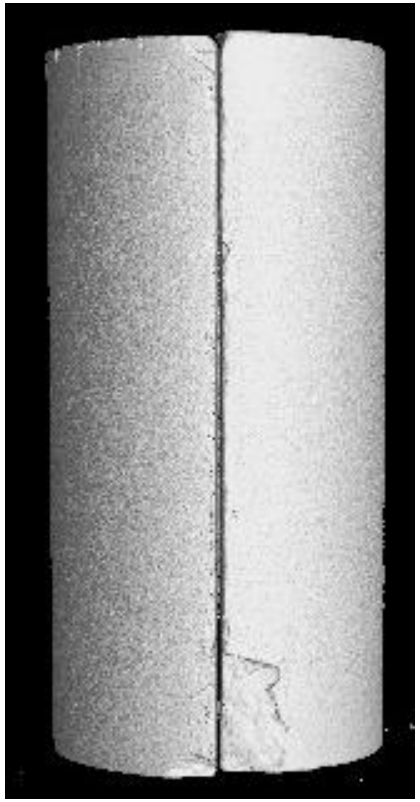
CT-Scan – Sample R3H



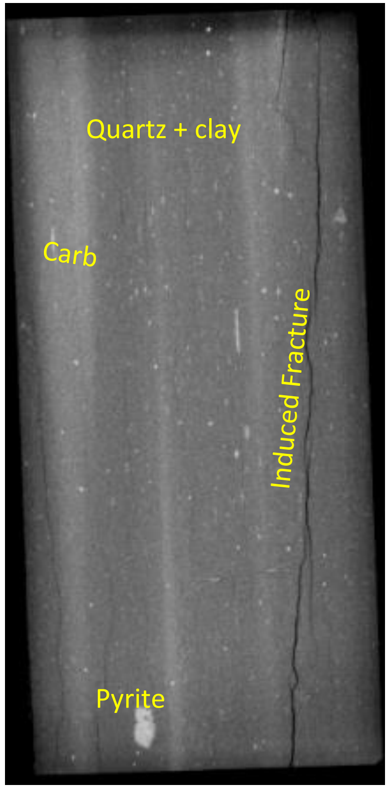
Front View



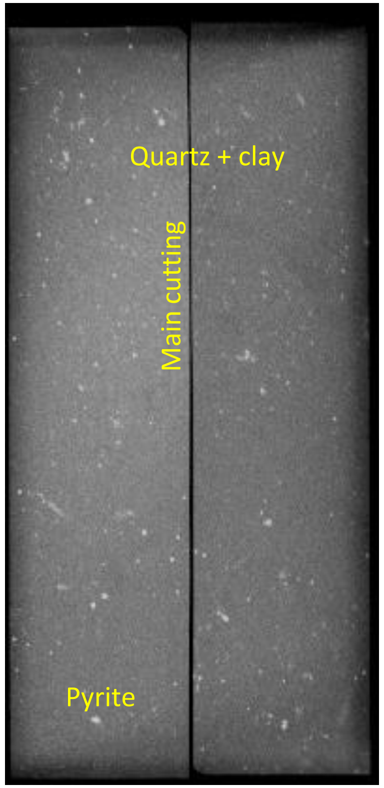
Side View



Solid View



Front View

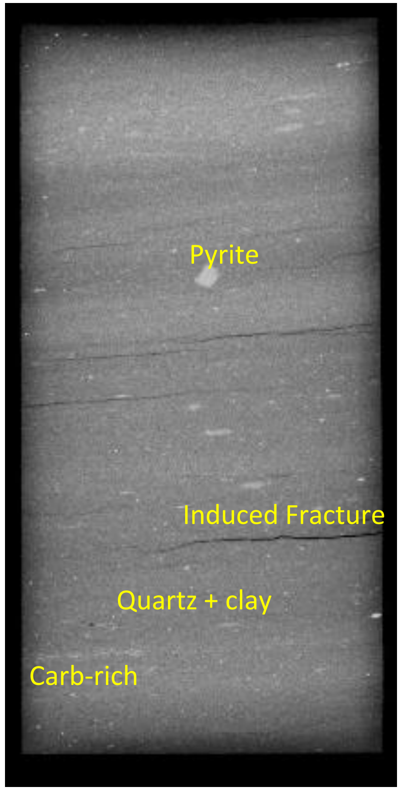


Side View

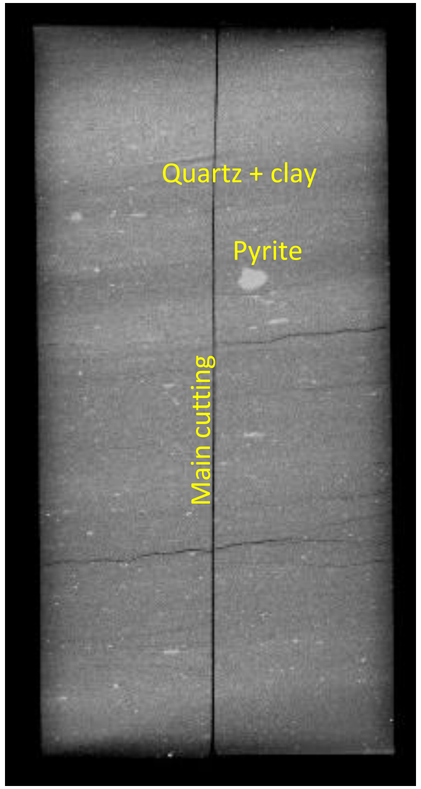
R3H1

R3H2

CT-Scan – Sample R3V

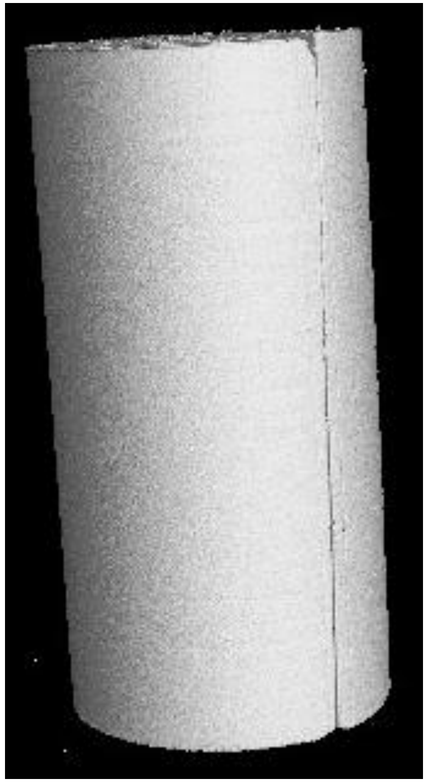


Front View

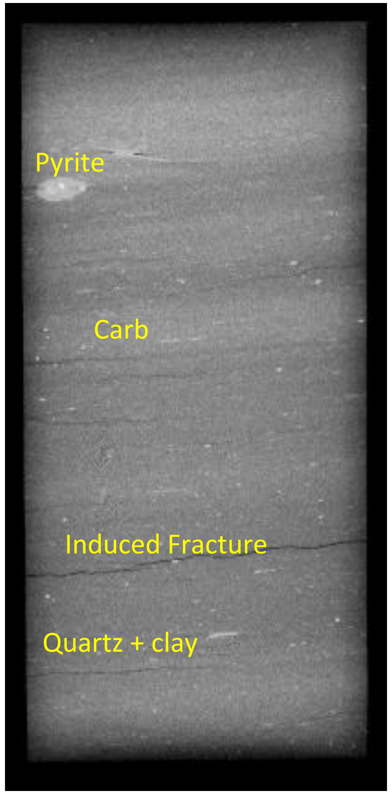


Side View

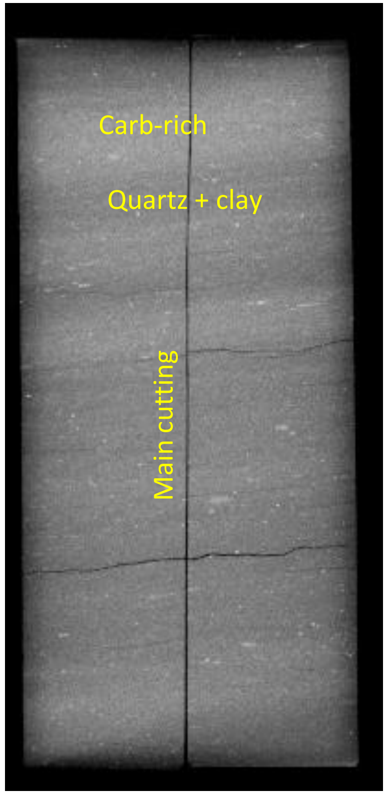
R3V1



Solid View



Front View

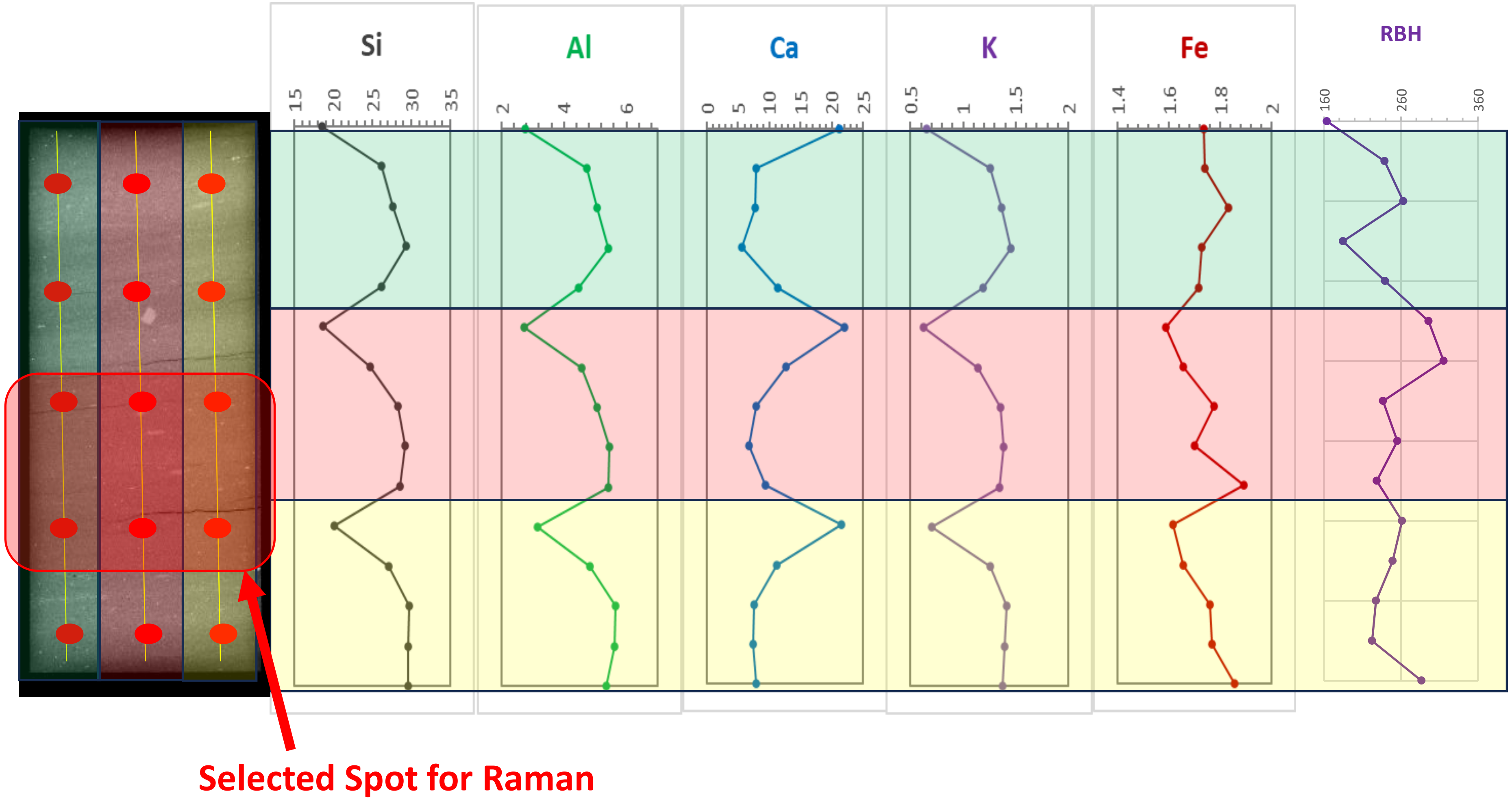


Side View

R3V2

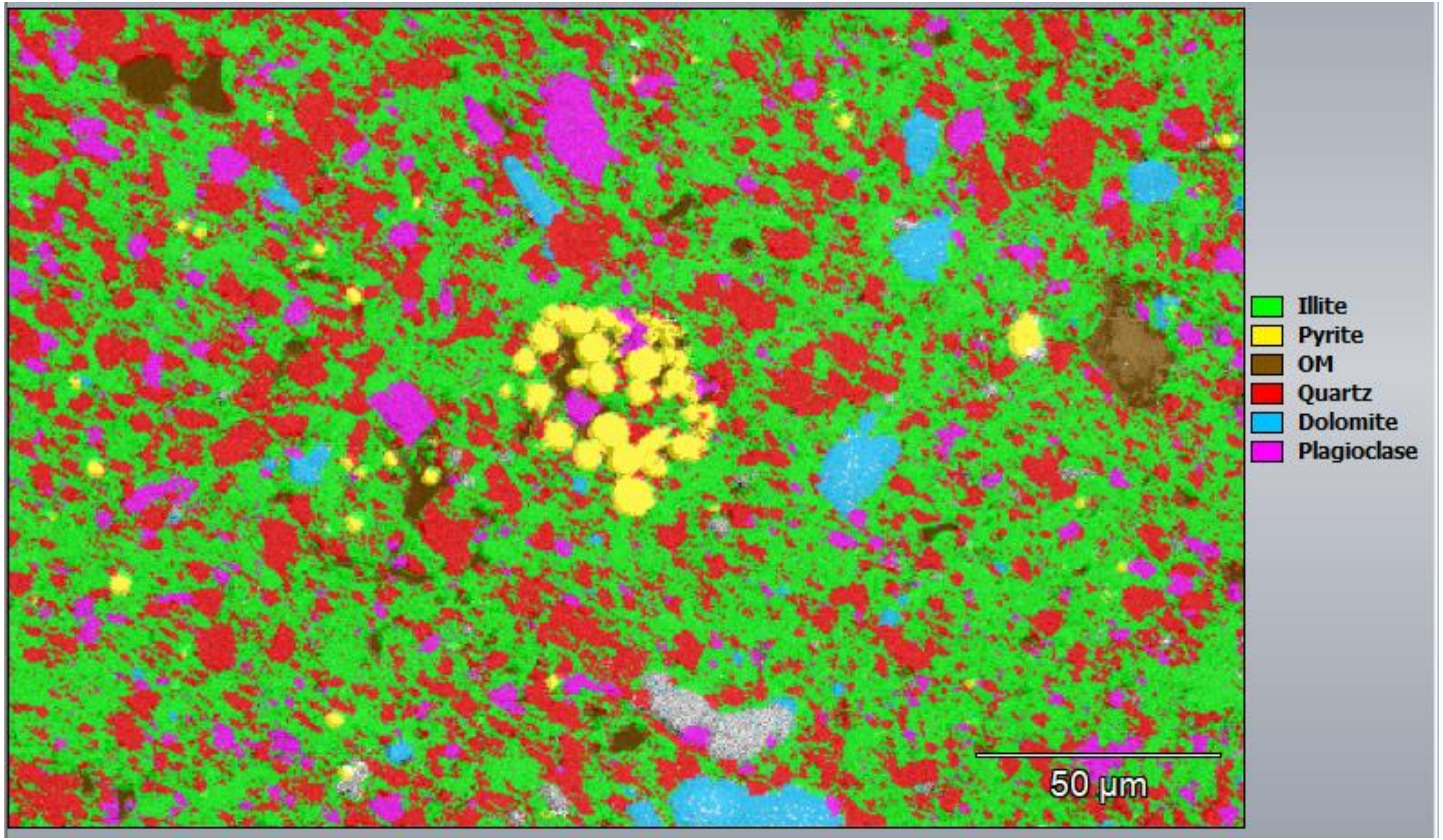
Samples (R3V1)

Combination of CT-Scan, XRF and RBH



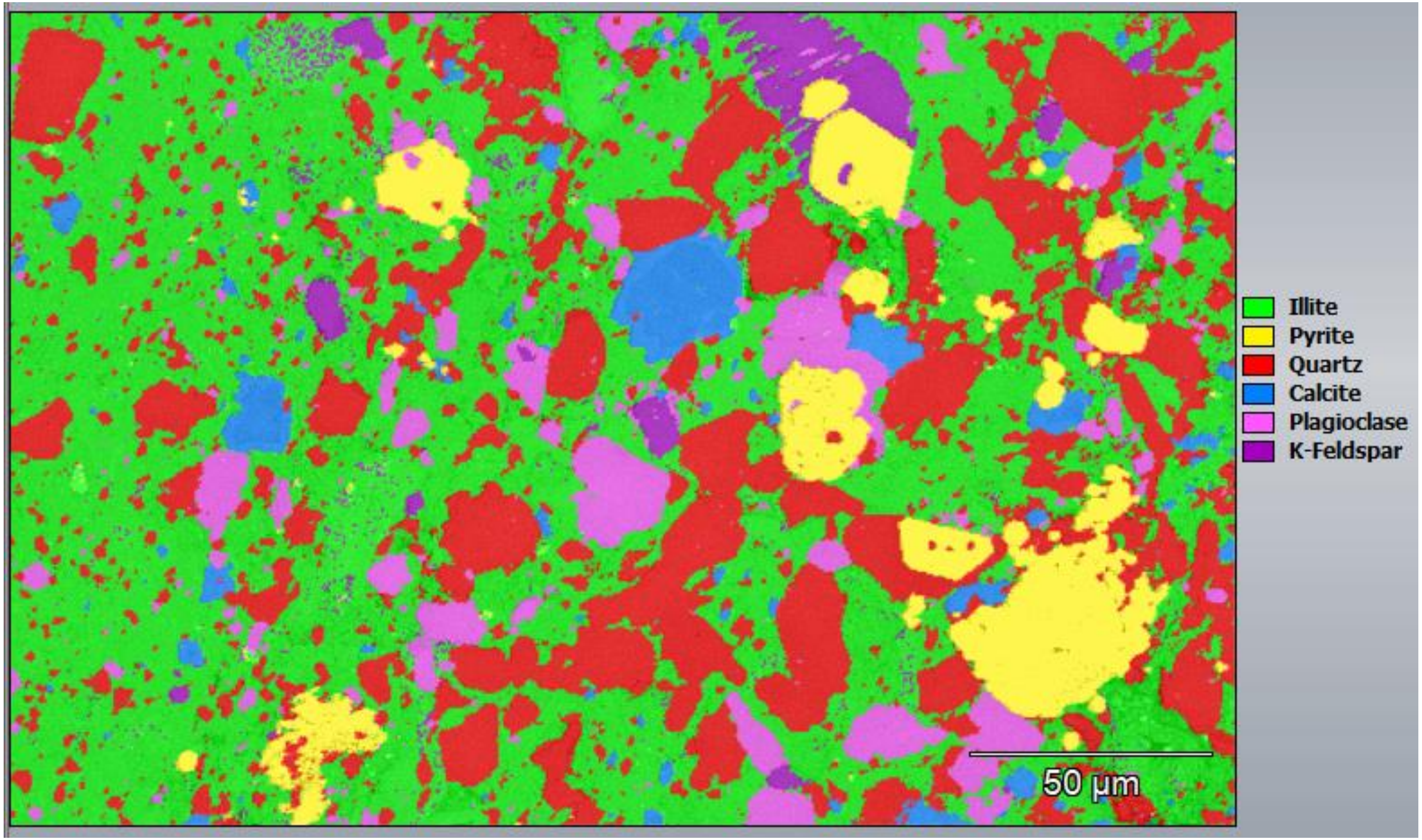
- Si, Al, and K increase on left side
- Si, Al, and K increase in middle portion
- Si, Al, and K increase on right side
- Fe constant throughout
- High carbonate at top and lower portions
- Generally, grade from brittle to ductile throughout sample
- High RBH in middle

Samples (D2V)



- High clay content in ductile samples
- Particles of quartz, carbonates and felspars are encapsulated within high amounts of clay matrix
- Pyrite occurs as individual pieces and pyrite framboids in other locations

Samples (R3V1)



- Reservoir is characterized by large grains
- Relatively Lower clay control on properties as in ductile samples
- Particles of quartz, carbonates and felspars are surrounded by clays
- Grain-to-grain contacts more prevalent in reservoir

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THANK YOU

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