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RESOURCE ASSESSMENT OF UNCONVENTIONAL OIL AND GAS SHALE FOR CRITICAL MATERIALS RECOVERY

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Introduction

Why shale?

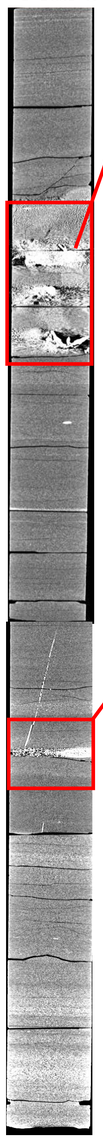
- The US has a huge amount of shale resources, ranking top 5 in the world
- The US has ~1 million production wells
- Many shale deposits have high metal contents

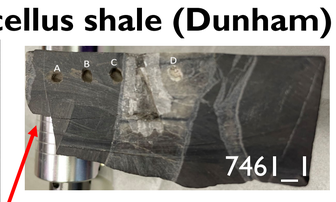
Project objective

- Quantify the contents of critical metals in major oil and gas shale reservoirs across the US
- Assess the extractability of critical metals, including REE, precious, and transition metals
- Explore the in-situ extractability of these metals using our chelator - water solvents

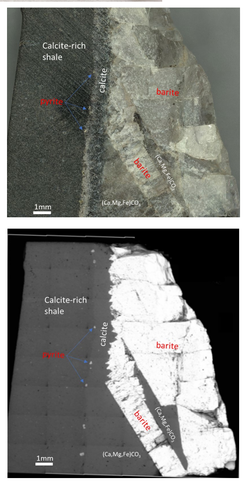
Selected shale intervals & characterization

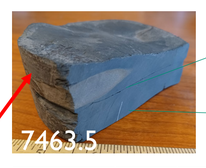
Marcellus shale (Dunham) core scan at 7460-7466'

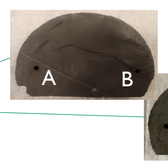


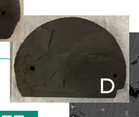


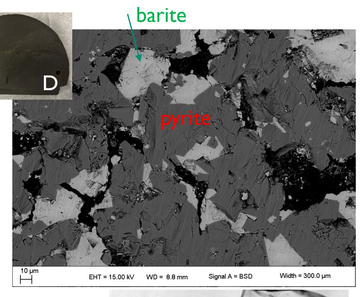
Sample IDM	QFM (wt%)	Calcite (wt%)	Ankerite (wt%)	Clay (wt%)
7461_1_A	5	92	0	0
7461_1_B	4	95	0	0
7461_1_C	4	93	0	0
7461_1_D	1	2	97	0
7461_2_A	23	15	3	50
7461_2_A2	24	17	4	48
7461_2_F	20	20	3	49
7461_2_B	5	87	1	2
7461_2_B2	5	85	1	4
7461_2_G	3	88	1	6
7463.5_A	28	5	2	57
7463.5_B	24	4	6	60
7463.5_C	24	9	2	54
7463.5_D	25	4	1	60
MS_Ref	40	24	4	29

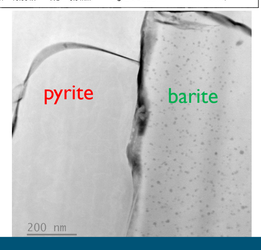






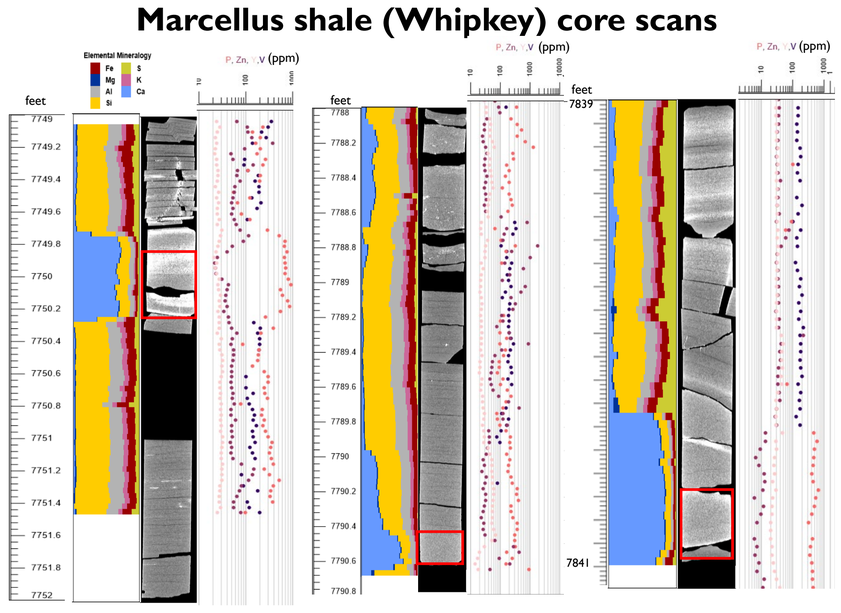


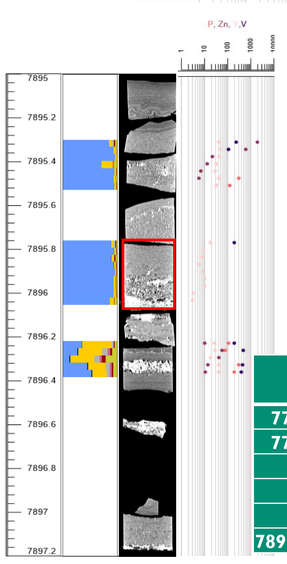


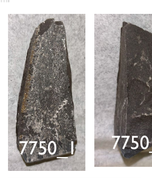


Sample ID	Ni (ppm)	Ba (ppm)	Mn (ppm)	REE (ppm)
7461_1_A	59	4786	425	109
7461_1_B	37	4287	445	84
7461_1_C	30	3824	487	96
7461_1_D	2959	2163	1679	6
7461_2_A	154	688	304	281
7461_2_A2	229	648	175	154
7461_2_F	140	673	248	154
7461_2_B	43	185	823	46
7461_2_B2	80	164	665	69
7461_2_G	29	260	424	40
7463.5_A	196	466	116	87
7463.5_B	206	386	113	68
7463.5_C	176	749	144	125
7463.5_D	222	618	113	72
MS_Ref	111	571	140	243

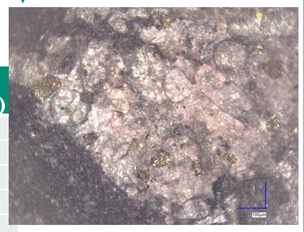
Marcellus shale (Whipkey) core scans





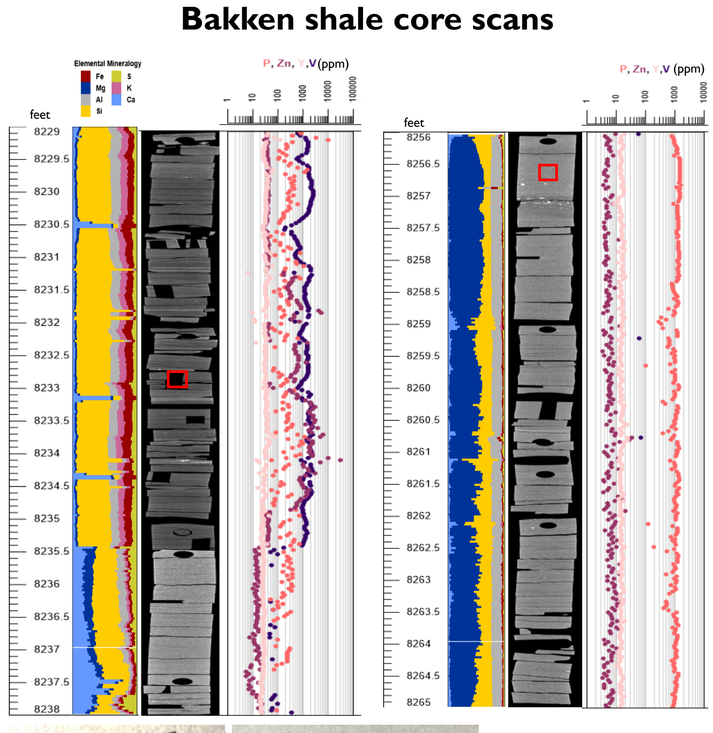


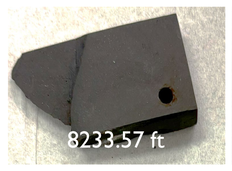
	QFM (wt%)	Calcite (wt%)	Ankerite (wt%)	Clay (wt%)
7750_1	7	82	0	4
7750_2	4	83	0	2
7791	7	86	0	5
7841	7	86	0	3
7888	28	65	0	4
7895.9_1	19	22	25	27



Co-existing pyrite and barite

Bakken shale core scans



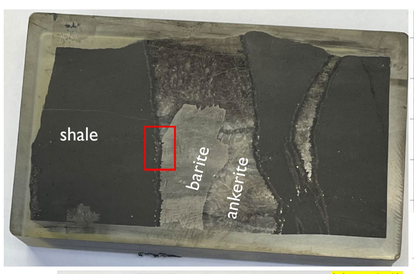


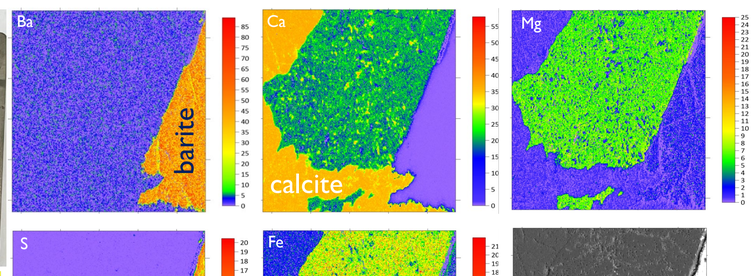
	QFM (wt%)	Calcite (wt%)	Ankerite (wt%)	Clay (wt%)
8233.57	43	0	0	50
8256.59	57	0	34	9

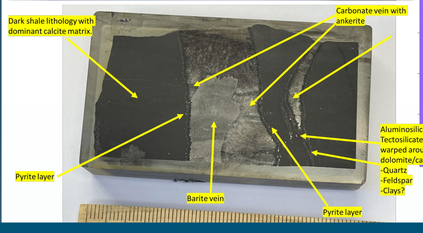
	Ni (ppm)	Ba (ppm)	Mn (ppm)	V (ppm)	REE (ppm)
8233.57	805	152	139	2272	193
8256.59	15	150	362	28	112

Characterization of Marcellus shale

Electron microprobe results: Barite and associated CMs

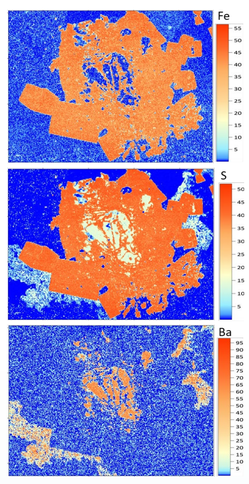






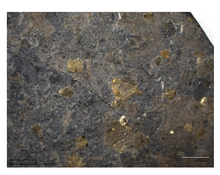
Ankerite - $Ca(Fe,Mg,Mn)(CO_3)_2$

Pyrite vs Barite

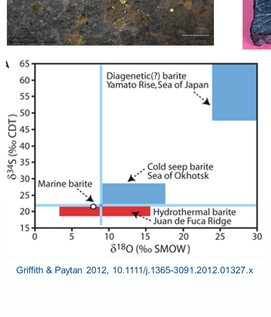


Sulfur isotope analysis

Pyrite grains



Barite grains

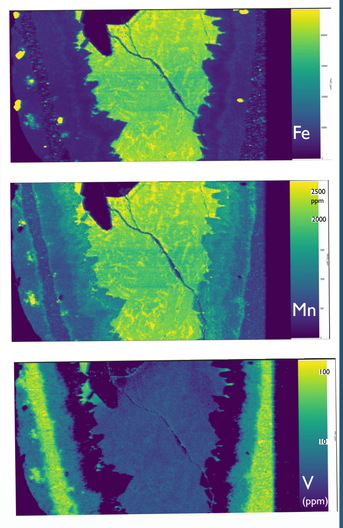


Griffith & Paytan 2012, 10.1111/j.1365-3091.2012.01327.x

Barite: 59 ‰,
Pyrite: 2.9 ‰
Barite and pyrite are not in sulfur isotopic equilibrium.

Laser ablation ICP on Marcellus shale 7461 sample

Laser ablation ICP reveals high Mn concentration in the ankerite region. V content is higher in shale matrix than in the veins.



Conclusions and next steps

Conclusions

- Marcellus shales have abundant, co-existing veins of calcite, barite, and ankerite, and layers of pyrites
- The matrix of Marcellus shale with veins is dominantly calcite, which is the easiest mineral for leaching
- Marcellus shale has abundant barite vein, which itself is a critical mineral
- Marcellus shale ankerite vein has nearly 0.3% Ni and 0.16% Mn, and is economically viable
- Bakken shale shows enrichment of Zn (> 2200 ppm) and Ni (> 800 ppm)

Next steps

- Finalize sample characterization
- Perform lab scale leaching tests on intervals of interest using environmentally friendly chelator-water solvent
- Perform flow through tests with core samples to mimic realistic extraction conditions

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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