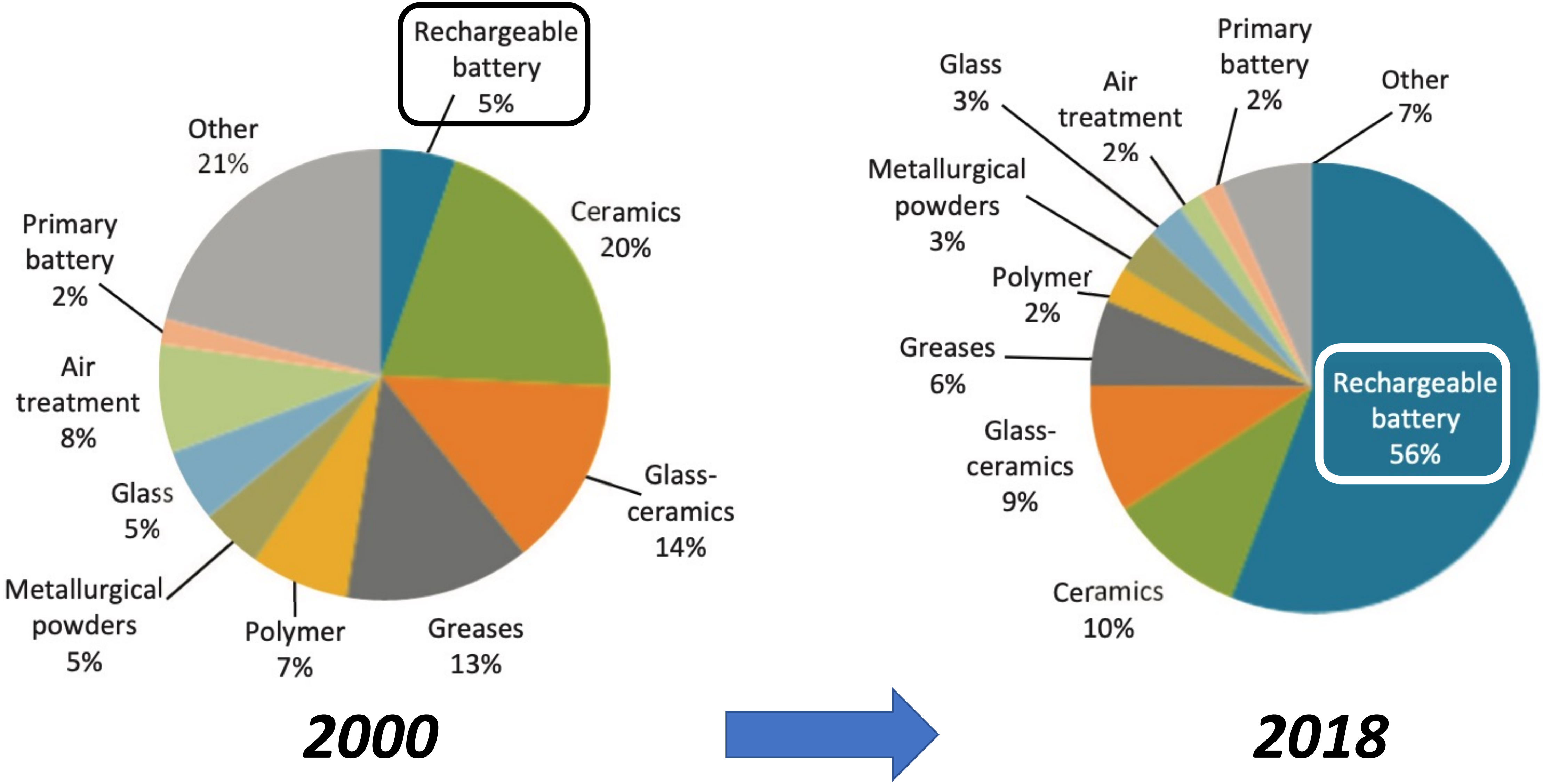
University of Nevada, Reno

Nevada Bureau of Mines and Geology

Overview of Lithium Deposits in Nevada

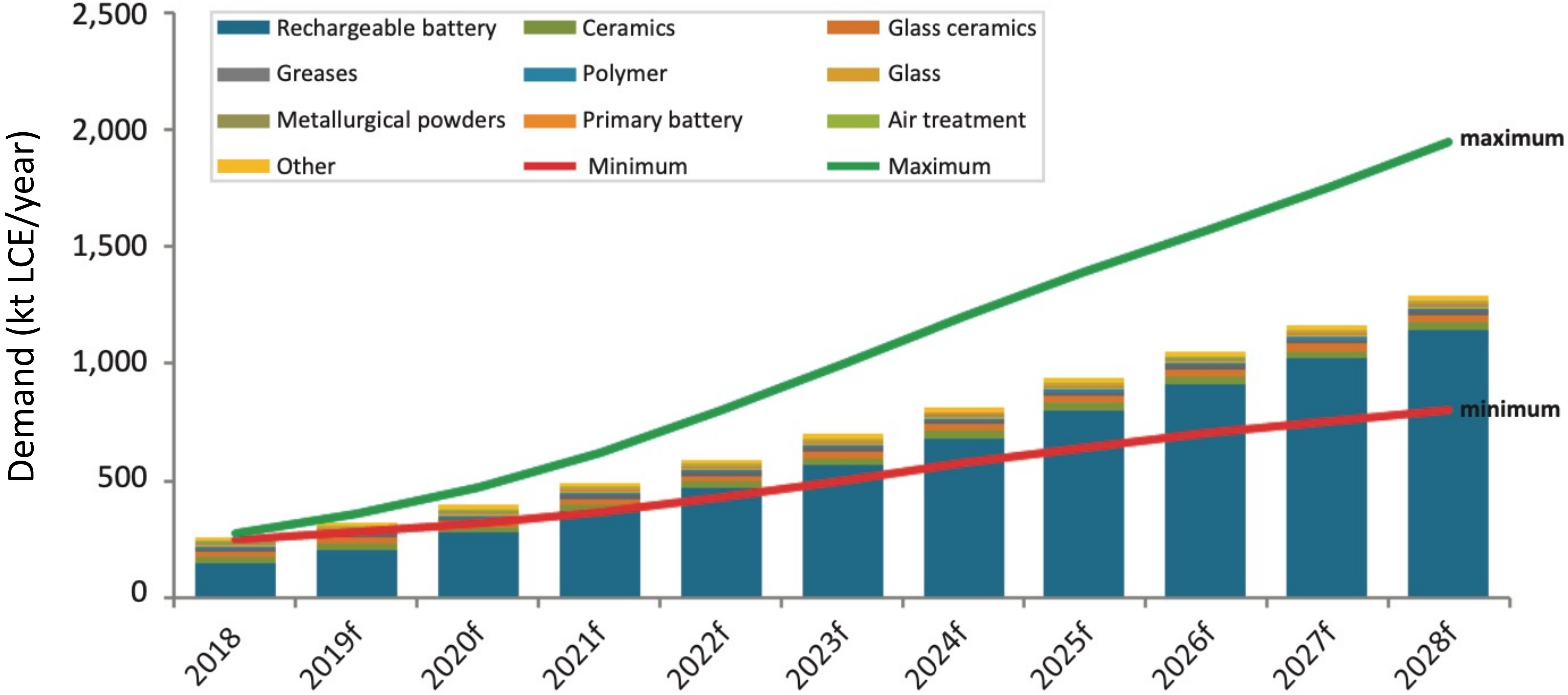
Dr. Matthieu Harlaux
University of Nevada, Reno

World Consumption of Lithium



Bibienne et al. (2020) – *Elements*

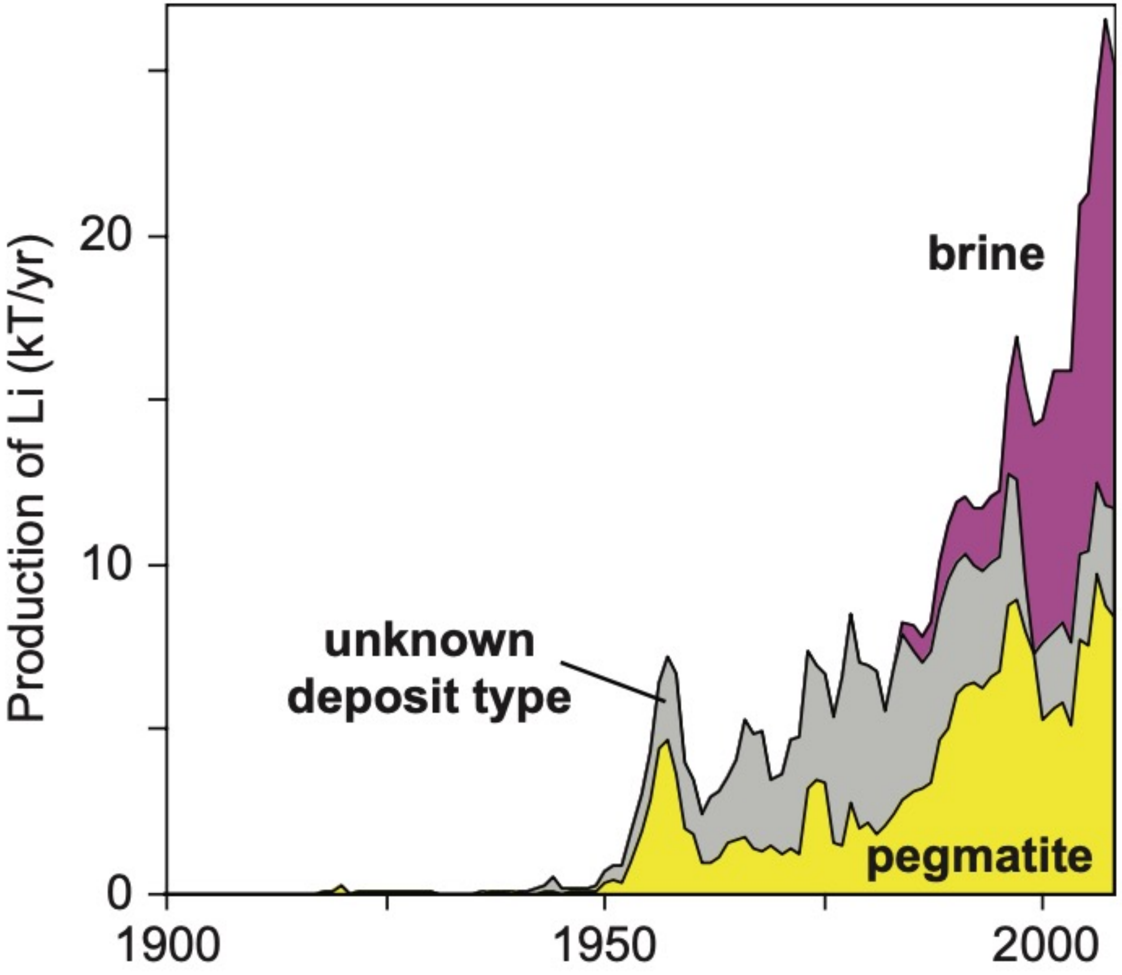
Global Lithium Demand Forecast



Lithium demand increase of 300-1000% by 2030

Bibienne et al. (2020) – *Elements*

Lithium Deposit Types



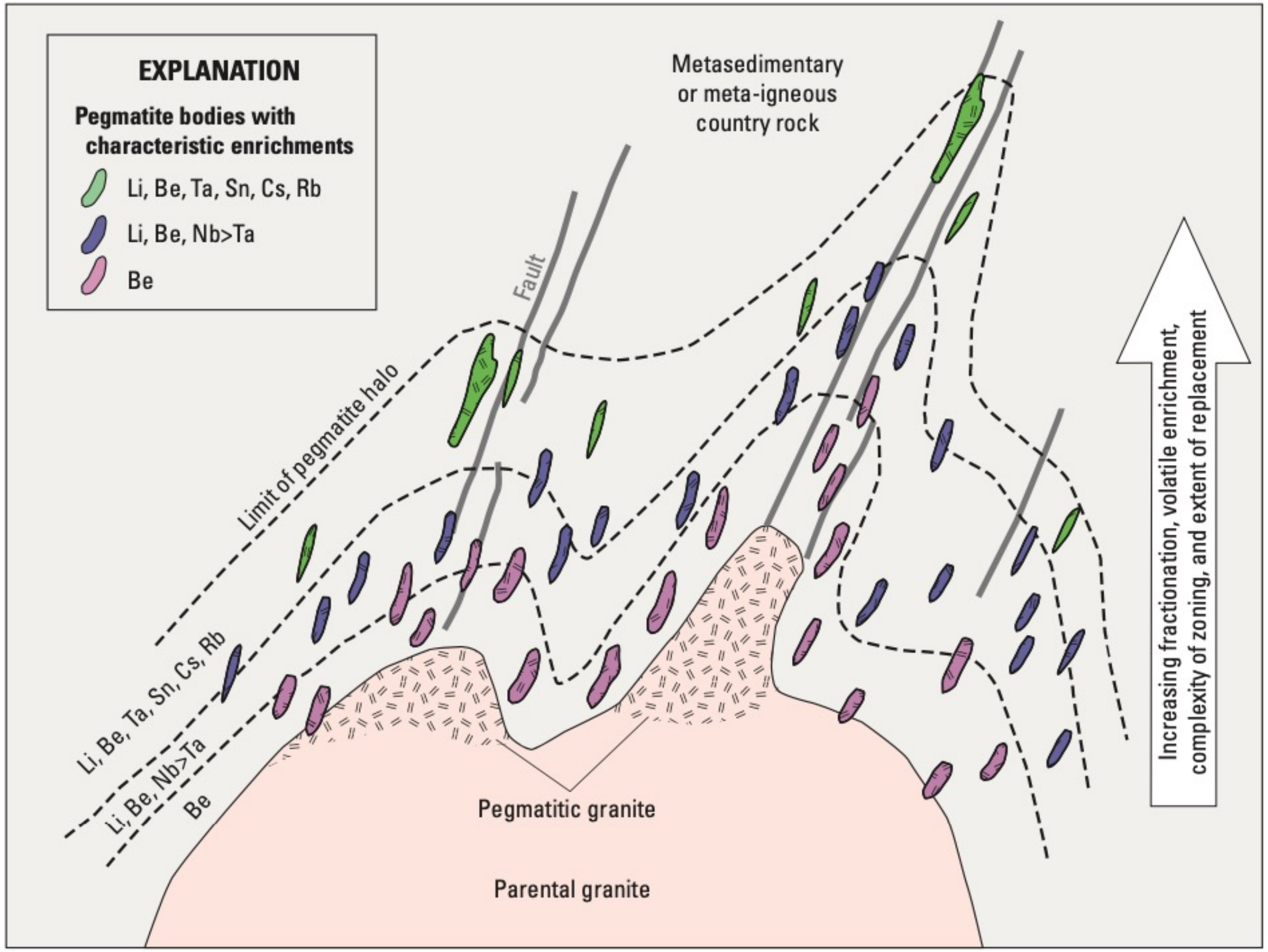
Munk et al. (2016) – *Reviews in Economic Geology*

Lithium brines ~60%
Subsurface pumping
~75% global reserves

Lithium pegmatites ~30%
Hard rock mining + crushing
~25% global reserves

Lithium clays and others ~10%
Mining + acid leaching
Global reserves not estimated

Lithium Pegmatite Deposits

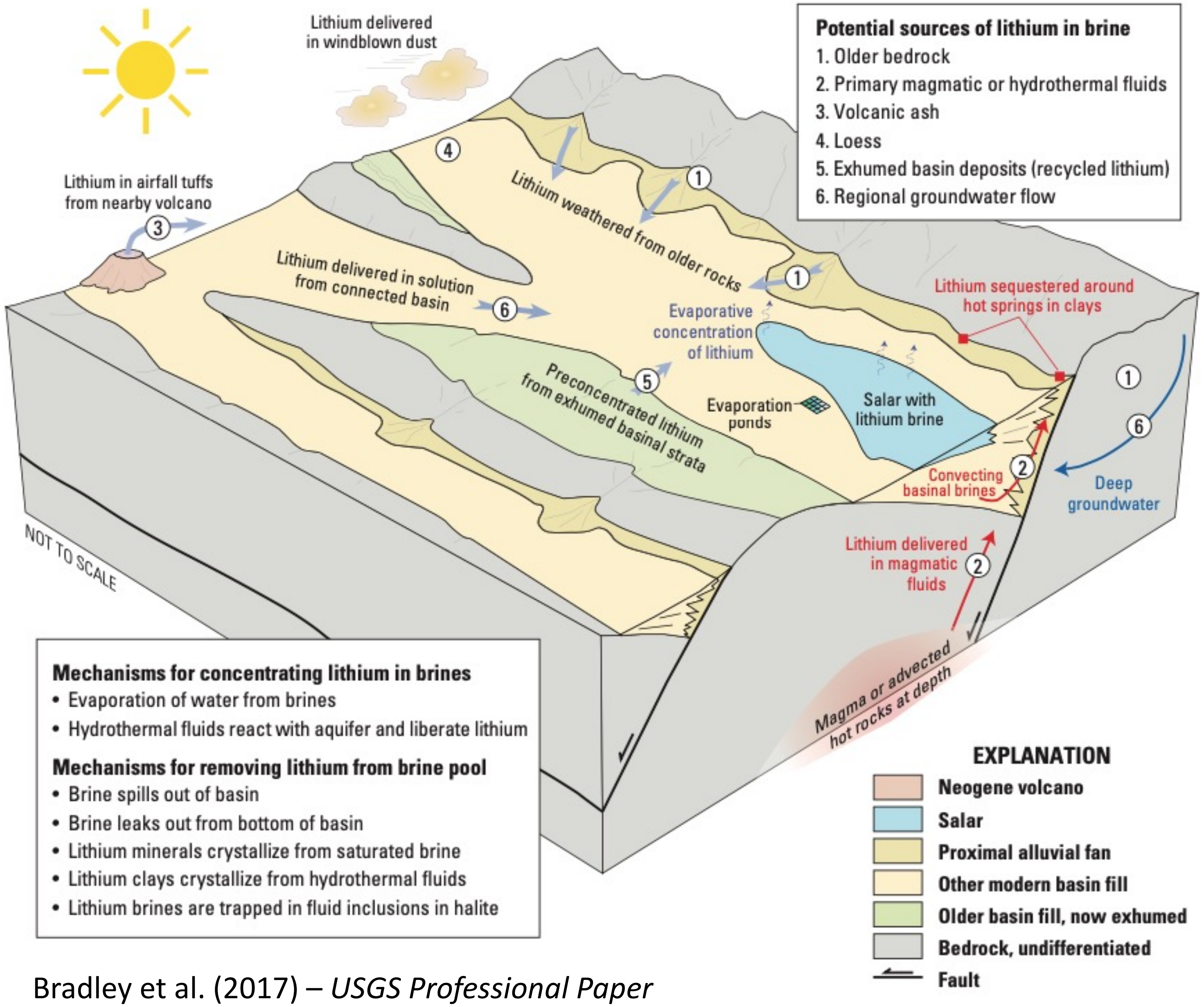


Bradley et al. (2017) – *USGS Professional Paper*

Giant spodumene ($LiAlSi_2O_6$) crystal in Plumbago North Pegmatite, Maine

Simmons et al. (2020) – *Miner Deposita*

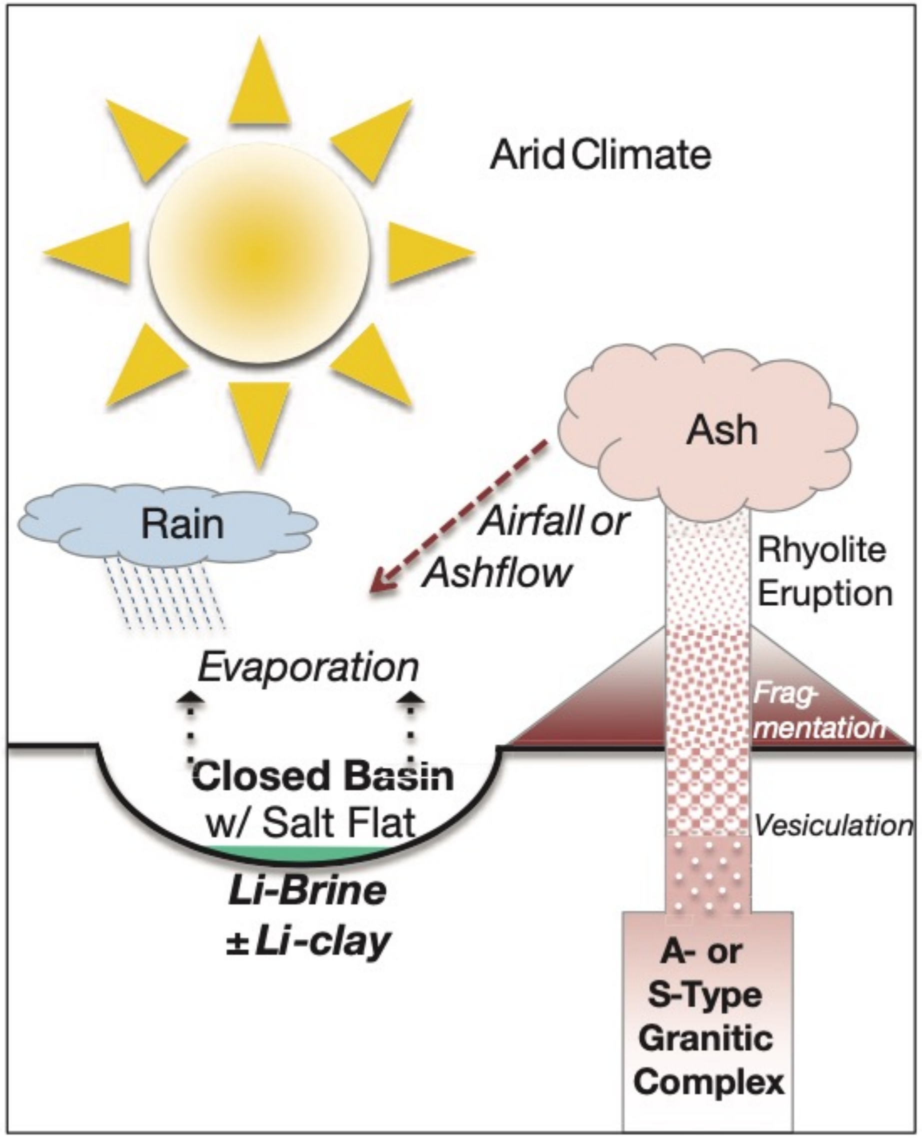
Lithium Brine Deposits



Bradley et al. (2017) – *USGS Professional Paper*

Lithium-brine evaporating ponds at Clayton Valley, Nevada

Lithium Clay Deposits



Hofstra et al. (2013) – *Economic Geology*

Lithium-bearing clays of the Cave Spring Formation at Rhyolite Ridge, Nevada

Reynolds and Chafetz (2020) – *GSN*

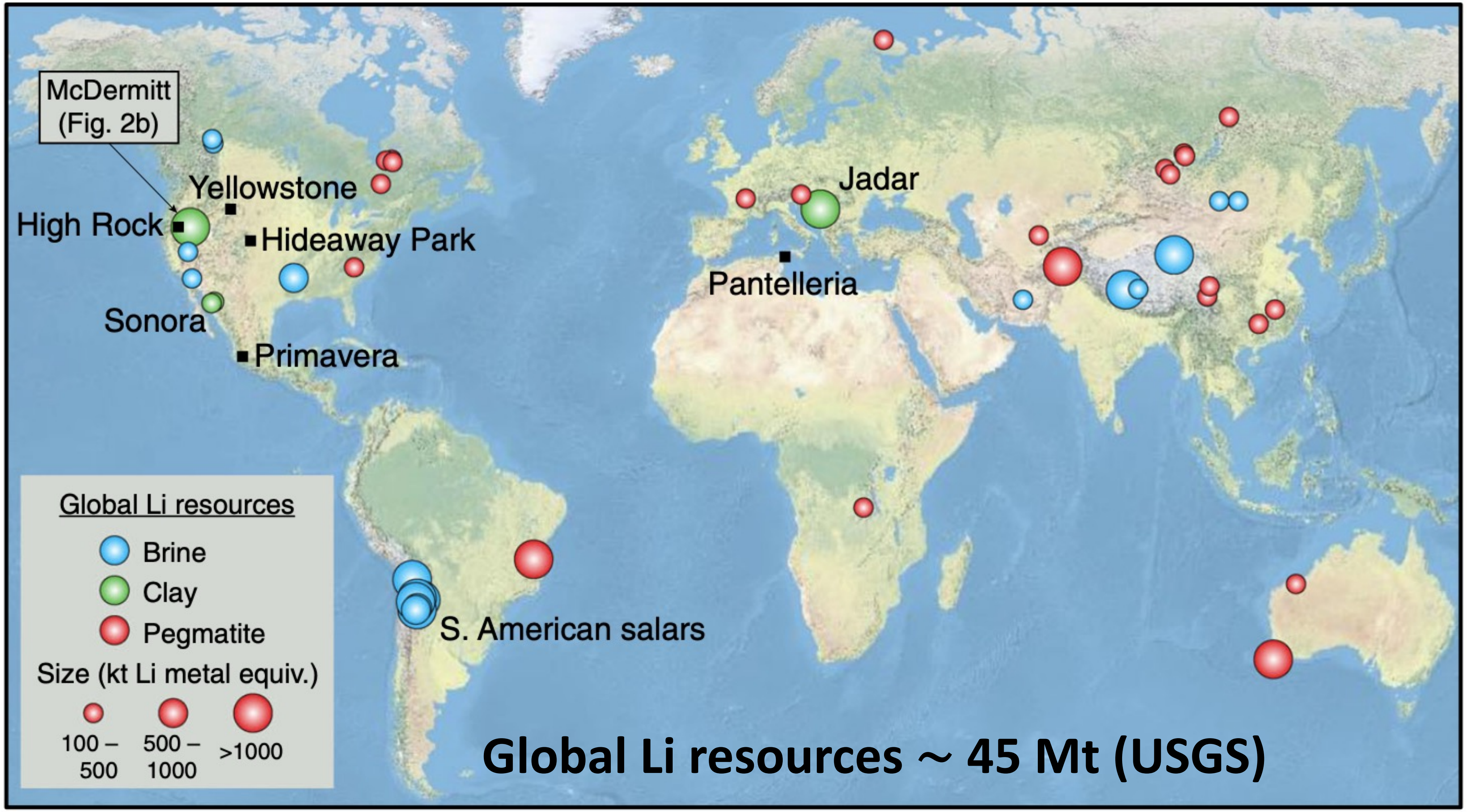
Exploration Indicators for Lithium Brines/Clays

<u>Six characteristics common to continental Li brines:</u>

1. Arid climate favoring evaporation
2. Closed basin containing a salar or salt lake
3. Associated igneous or geothermal activity
4. Tectonically driven subsidence
5. Suitable Li source rocks (tuff, ignimbrite)
6. Sufficient time to concentrate Li in brines/clays

Munk et al. (2016) – *Reviews in Economic Geology*

World Distribution of Lithium Deposits



Benson et al. (2017) – *Nature Communications*

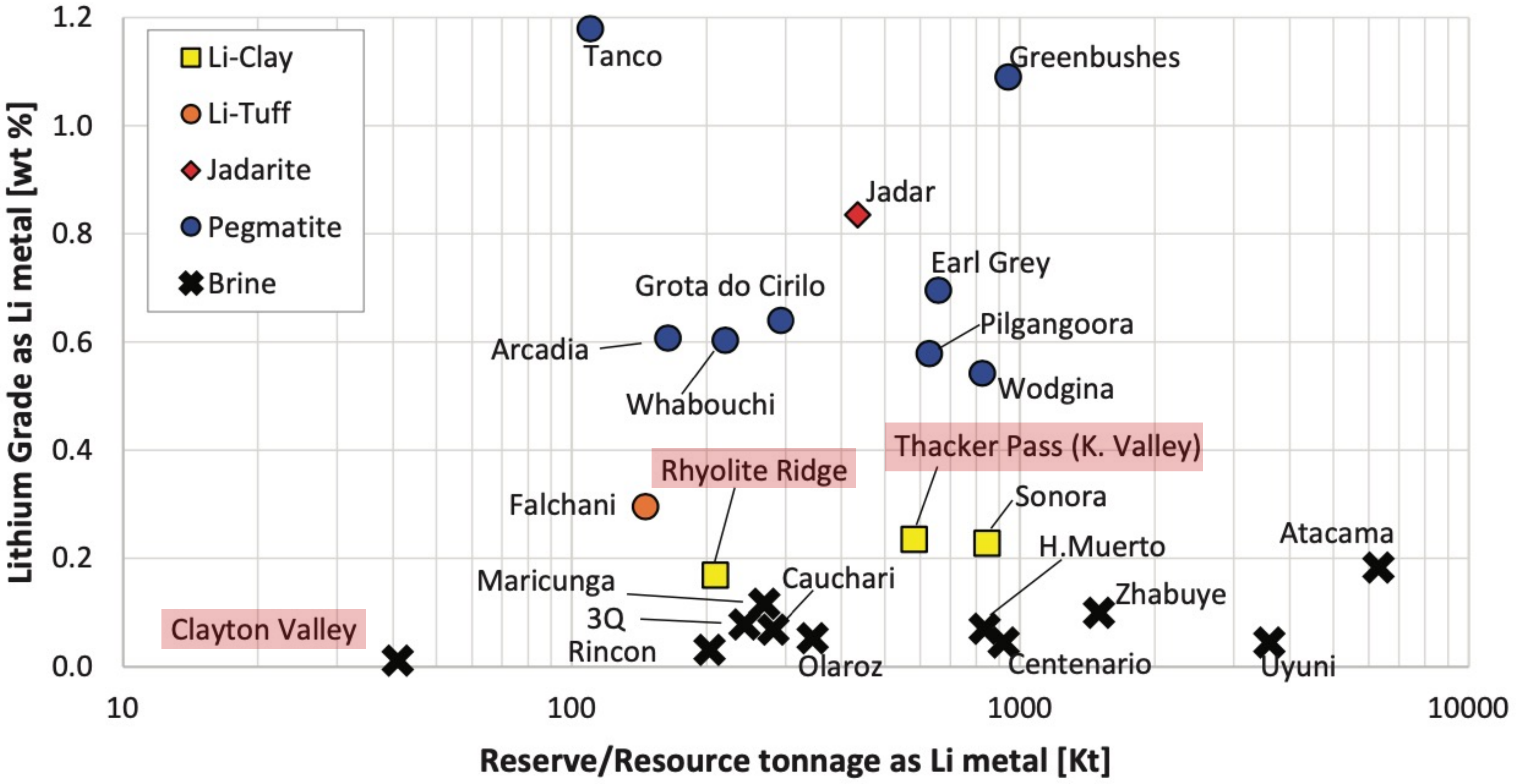
World-Class Lithium Deposits

Deposit	Type	Location	Main Owner	Li (Kt)	Grade (wt% Li)	Resource/ Reserve
Greenbushes	Pegmatite	Greenbushes (Australia)	Tianqi Lithium	943	1.091	R[1,2]
Wodgina	Pegmatite	Pilbara (Australia)	Mineral Resources	826	0.543	R[1,3]
Earl Grey	Pegmatite	Goldfields (Australia)	Kidman Resources & SQM	658	0.697	R[1,4]
Pilgangoora	Pegmatite	Pilbara (Australia)	Pilbara Minerals	628	0.580	R
Grota do Cirilo	Pegmatite	Minas Gerais (Brazil)	Sigma Lithium	293	0.641	r: M+I[5]
Whabouchi	Pegmatite	Quebec (Canada)	Nemaska Lithium	220	0.604	R[1, 6]
Arcadia	Pegmatite	Harare (Zimbabwe)	Prospect Resources	164	0.608	R[7]
Tanco	Pegmatite	Manitoba (Canada)	Sinonime Rare Metals	110	1.180	R[8]
Atacama	Brine	Atacama (Chile)	SQM; Albermarle	6,300	0.184	R[9]
Uyuni	Brine	Oruro and Potosí (Bolivia)	COMIBOL	3,600	0.045	R[9]
Zhabuye	Brine	Tibet (China)	Tibet Shigatse & Tianqi	1,500	0.100	R[10]
Centenario	Brine	Salta (Argentina)	Eramet	921	0.045	r: M+I[11]
Hombre Muerto	Brine	Catamarca (Argentina)	Livent	835	0.071	R[11]
Olaroz/Cauchari	Brine	Jujuy (Argentina)	Orocobre	345	0.053	r: M[12]
Cauchari	Brine	Jujuy (Argentina)	Lithium Americas & Exar	282	0.069	R[11,13]
Maricunga	Brine	Atacama (Chile)	Minera Salar Blanco	269	0.117	R[14]
3Q	Brine	Catamarca (Argentina)	Neo Lithium	243	0.079	R[11,15]
Rincon	Brine	Salta (Argentina)	Argosy Minerals	203	0.032	R[11]
Clayton Valley	Brine	Nevada (USA)	Pure Energy Minerals	41	0.012	R[16]
Sonora	Li-Clay	Sonora (Mexico)	Bacanora & Ganfeng	845	0.229	R[1,17]
Thacker Pass	Li-Clay	Nevada (USA)	Lithium Americas	582	0.236	R[1,18]
Rhyolite Ridge	Li-clay	Nevada (USA)	Inoneer Resources	209	0.170	r: M+I[19]
Falchani	Li-Tuff	Puno (Peru)	Plateau Energy Metals	146	0.296	r: I[20]
Jadar	Jadarite	Jadar (Serbia)	Rio Tinto	435	0.836	r: I[21]

R = reserve; r = resource; M = measured; I = indicated

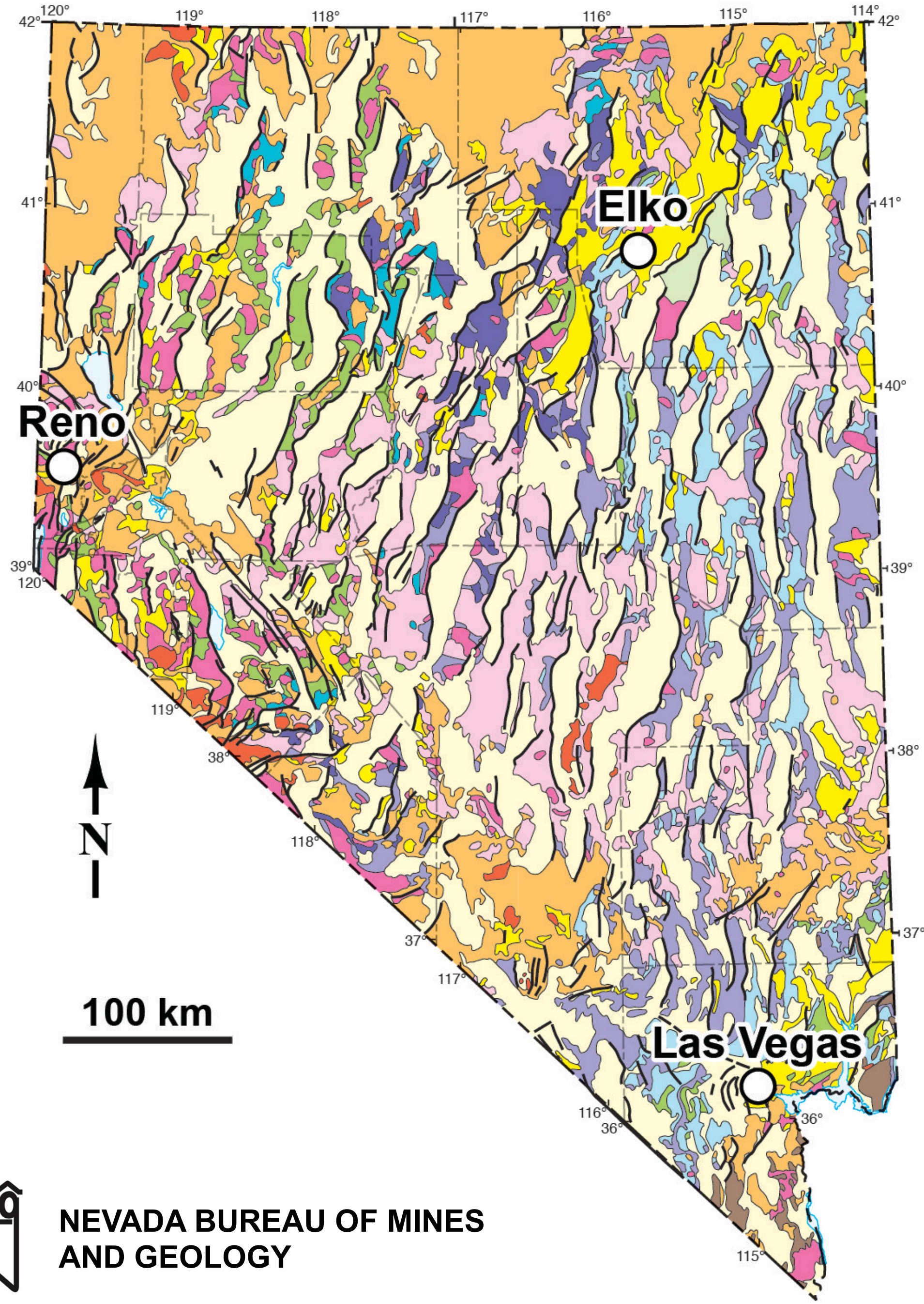
Bowell et al. (2020) – *Elements*

Grade vs. Tonnage of Lithium Deposits



Bowell et al. (2020) – *Elements*

Generalized Geologic Map of Nevada



- County boundaries
- Quaternary and suspected Quaternary faults, less than 1.6 Ma (million years old), dashed where age uncertain
- Lakes and reservoirs
- Alluvial and playa deposits
- Volcanic rocks, less than 6 Ma
- Upper volcanic rocks, 6–17 Ma
- Tuffaceous sedimentary rocks, 6–17 Ma
- Lower volcanic rocks, mostly 17–43 Ma
- Intrusive rocks, Mesozoic and Tertiary
- Igneous and metamorphic complex, Jurassic or Cretaceous
- Sedimentary, volcanic, and intrusive rocks, Mesozoic
- Sedimentary and volcanic assemblage, upper Paleozoic
- Carbonate and other sedimentary rocks, upper Paleozoic
- Sedimentary and volcanic assemblage, lower Paleozoic
- Carbonate and other sedimentary rocks, lower Paleozoic and Late Proterozoic
- Metamorphic and intrusive rocks, Early and Middle Proterozoic

NEVADA BUREAU OF MINES AND GEOLOGY

Case Study #1: Clayton Valley, Nevada

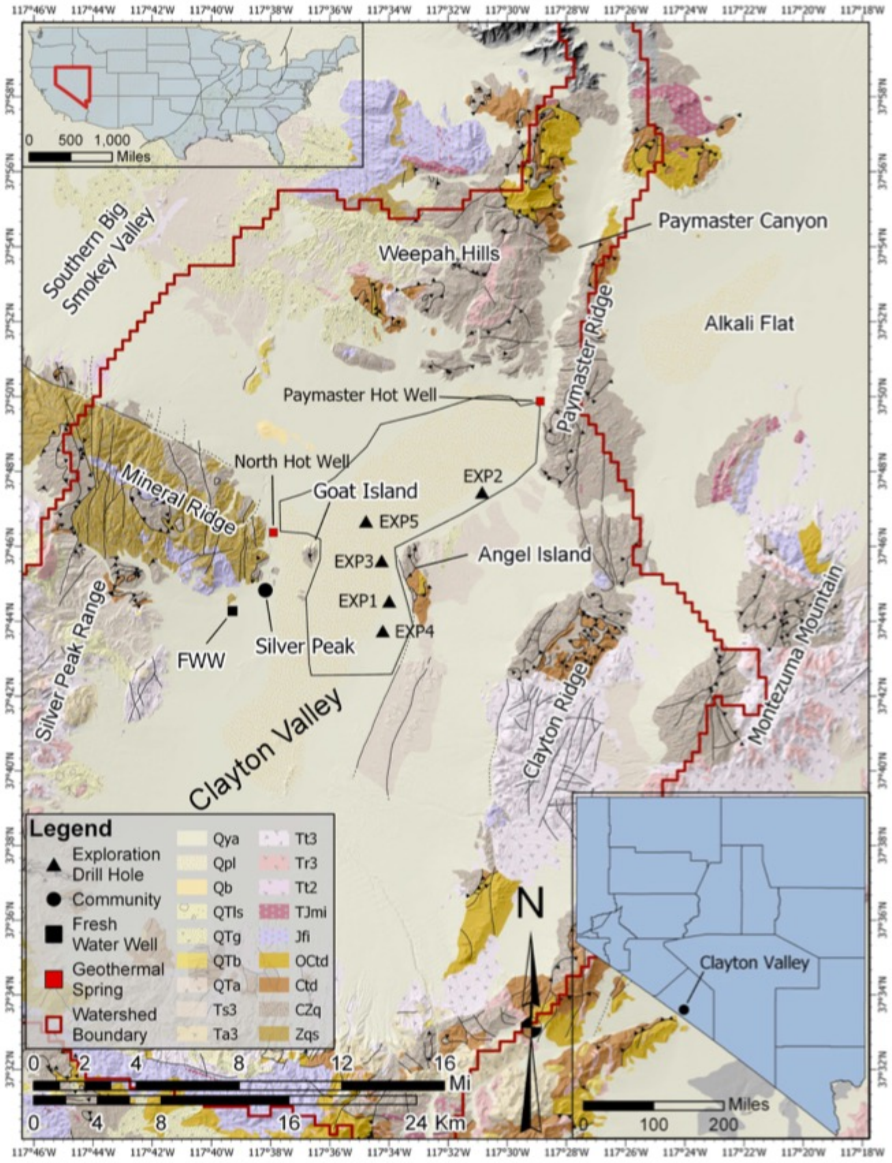
- **Only-producing Li mine** in the U.S. and in North America
- Operated by **Albemarle**
- Ongoing exploration by **Pure Energy Minerals**

Lithium-brine evaporating ponds at Clayton Valley, Nevada (Albemarle)

Case Study #1: Clayton Valley, Nevada

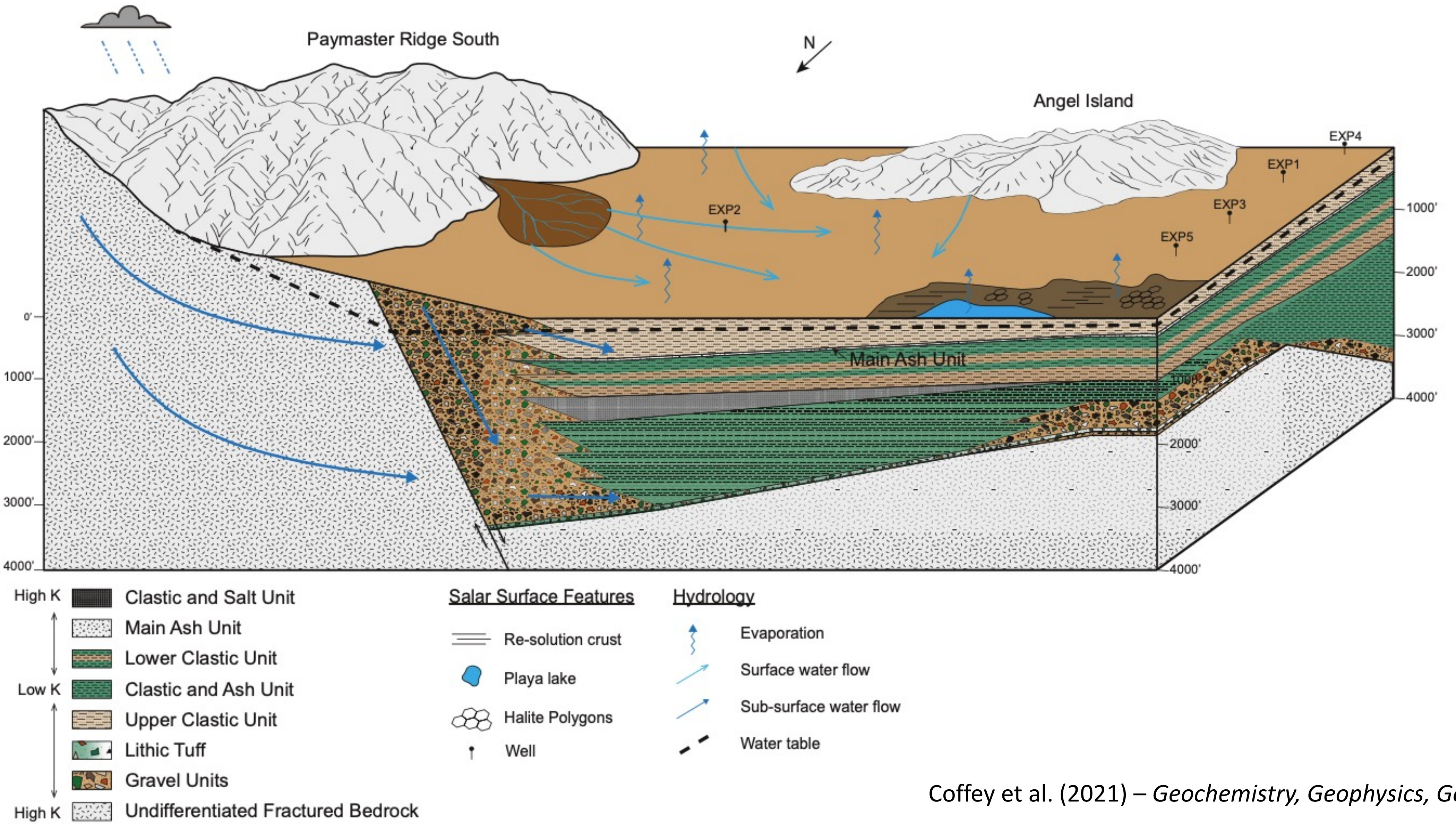
Regional Geology

- **Late Neoproterozoic-Paleozoic sedimentary rocks** deposited along the west margin of the North American craton
- **Jurassic-Cretaceous granitoids** (155 to 85 Ma) related to the Sierra Nevada Cordillera
- **Basin & Range extension** commenced during Miocene at 16 Ma
- **Late Miocene to Pleistocene tuffaceous lacustrine sediments** during wetting/drying periods



Coffey et al. (2021) – *Geochemistry, Geophysics, Geosystems*

Case Study #1: Clayton Valley, Nevada

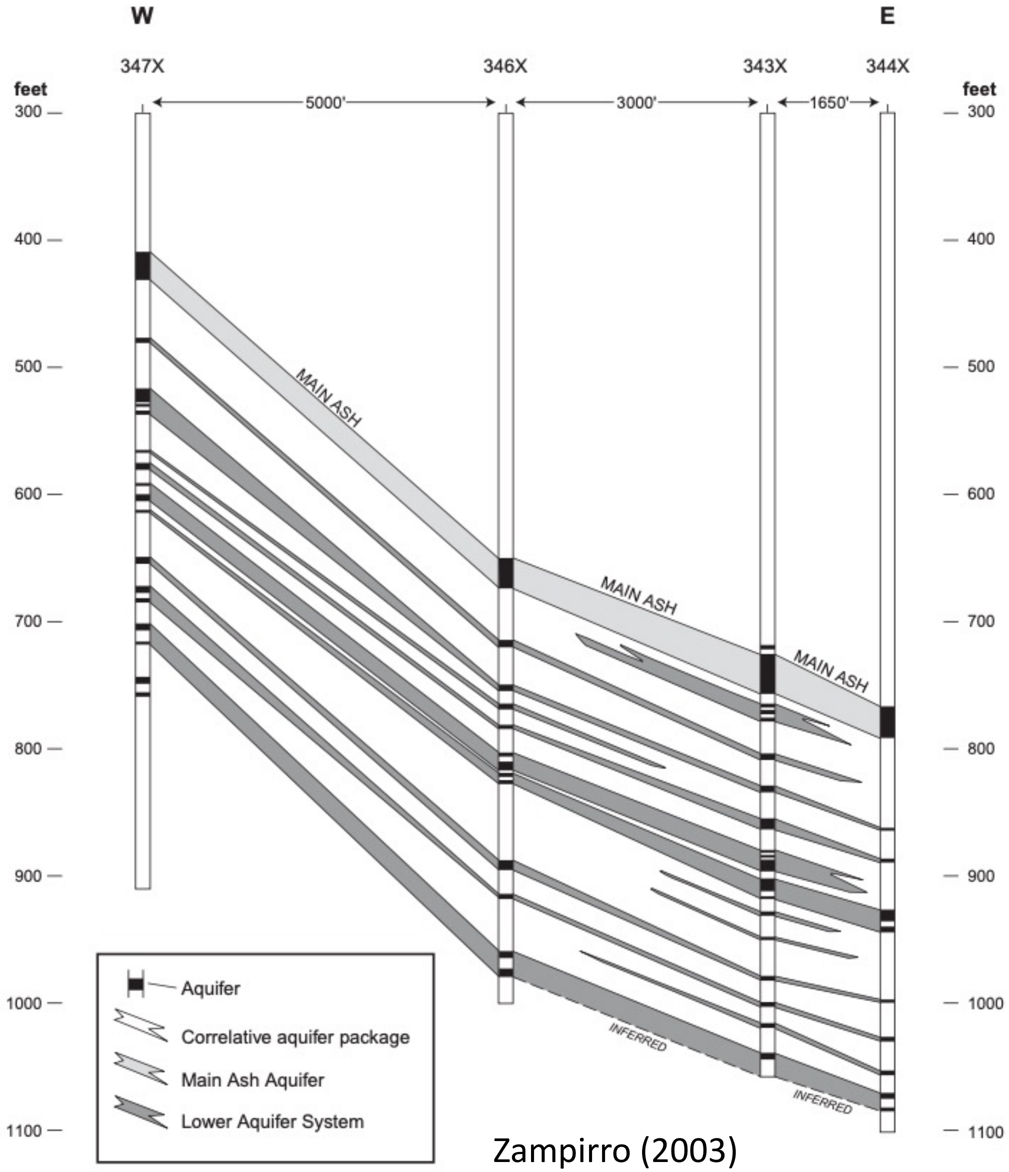


Coffey et al. (2021) – *Geochemistry, Geophysics, Geosystems*

Case Study #1: Clayton Valley, Nevada

Hydrogeology

- Six main aquifers
- Ash, tuff, gravel, silt, and sand units
- Freshwaters: <1 µg/L Li
- Groundwaters/springs: 1-40 mg/L Li
- Brines: 200-400 mg/L Li



Zampirro (2003)

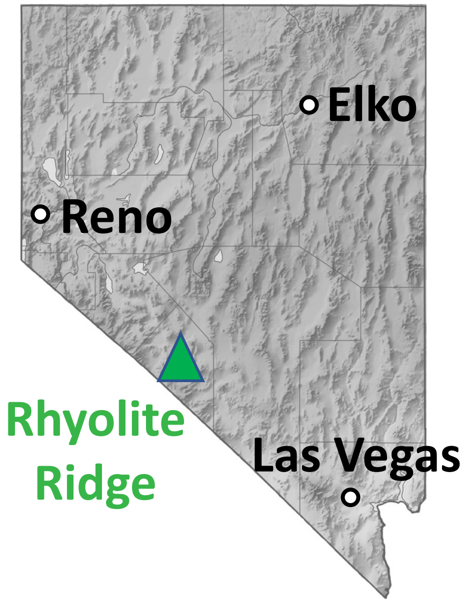
Case Study #1: Clayton Valley, Nevada

Inferred Resource Estimate for Lithium

PURE ENERGY MINERALS	Average Lithium Concentration in Brine Volume (mg/L)	Brine Volume (m^3) x 10^3	Average Specific Yield	Drainable Brine Volume (m^3) x 10^3	Lithium (kTonnes)	$LiOH \cdot H_2O$ (kTonnes)	LCE (kTonnes)
Resource Volumes by Average Lithium Concentration	22	550,600	0.06	33,040	0.7	4.39	3.87
	65	2,424,000	0.06	145,400	9.5	57.16	50.32
	132	579,200	0.06	34,750	4.6	27.73	24.41
	221	1,971,000	0.06	118,200	26.1	158.00	139.09
Total	**123**	**5,524,000**	**0.06**	**331,500**	**40.9**	**247.3**	**217.7**

https://pureenergyminerals.com

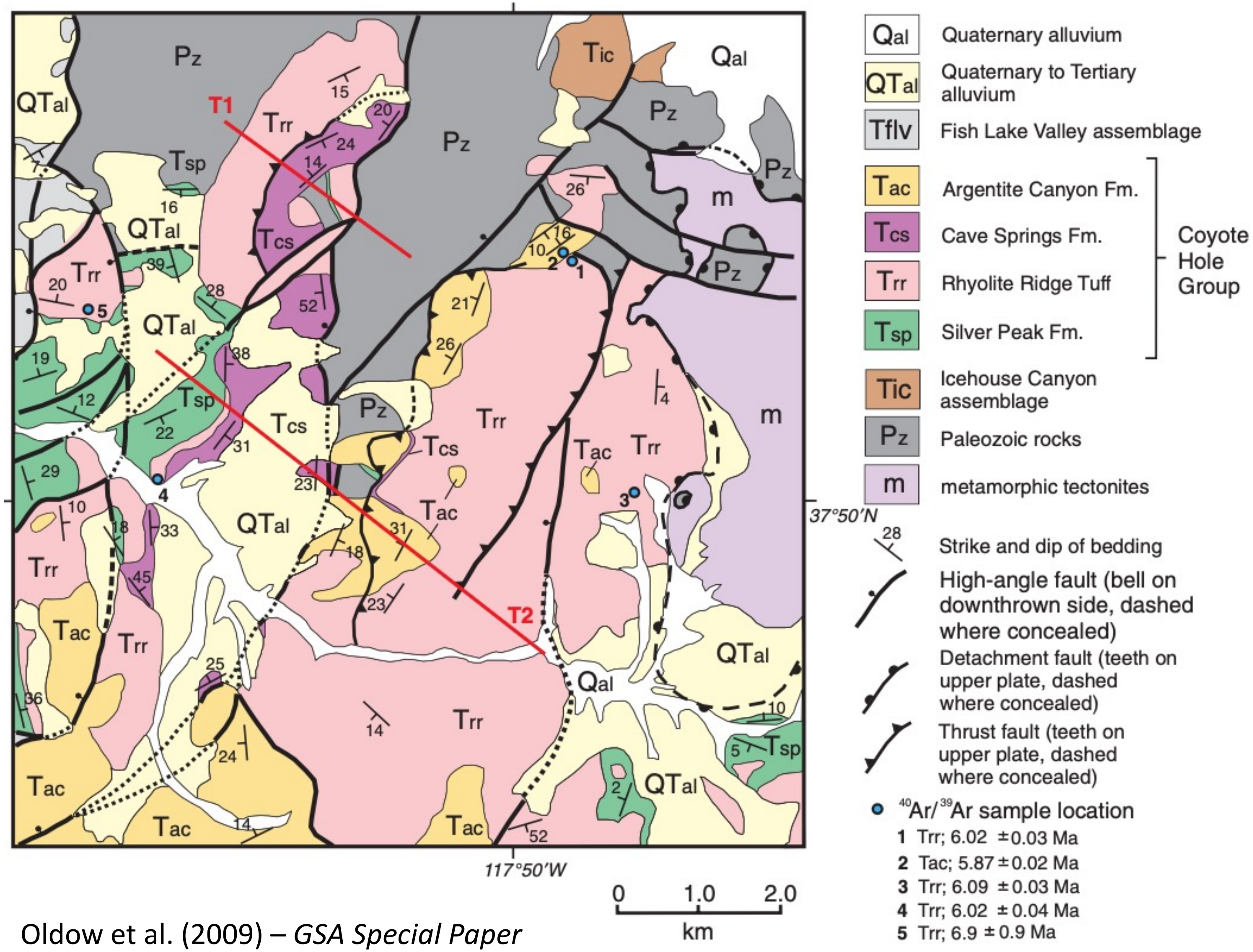
Case Study #2: Rhyolite Ridge, Nevada



- **Lithium-boron clays** associated to late Miocene rhyolitic rocks
- Ongoing exploration by **Ioneer**

View of the Cave Spring Formation (white) overlying the Rhyolite Ridge Tuff (pink)

Case Study #2: Rhyolite Ridge, Nevada

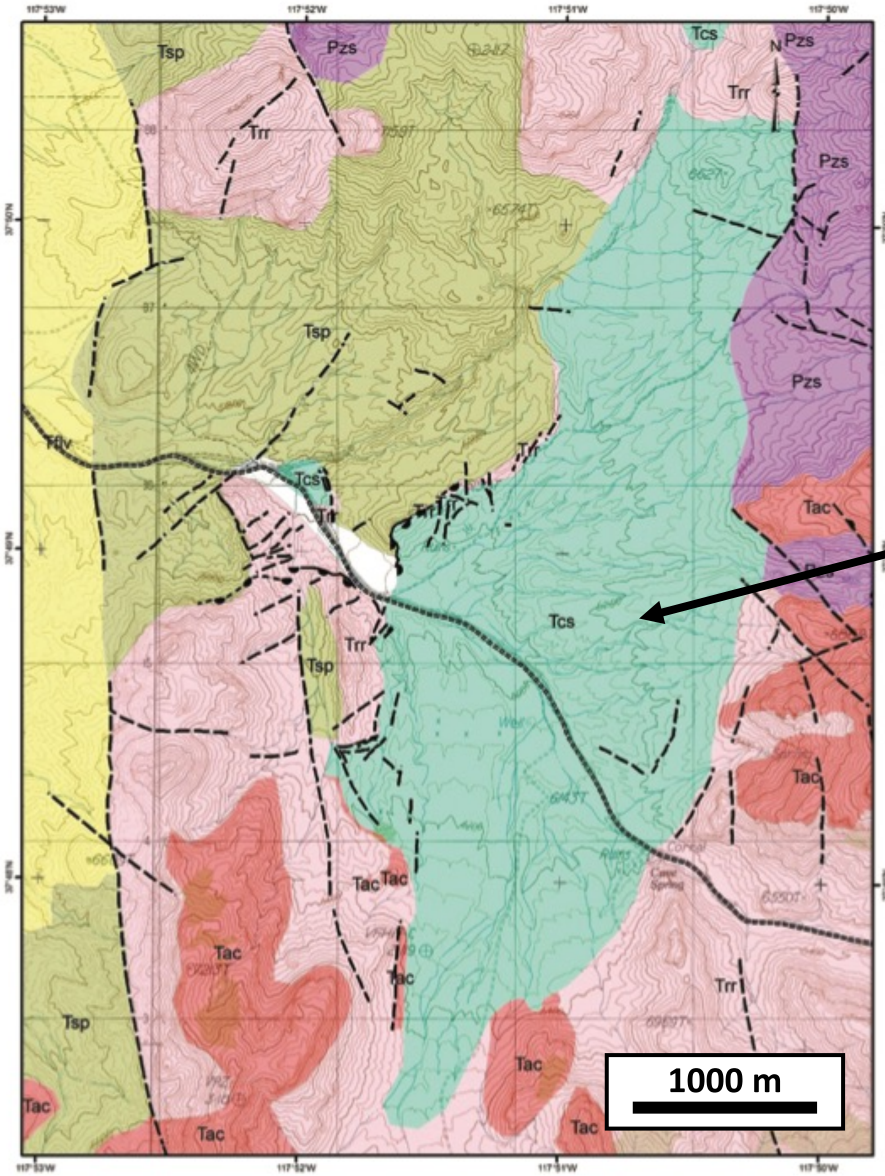


Oldow et al. (2009) – *GSA Special Paper*

Regional Geology

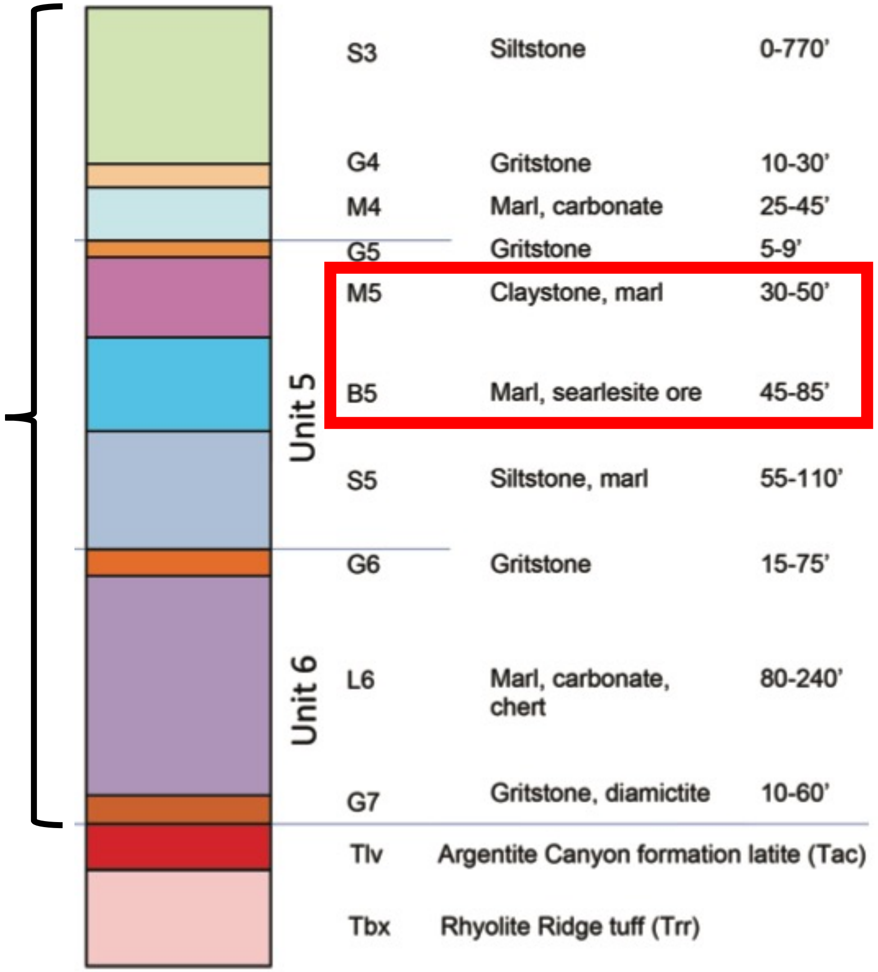
- **Paleozoic sedimentary rocks** deposited on the ancient western passive margin of North America
- **Late Miocene-Pliocene uplift and exhumation** of metamorphic core complex
- **Miocene to Pliocene volcanic and volcanoclastic rocks (~16 to 6 Ma)** deposited on the Paleozoic/Mesozoic basement

Case Study #2: Rhyolite Ridge, Nevada



Cave Spring Formation

Stratigraphy



Main ore zone for Li and B

Reynolds and Chafetz (2020) – *GSN Symposium*

Case Study #2: Rhyolite Ridge, Nevada

Massive claystone
Li ore

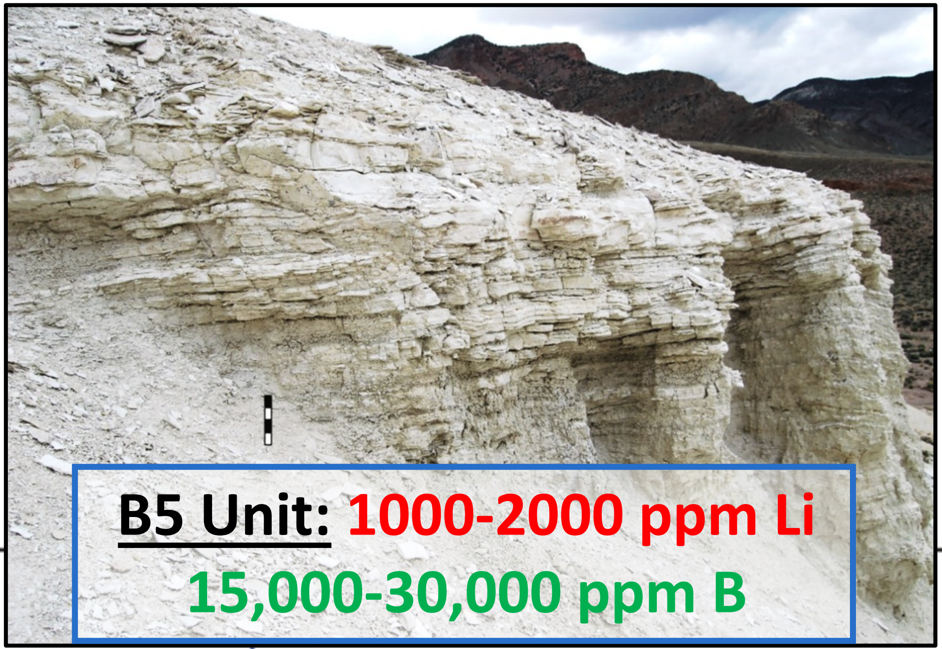
Finely laminated marl
Li-B ore

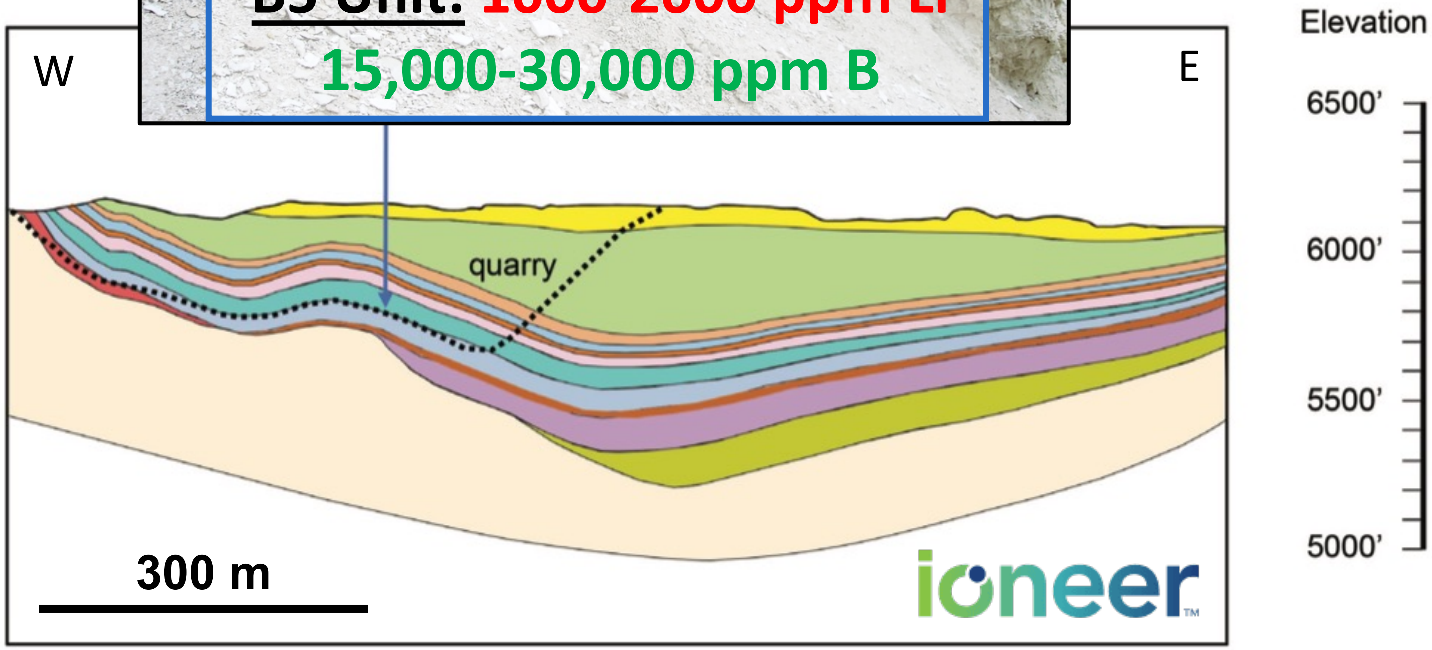
Siltstone

Unit	Feet	Li	B	Mg	Ca	Rb	Cs	Na	As	Sr
G5	455	264	80	0.76	3.69	26	9	0.04	79	917
M5	460	1680	140	4.17	5.89	44	15	0.10	77	1890
	465	1940	160	6.57	14.75	39	102	0.20	106	7390
	470	2360	280	6.28	16.75	51	147	0.37	141	>10000
	475	2410	480	5.99	13.40	87	202	0.46	98	>10000
	480	2380	2380	6.04	13.85	98	293	0.98	85	>10000
	485	2360	4870	6.24	15.75	50	32	1.46	42	>10000
	490	2500	6560	6.86	13.45	44	42	1.89	59	>10000
	495	2620	7080	7.26	11.80	93	56	1.93	75	>10000
B5	500	2370	12000	5.36	8.99	182	84	2.66	157	>10000
	505	2000	16000	4.10	8.12	217	97	3.19	71	9730
	510	1650	20000	3.25	7.86	264	124	2.99	71	8240
	515	1550	17000	3.37	9.31	301	135	2.89	80	8180
	520	1770	17000	3.40	10.20	349	142	3.46	77	9260
	525	1660	19000	3.45	10.25	209	119	3.95	63	9200
	530	1480	26000	3.97	8.35	133	87	5.33	27	6070
	535	1550	27000	3.74	6.17	260	142	5.47	33	6080
	540	1450	29000	2.83	5.38	309	220	5.71	63	4240
	545	1260	29000	2.16	5.16	317	211	5.77	101	3980
	550	1590	28000	2.23	4.88	418	277	5.44	173	3900
	555	1440	28000	2.69	4.66	366	230	5.31	209	4030
	560	1260	23000	2.86	5.58	305	184	4.38	116	4470
	565	1230	16000	3.82	11.15	213	135	3.32	207	4760
	570	980	15000	3.32	7.54	105	142	3.16	323	3610
S5	575	1020	4580	3.20	6.28	99	362	1.49	233	6530
	580	1520	350	3.98	6.51	148	140	0.37	282	7200
	585	940	150	2.69	7.41	89	164	0.31	104	2100

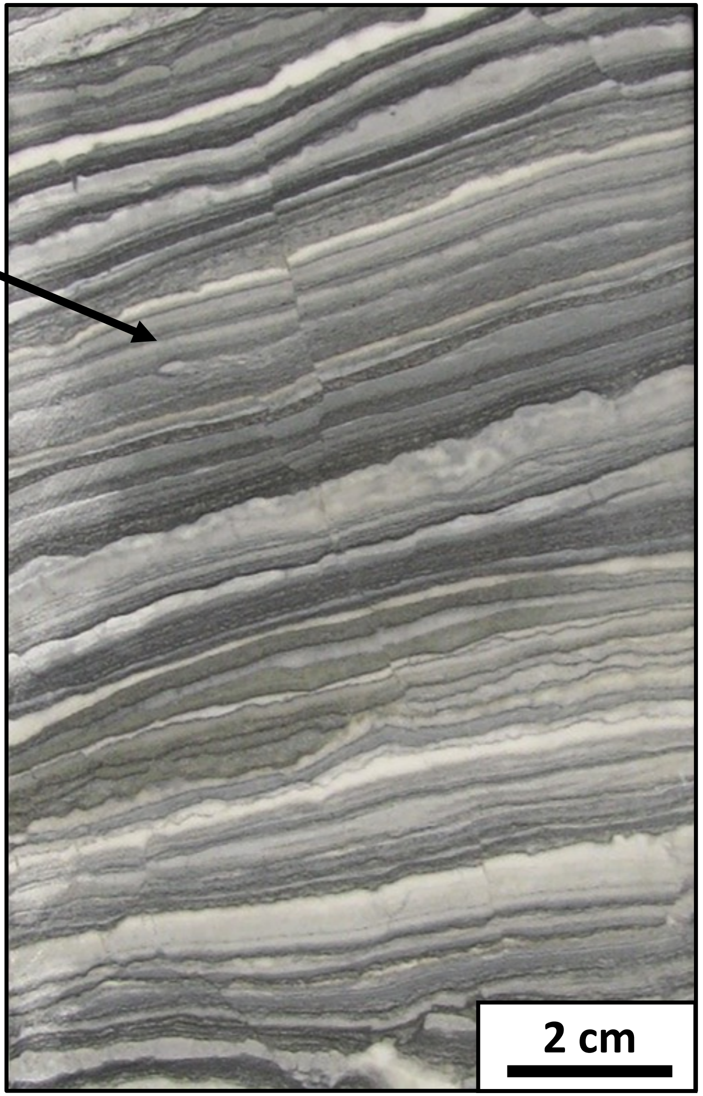
Reynolds and Chafetz (2020)
– *GSN Symposium*

Case Study #2: Rhyolite Ridge, Nevada





Searlesite
$NaBSi_2O_5(OH)_2$
+ mixed
Li-illite/smectite
and carbonates



Reynolds and Chafetz (2020) – *GSN Symposium*

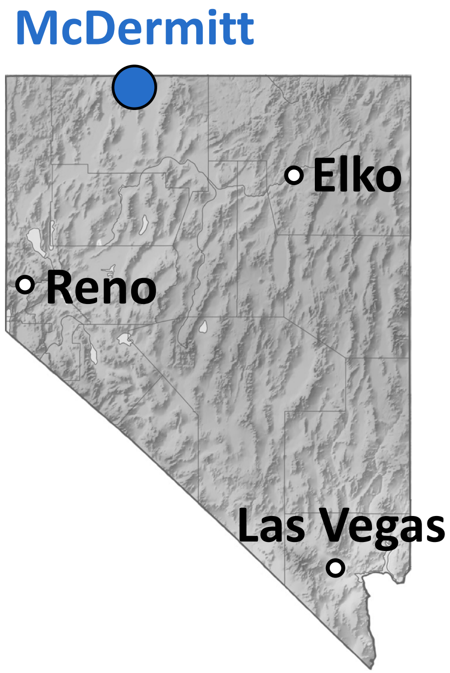
Case Study #2: Rhyolite Ridge, Nevada

Mineral Resource and Reserve Estimate – Rhyolite Ridge Project			
	Metric Tons (Million)	Lithium (ppm)	Boron (ppm)
Mineral Resource (Jan. 2020)			
Measured	39.0	1,700	14,550
Indicated	88.9	1,550	14,150
Inferred	19.5	1,600	13,800
Total	**146.5**	**1,600**	**14,200**
Ore Reserve (March 2020)			
Proved Ore Reserve	29.0	1,899	16,271
Probable Ore Reserve	31.3	1,702	14,629
Total Proved & Probable	**60.2**	**1,797**	**15,418**

ppm = parts per million

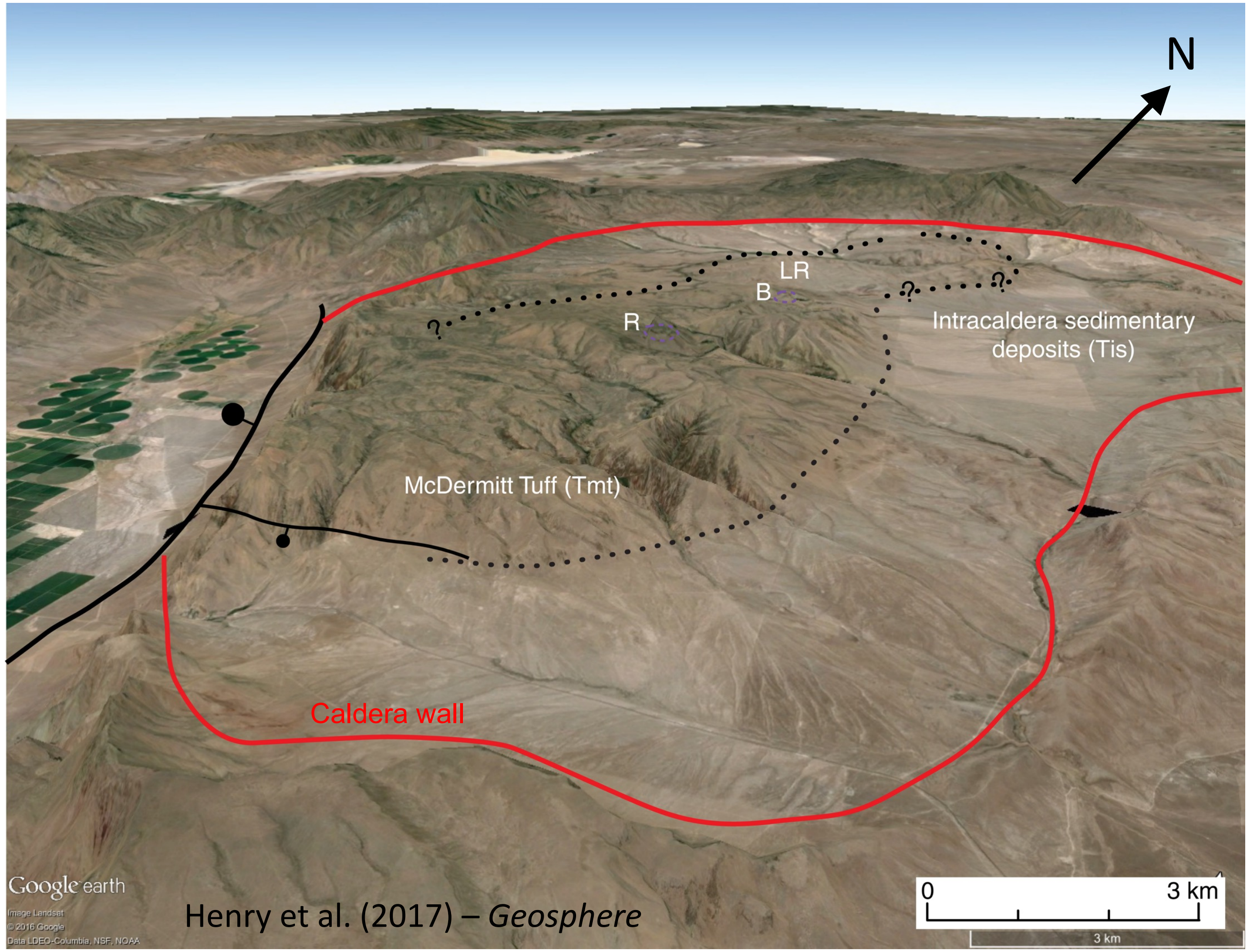
https://www.ioneer.com

Case Study #3: McDermitt Caldera, Nevada



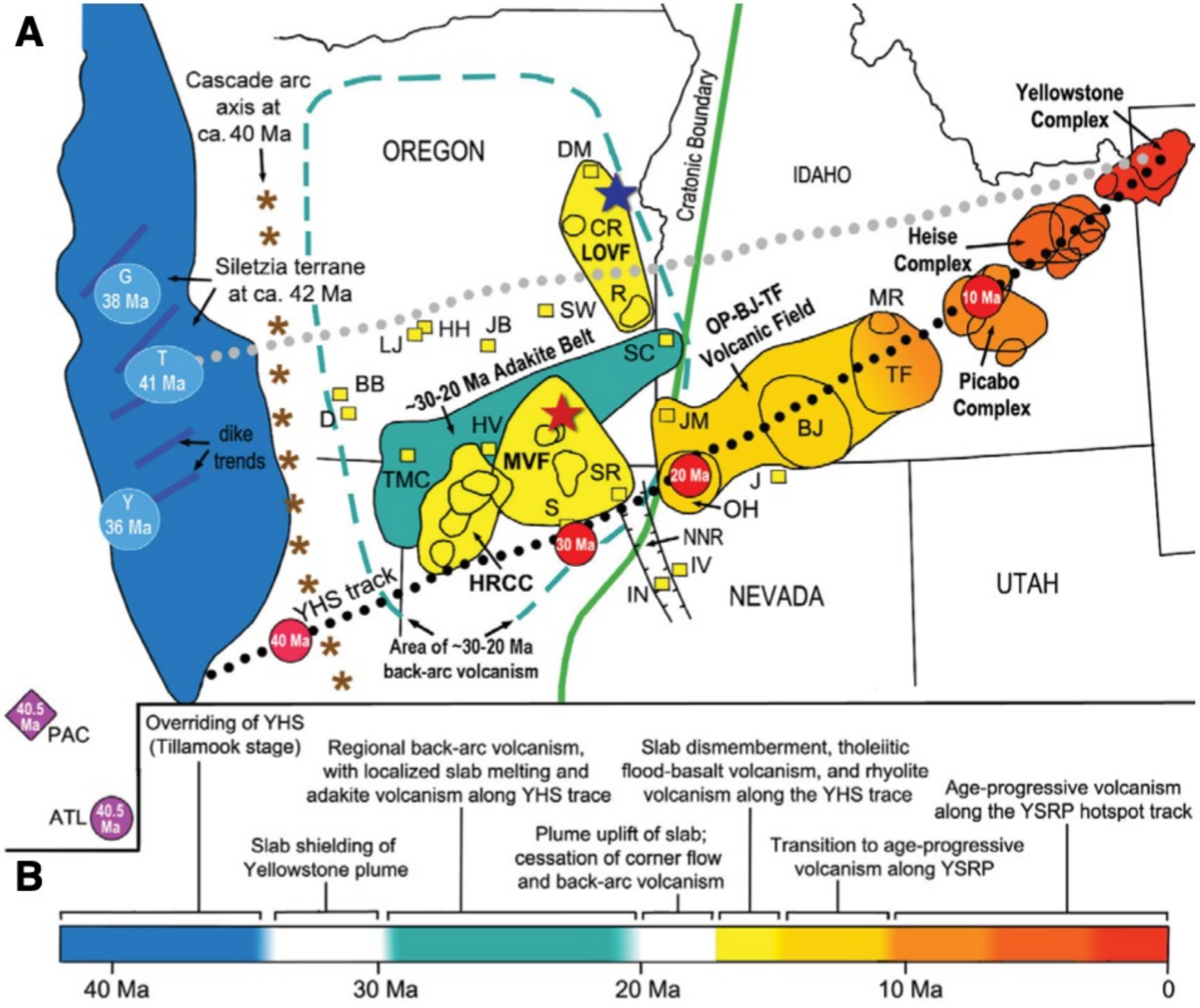
LithiumAmericas

- **Lithium clays** associated to a Miocene volcanic caldera
- Ongoing exploration by **Lithium Americas**



Overview of the McDermitt caldera looking north across resurgent dome

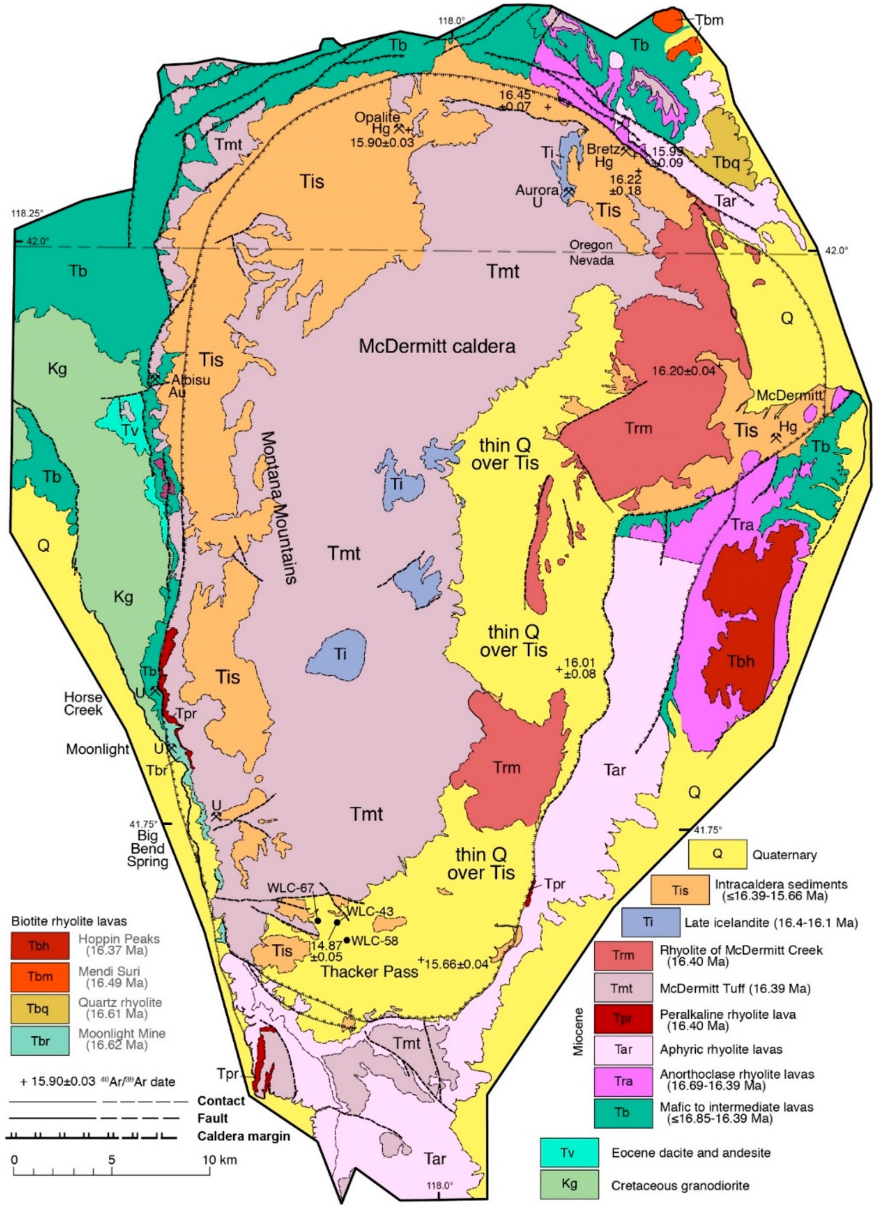
Case Study #3: McDermitt Caldera, Nevada



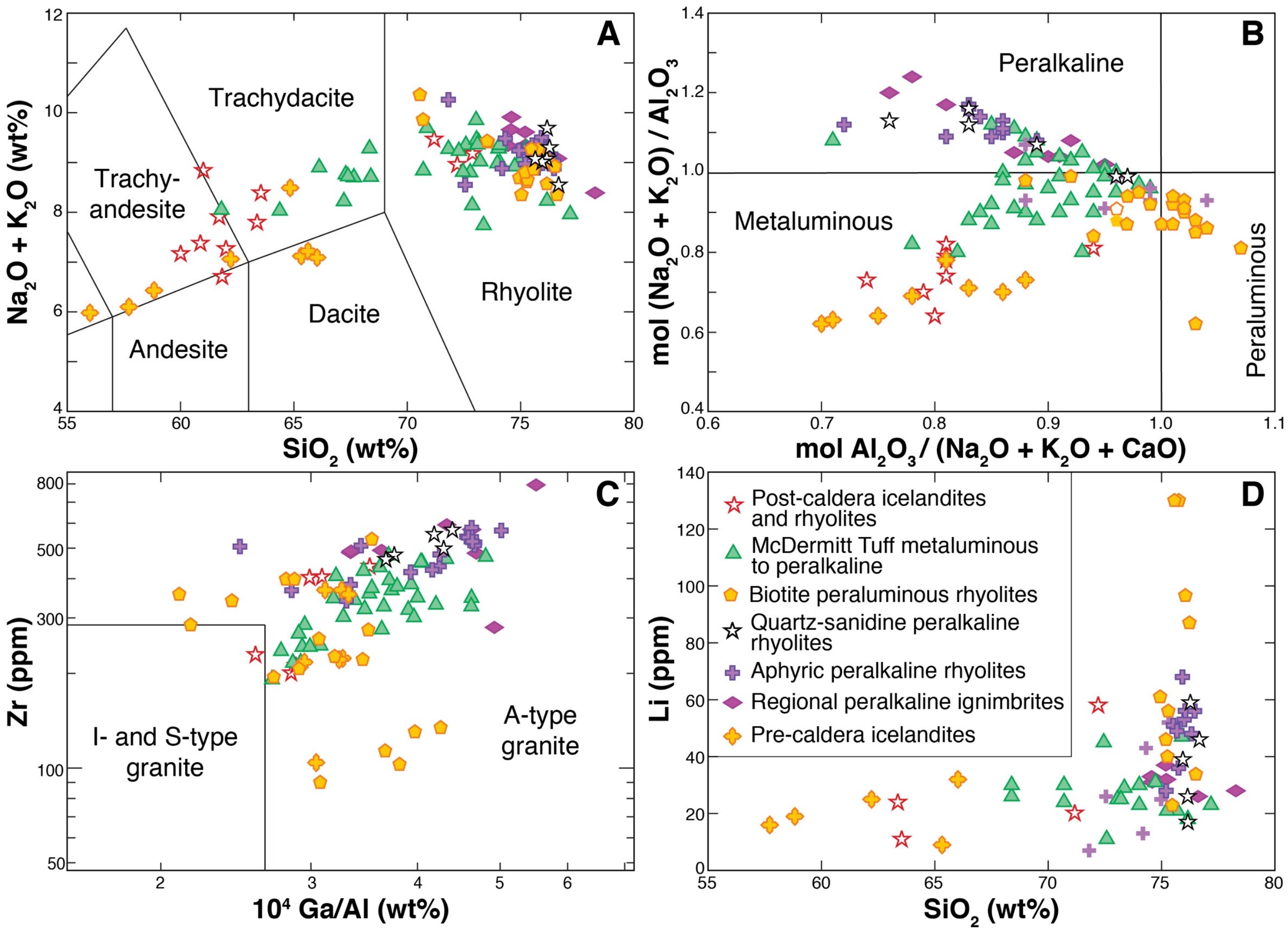
Evolution of the Yellowstone hotspot track relative to the North American plate

Camp and Wells (2021) – *GSA Today*

Case Study #3: McDermitt Caldera, Nevada



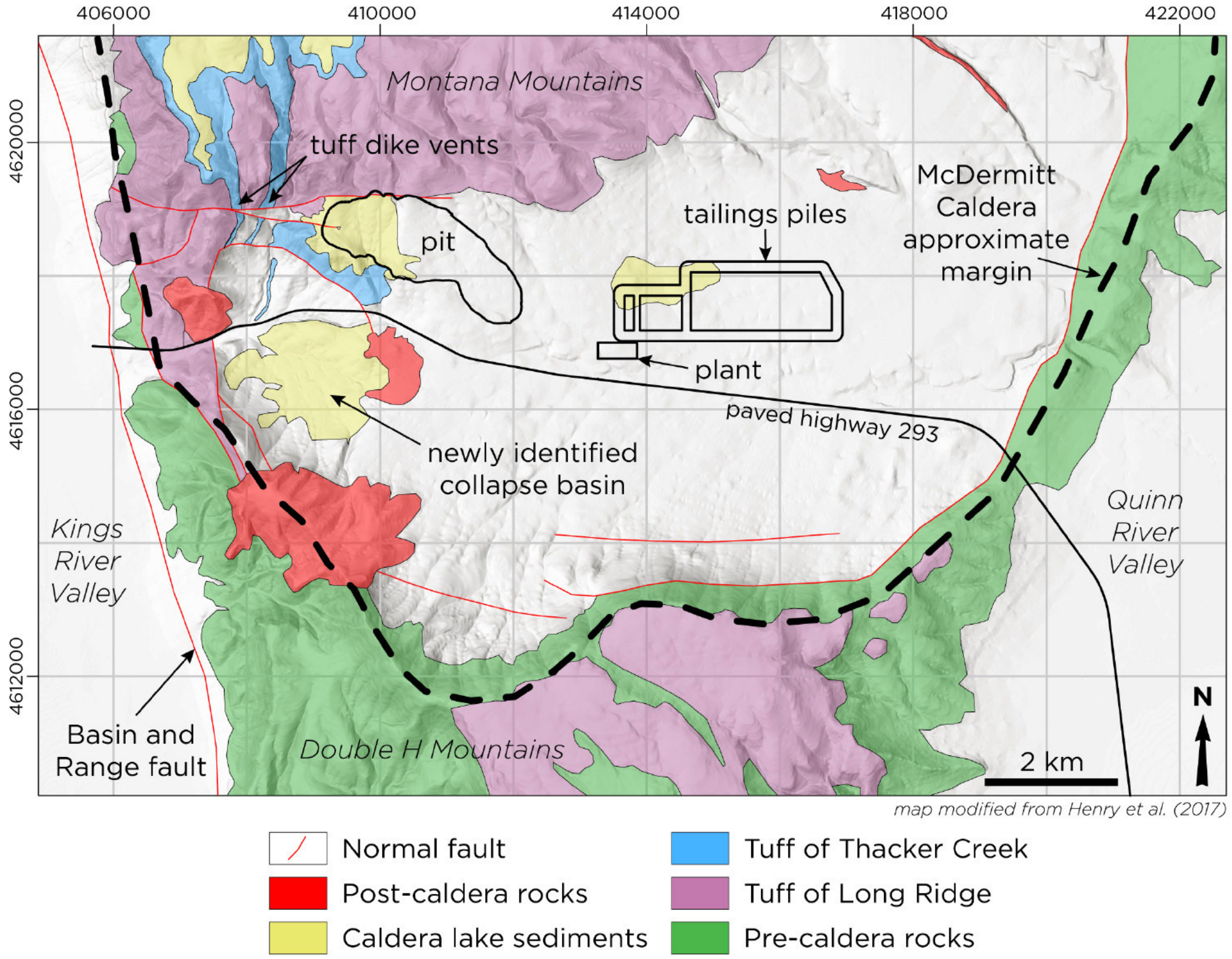
Geochemistry of volcanic rocks

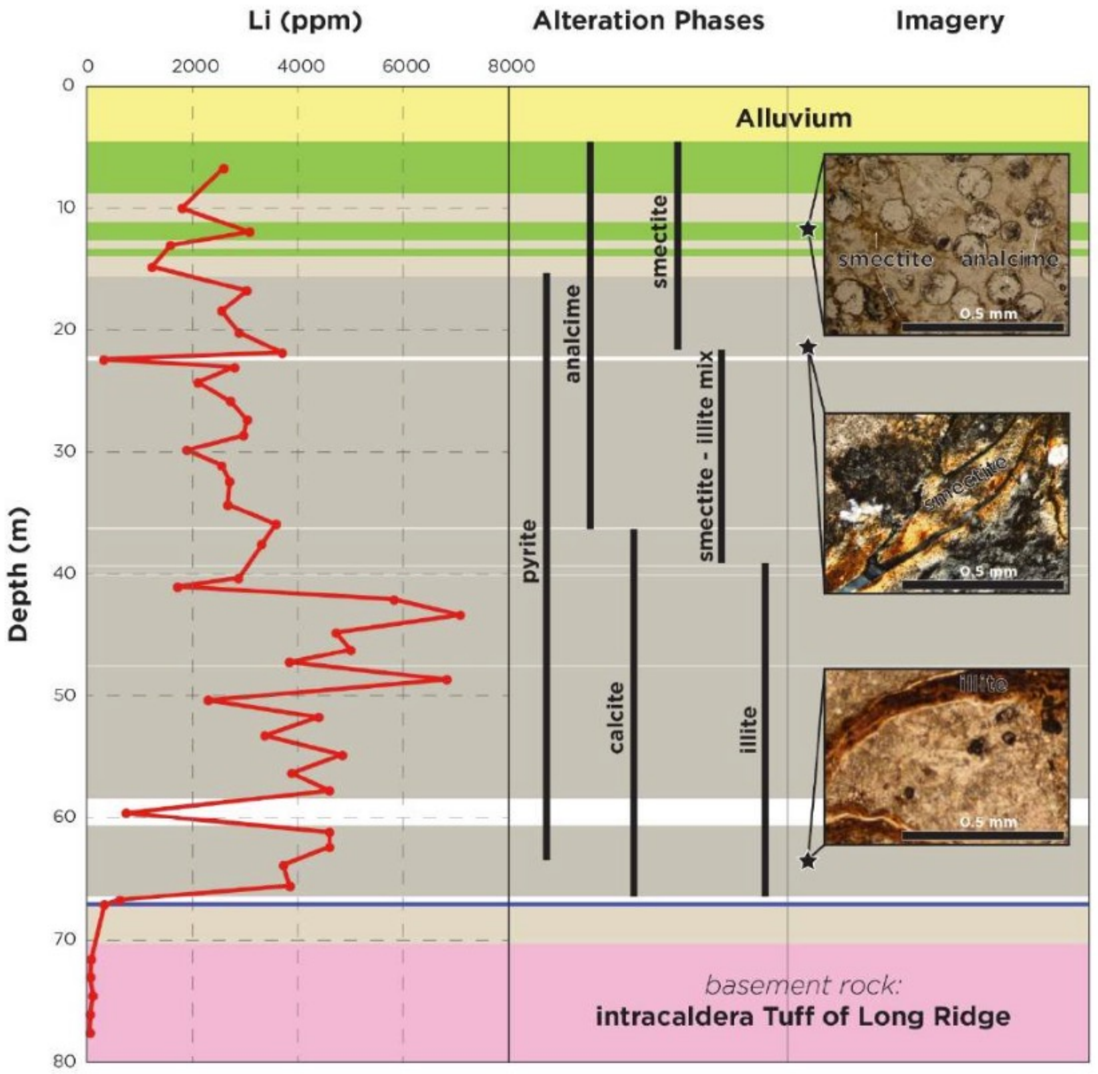


Modified from Castor and Henry (2020) – *Minerals*

Case Study #3: McDermitt Caldera, Nevada

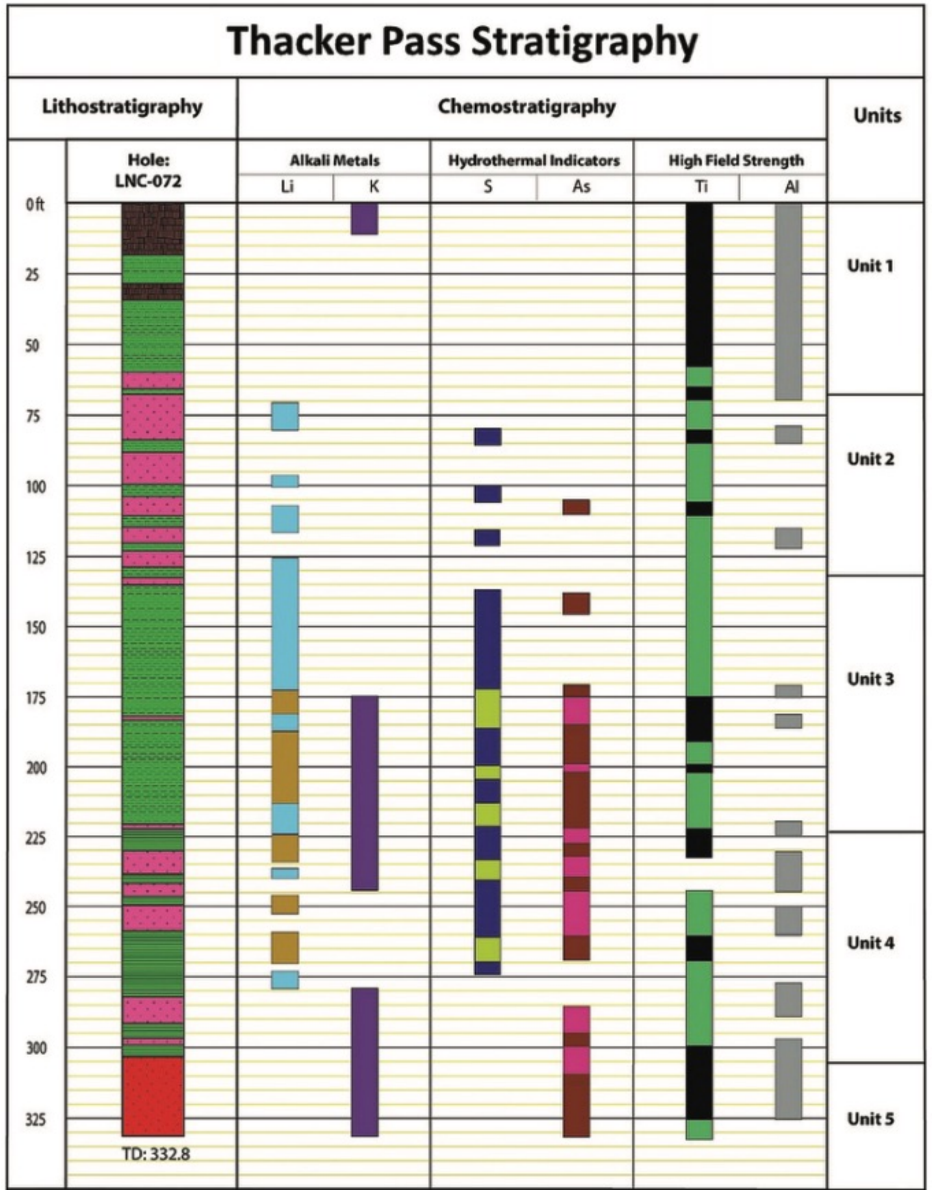
Thacker Pass deposit





Lithium Nevada Corporation (2018)

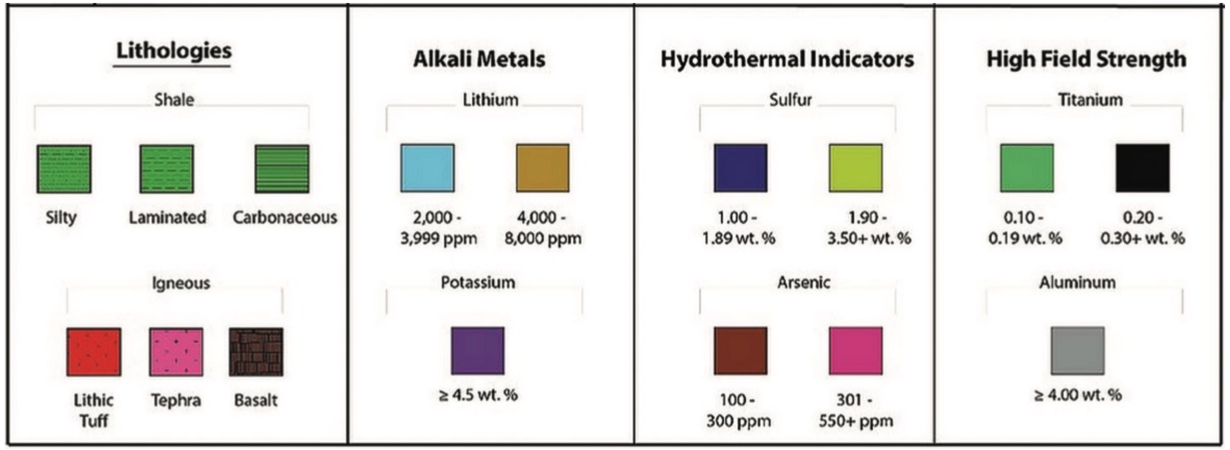
Case Study #3: McDermitt Caldera, Nevada



Hectorite

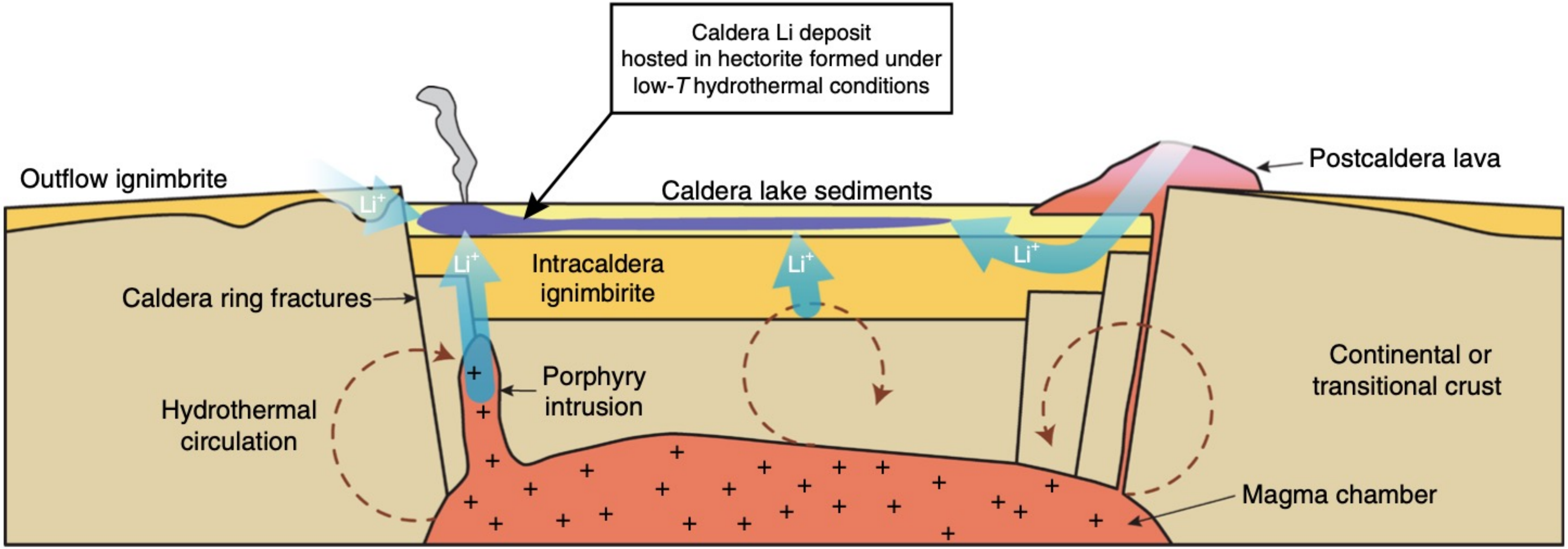
$Na_{0.3}(Mg,Li)_3$
$(Si_4O_{10})(OH)_2$

Li-smectite



Ingraffia et al. (2020) – *GSN Symposium*

Case Study #3: McDermitt Caldera, Nevada



Conceptual model for the formation of caldera-hosted Li clay deposits

Benson et al. (2017) – *Nature Communications*

Case Study #3: McDermitt Caldera, Nevada

Mineral Resources	Tonnage ('000 metric tonnes)	Average Li (ppm)	Lithium Carbonate Equivalent (LCE) ('000 metric tonnes)
Measured	242,150	2,948	3,800
Indicated	143,110	2,864	2,182
Measured and Indicated	385,260	2,917	5,982
Inferred	147,440	2,932	2,301

Mineral Reserves	Tonnage ('000 metric tonnes)	Average Li (ppm)	LCE ('000 metric tonnes)
Proven	133,944	3,308	2,358
Probable	45,478	3,210	777
Proven and Probable	179,422	3,283	3,135

https://www.lithiumamericas.com

LithiumAmericas

Outstanding Research Questions

- What are the **structural controls** for the development of closed basins concentrating Li in brines and clays?

- Are **anomalous heat flows** required for the formation of Li brine aquifers?

- Does **hydrothermal activity** play a role on lithium redistribution and enrichment in the sedimentary strata?

- What effect has the **smectite/illite transformation** on Li enrichment?

- Why are there only a few **Li-rich basins** in Nevada while most of them share similar characteristics?

- What makes the **McDermitt caldera unique** for Li mineralization along the Yellowstone hotspot track?

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