Field Indicators for TDS Prediction from Appalachian Mine Spoils

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40
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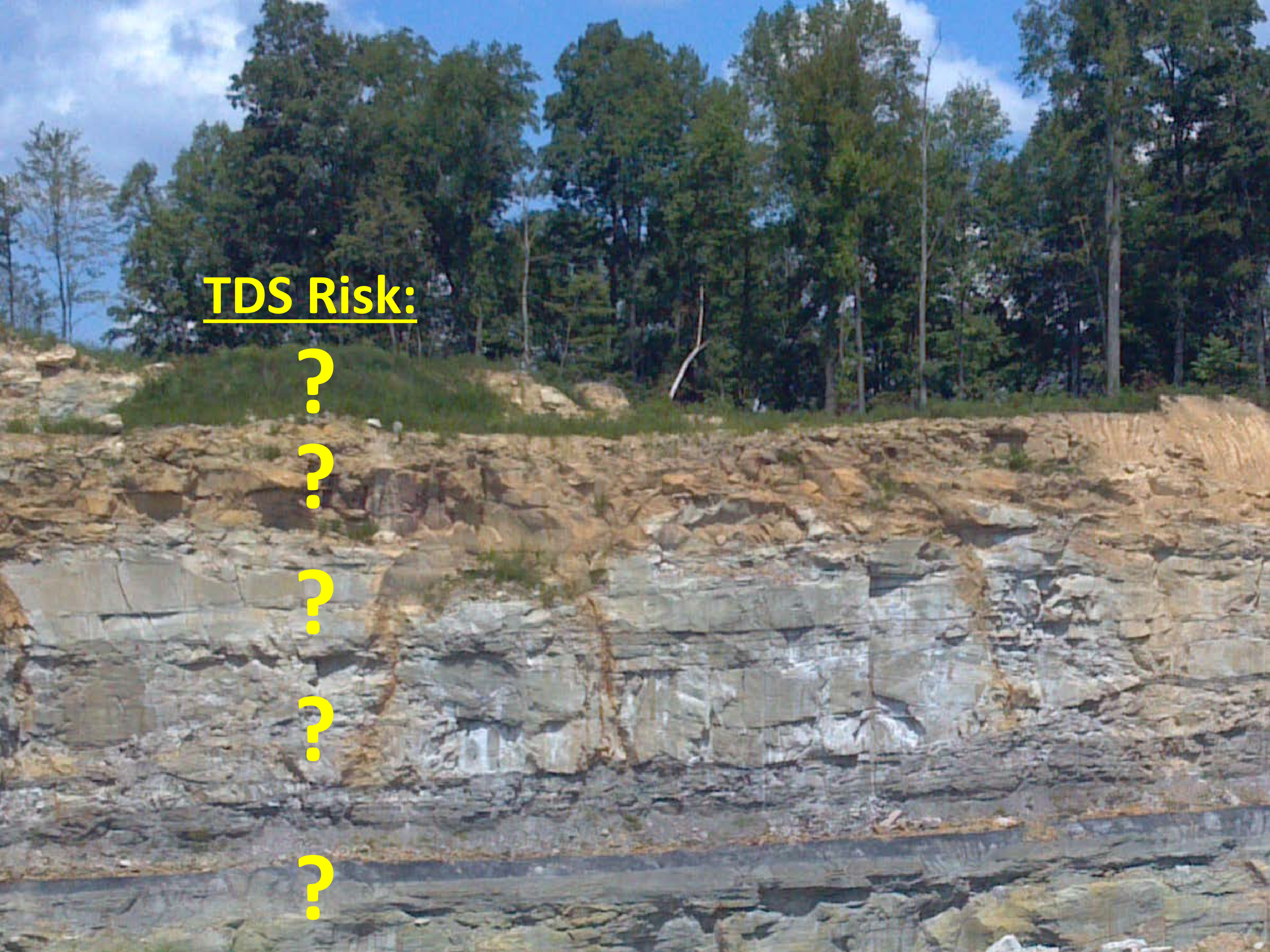

TDS Risk:
?
?
?
?
?

Objectives:

Measure the net TDS elution potential of a range of materials originating from surface coal mines in Central Appalachia and analyze the following geochemical properties:

- Saturated paste SC, pH, and ionic composition
- Microwave assisted acid digestion and total sulfur (total-S)
- Citrate-dithionite (CD) - extractable Al, Fe, and Mn
- Hydrogen peroxide (H_2O_2) pH and SC

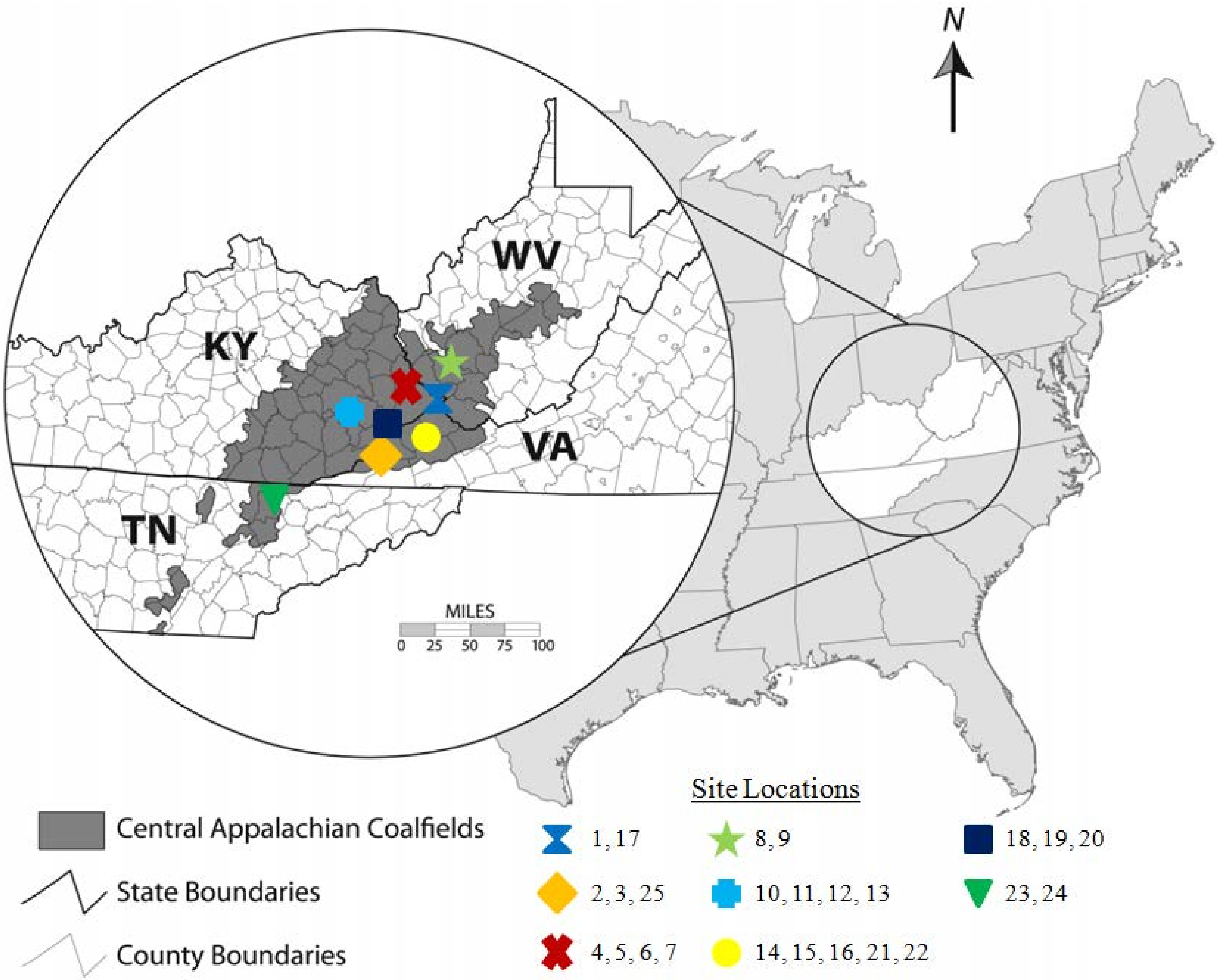
Investigate the nature of the boundary between weathered and unweathered strata to determine if:

- An abrupt boundary exists at some confining layer, such as a shale or mudstone layer; or
- The boundary is more diffuse, being more related to the distance from the earth's surface.

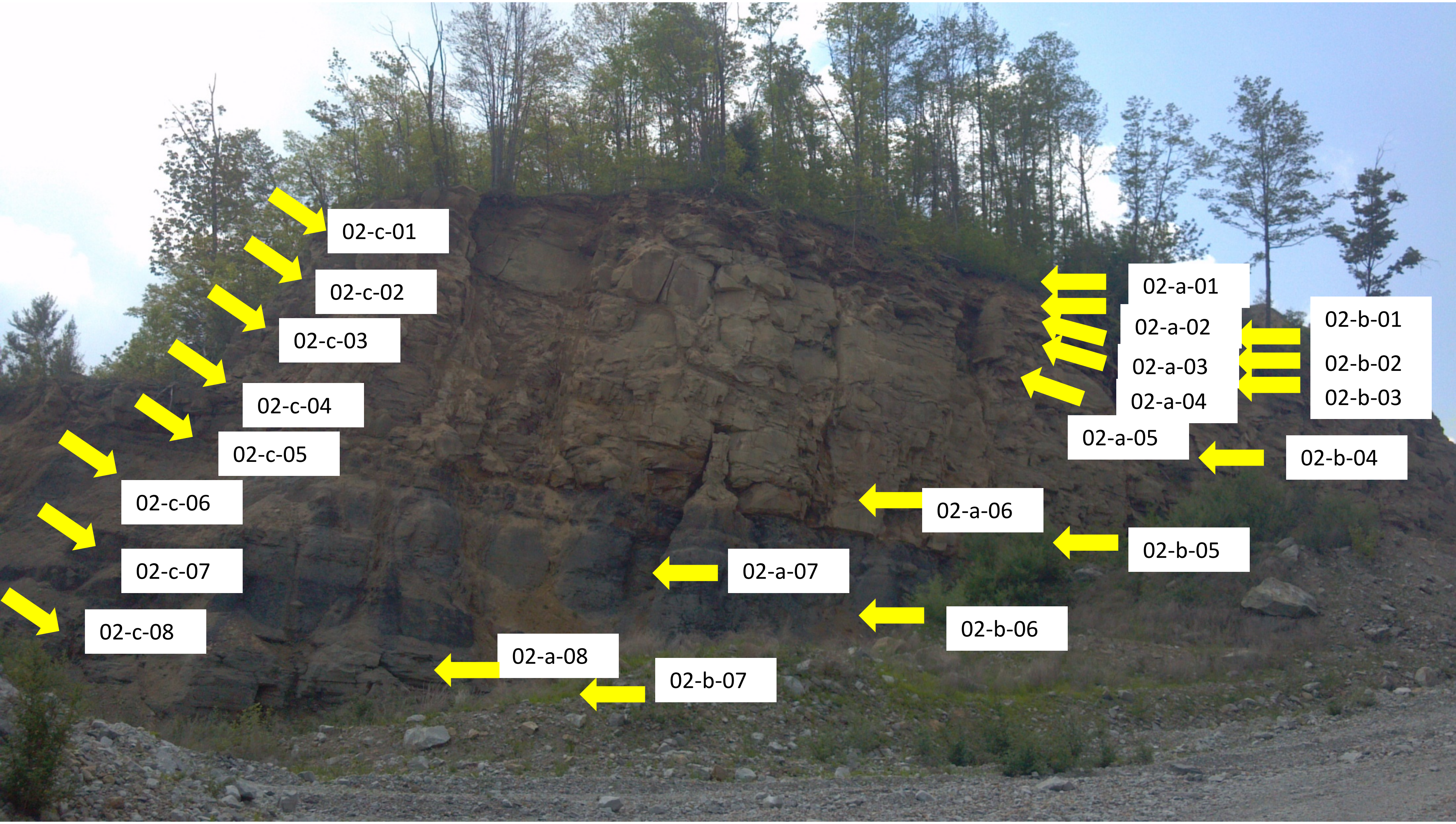
Objectives:

Develop a set of simple field indicators for predicting TDS elution potential by statistically relating the geochemical properties described above to the following properties:

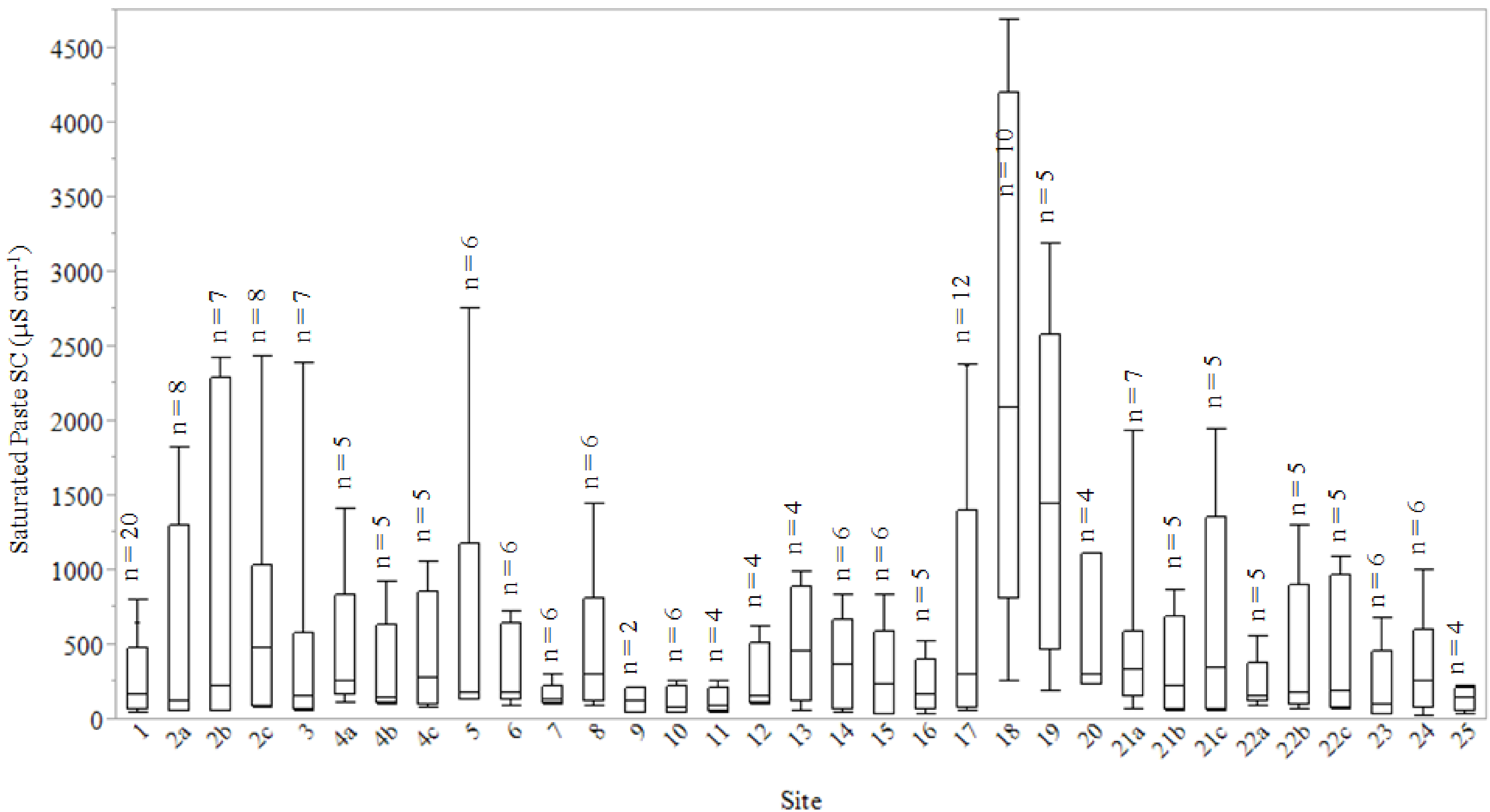
- **Munsell color, hue, value, and chroma**
- **Rock type**
- **Horizon Type**
- **Degree of preweathering**
- **Hydrochloric (HCl) acid fizz test**
- **H_2O_2 reaction**


N
WV
KY
VA
TN
MILES
0 25 50 75 100
Site Locations
1, 17
8, 9
18, 19, 20
2, 3, 25
10, 11, 12, 13
23, 24
4, 5, 6, 7
14, 15, 16, 21, 22
Central Appalachian Coalfields
State Boundaries
County Boundaries

Sampling and Replication Scheme:

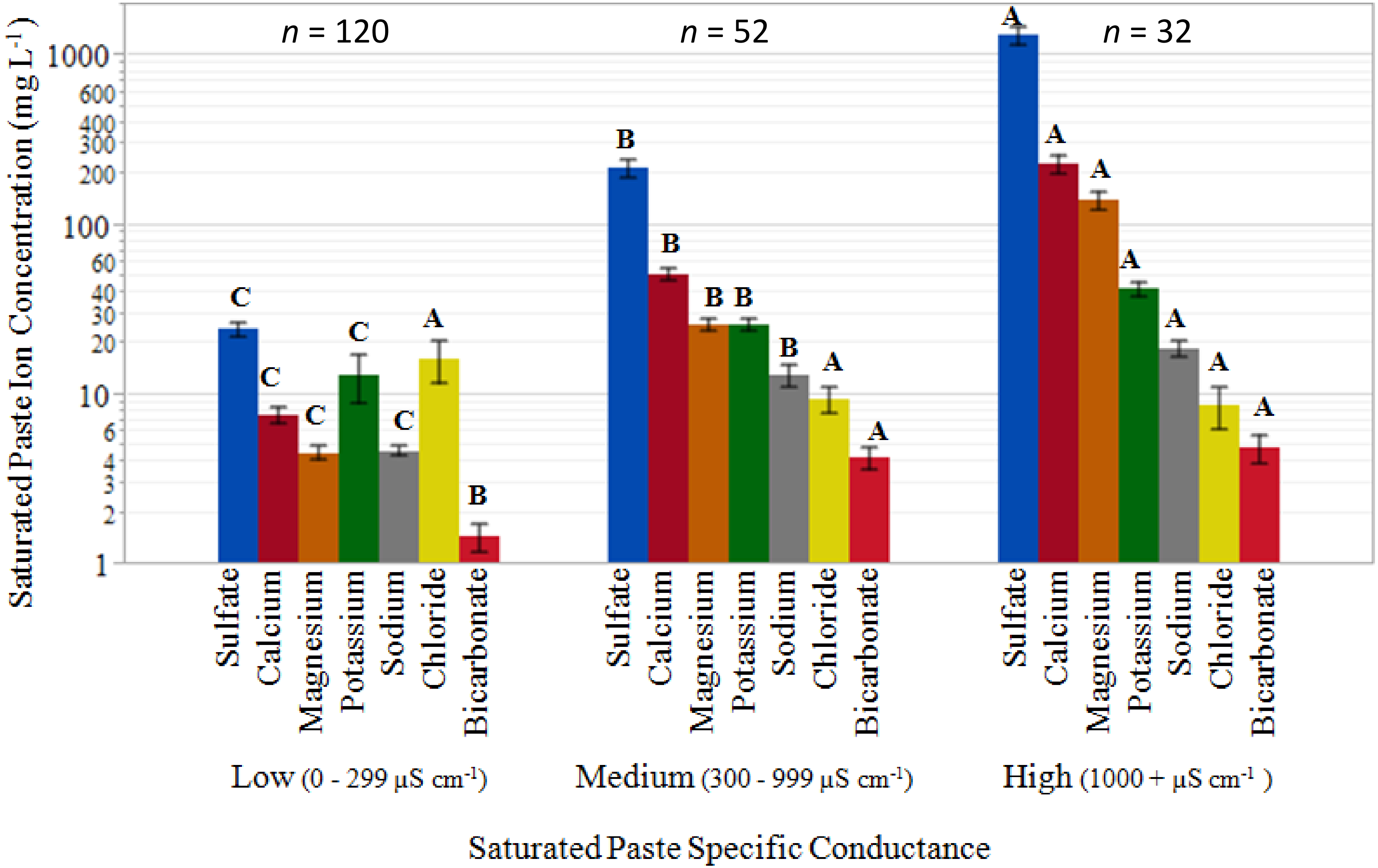


Each distinct layer was sampled and described according to the NRCS Field Book for Describing and Sampling Soils, version 3.0

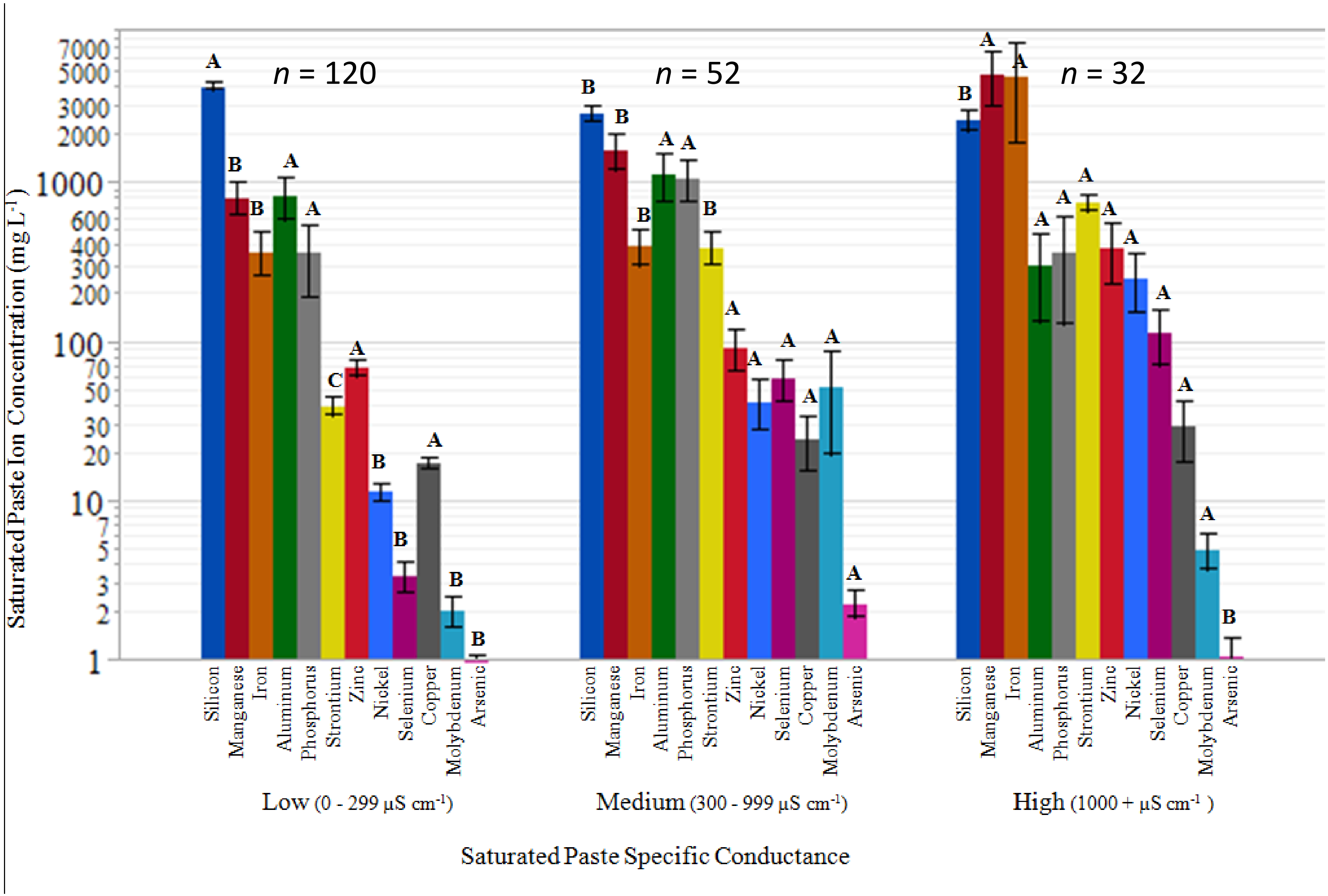


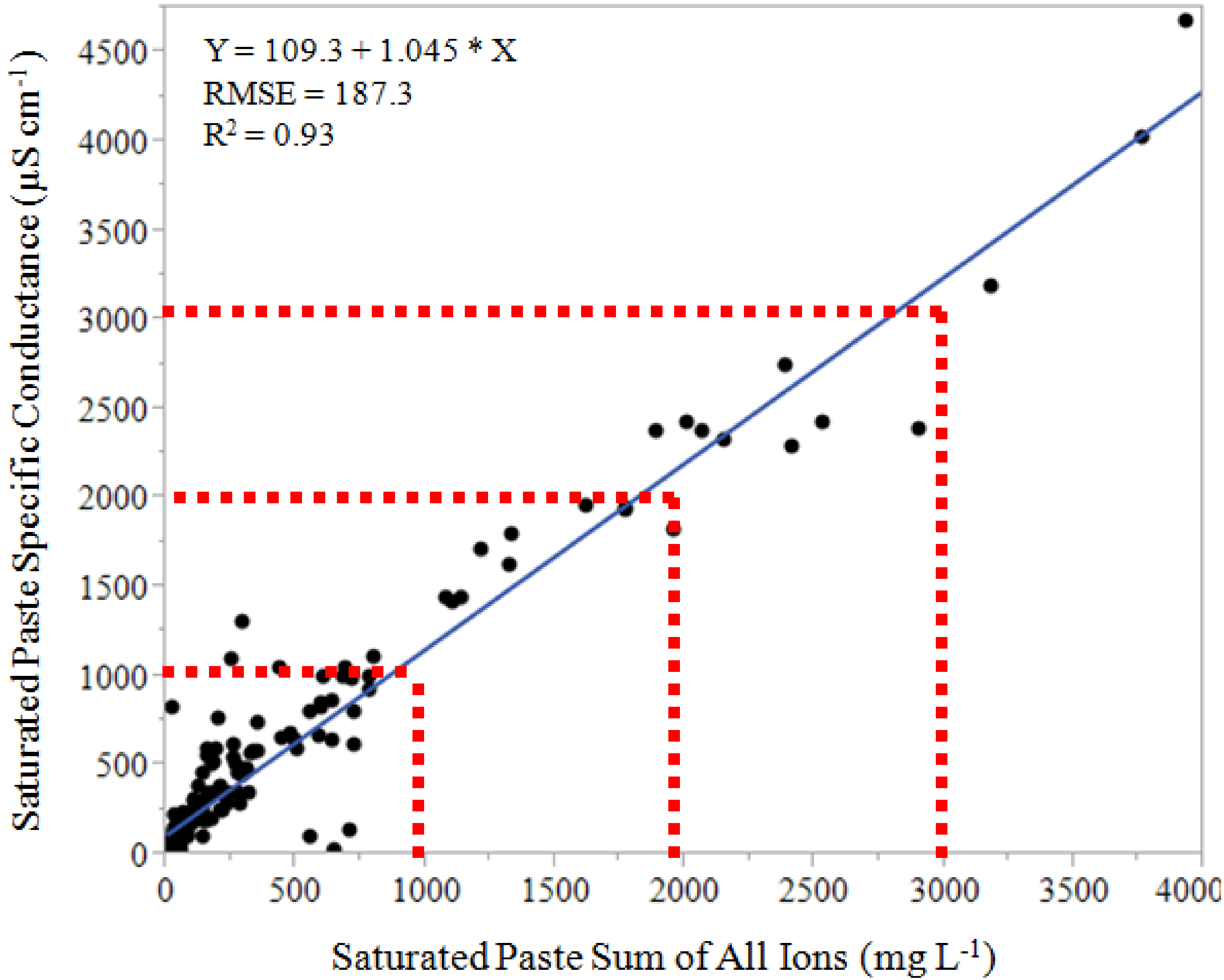
Saturated Paste Specific Conductance Across all Sites

Saturated Paste Major Ions



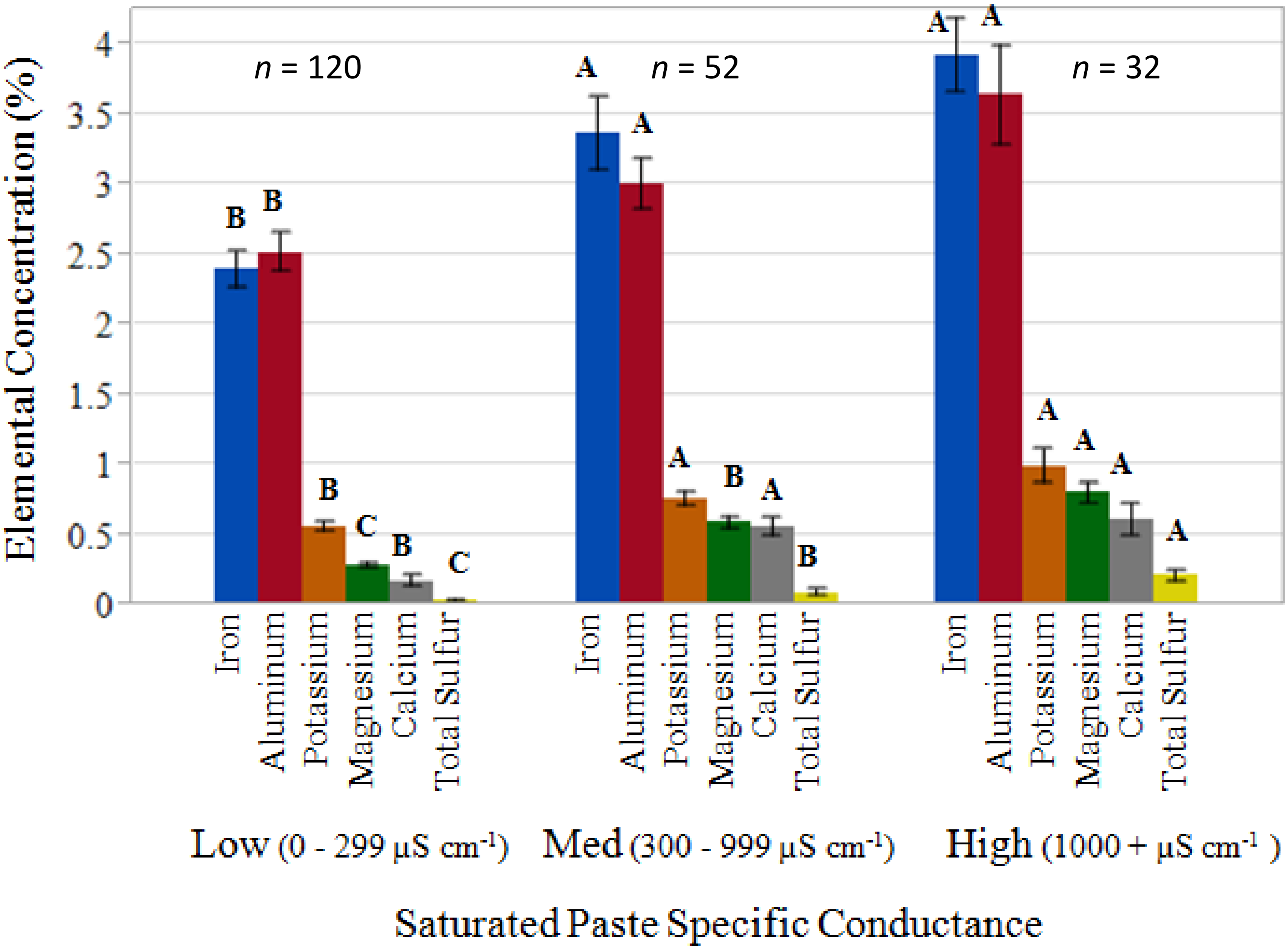
Saturated Paste Minor Ions

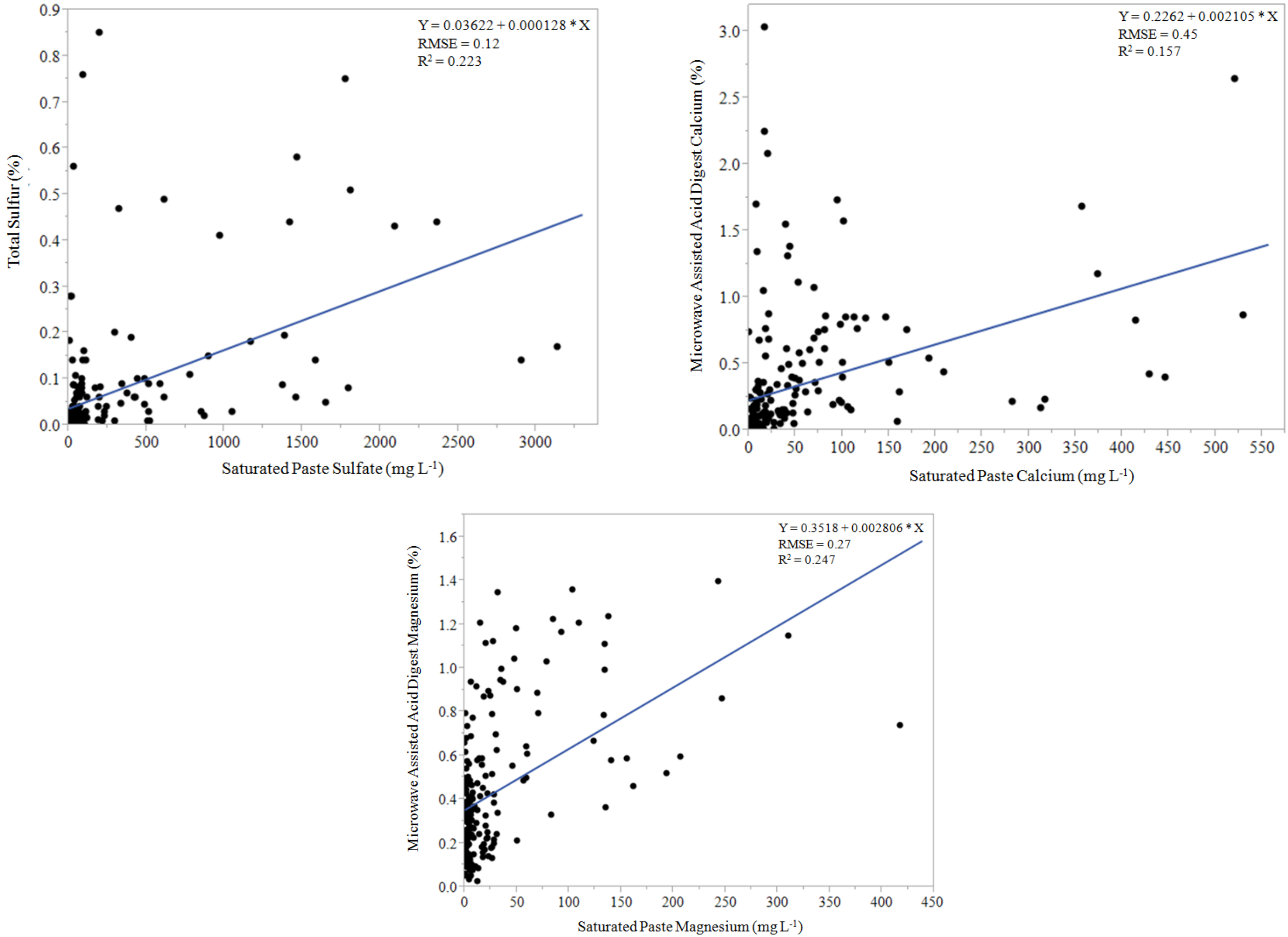




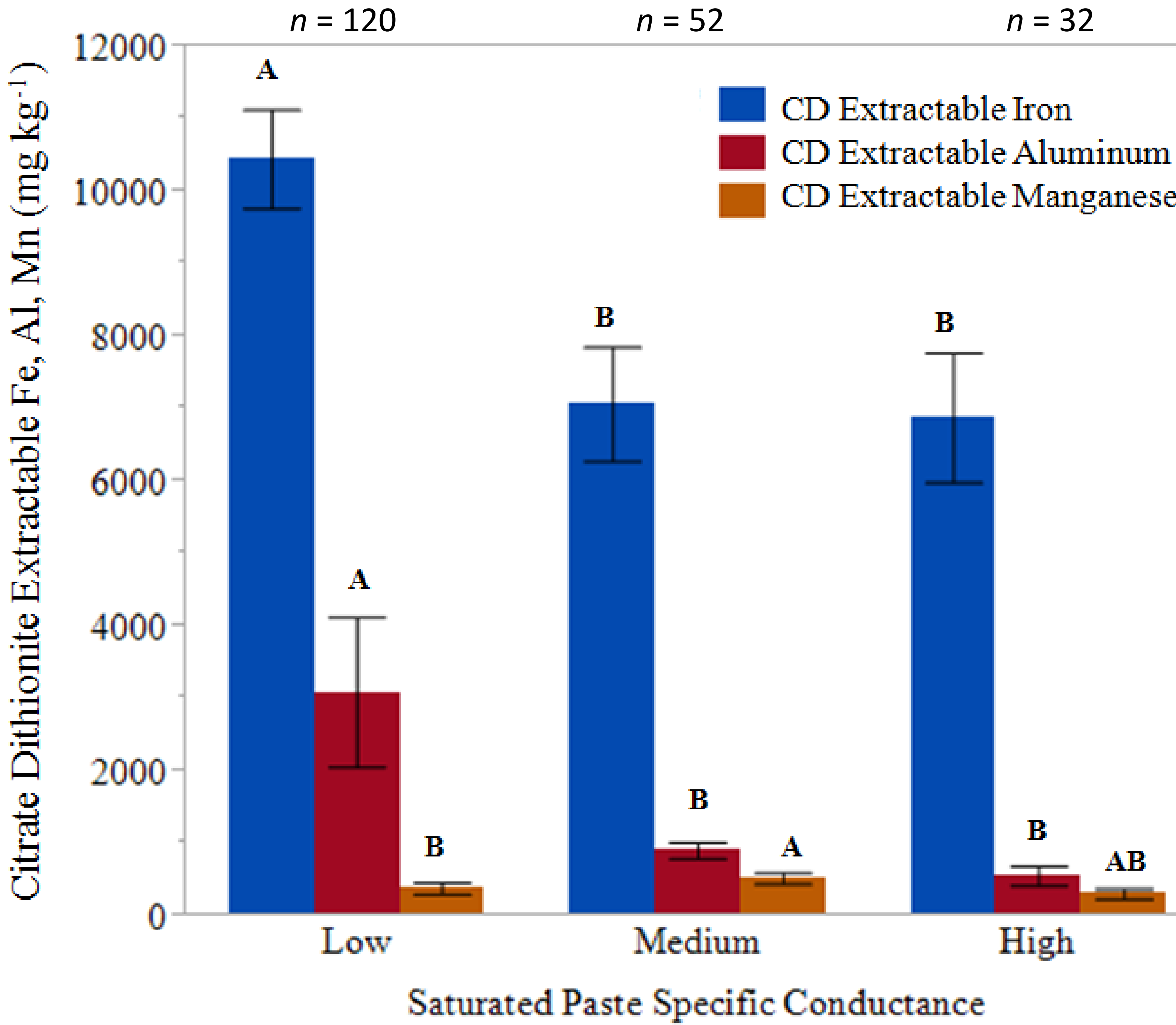
Y = 109.3 + 1.045 * X
RMSE = 187.3
R2 = 0.93
Saturated Paste Specific Conductance (µS cm-1)
Saturated Paste Sum of All Ions (mg L-1)
0
500
1000
1500
2000
2500
3000
3500
4000
4500

Microwave Assisted Acid Digest Major Ions

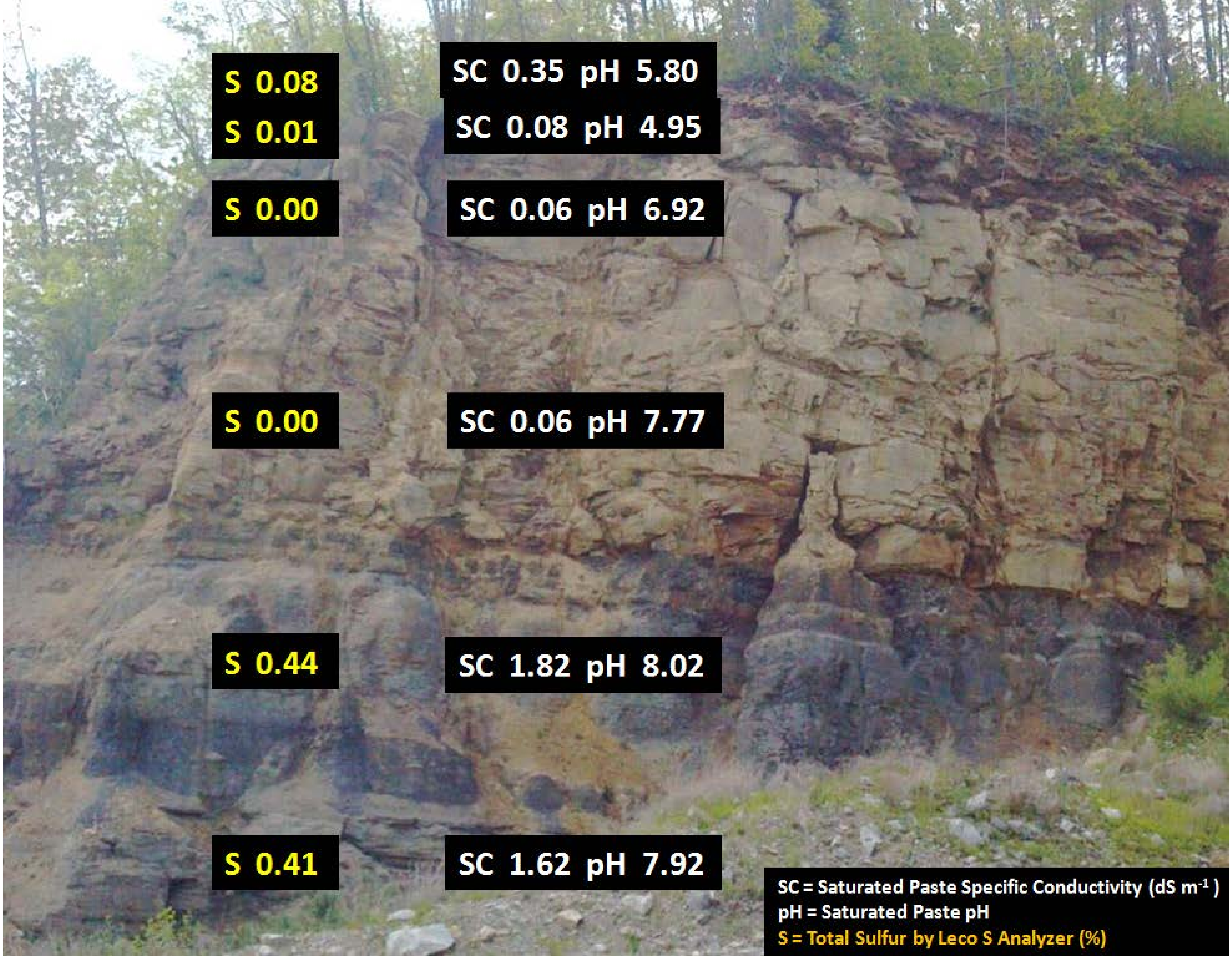




Y = 0.03622 + 0.000128 * X
RMSE = 0.12
R2 = 0.223
Total Sulfur (%)
Saturated Paste Sulfate (mg L-1)
Y = 0.2262 + 0.002105 * X
RMSE = 0.45
R2 = 0.157
Microwave Assisted Acid Digest Calcium (%)
Saturated Paste Calcium (mg L-1)
Y = 0.3518 + 0.002806 * X
RMSE = 0.27
R2 = 0.247
Microwave Assisted Acid Digest Magnesium (%)
Saturated Paste Magnesium (mg L-1)



n = 120
n = 52
n = 32
12000
10000
8000
6000
4000
2000
0
Citrate Dithionite Extractable Fe, Al, Mn (mg kg-1)
CD Extractable Iron
CD Extractable Aluminum
CD Extractable Manganese
A
A
B
B
B
A
B
B
AB
Low
Medium
High
Saturated Paste Specific Conductance

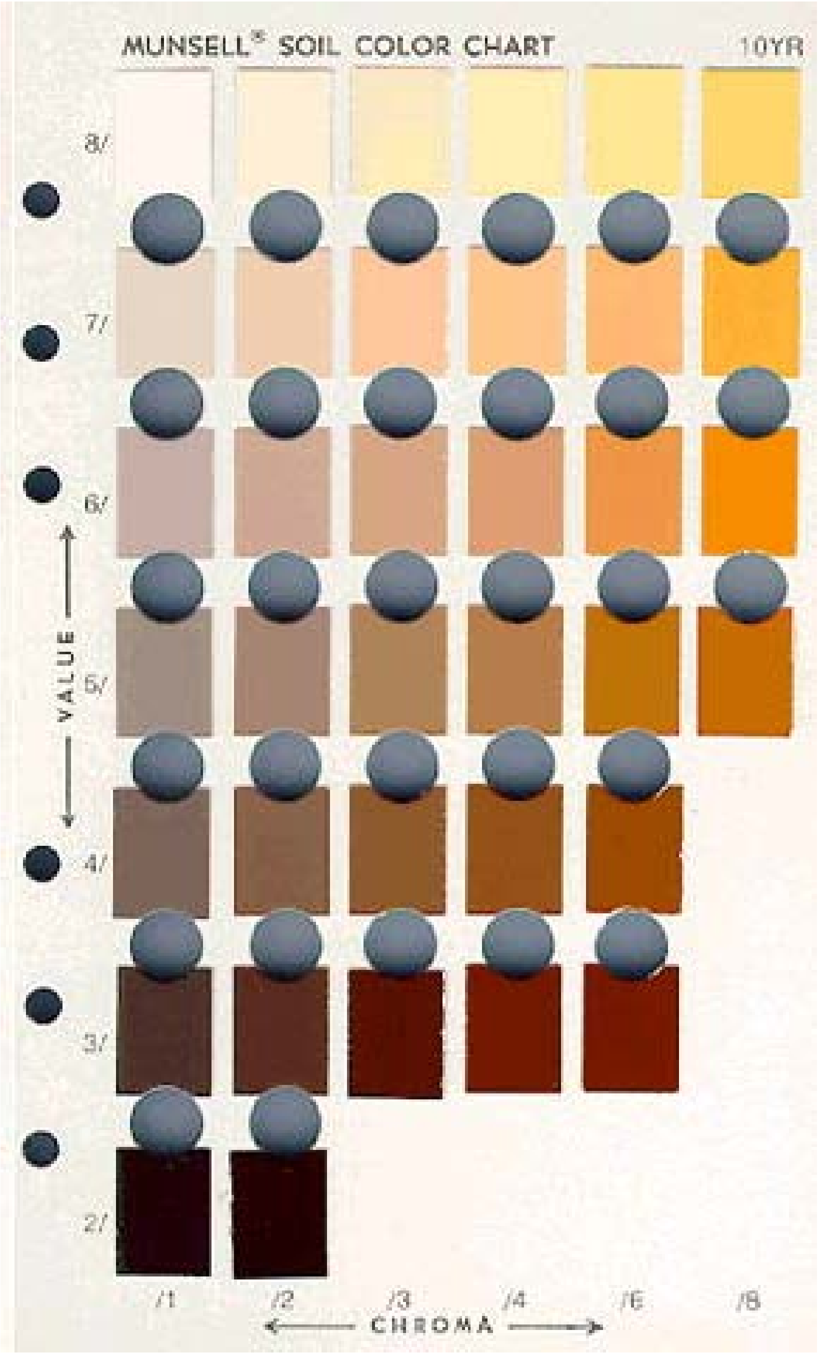

S 0.08
S 0.01
SC 0.35 pH 5.80
SC 0.08 pH 4.95
S 0.00
SC 0.06 pH 6.92
S 0.00
SC 0.06 pH 7.77
S 0.44
SC 1.82 pH 8.02
S 0.41
SC 1.62 pH 7.92
SC = Saturated Paste Specific Conductivity (dS m-1)
pH = Saturated Paste pH
S = Total Sulfur by Leco S Analyzer (%)

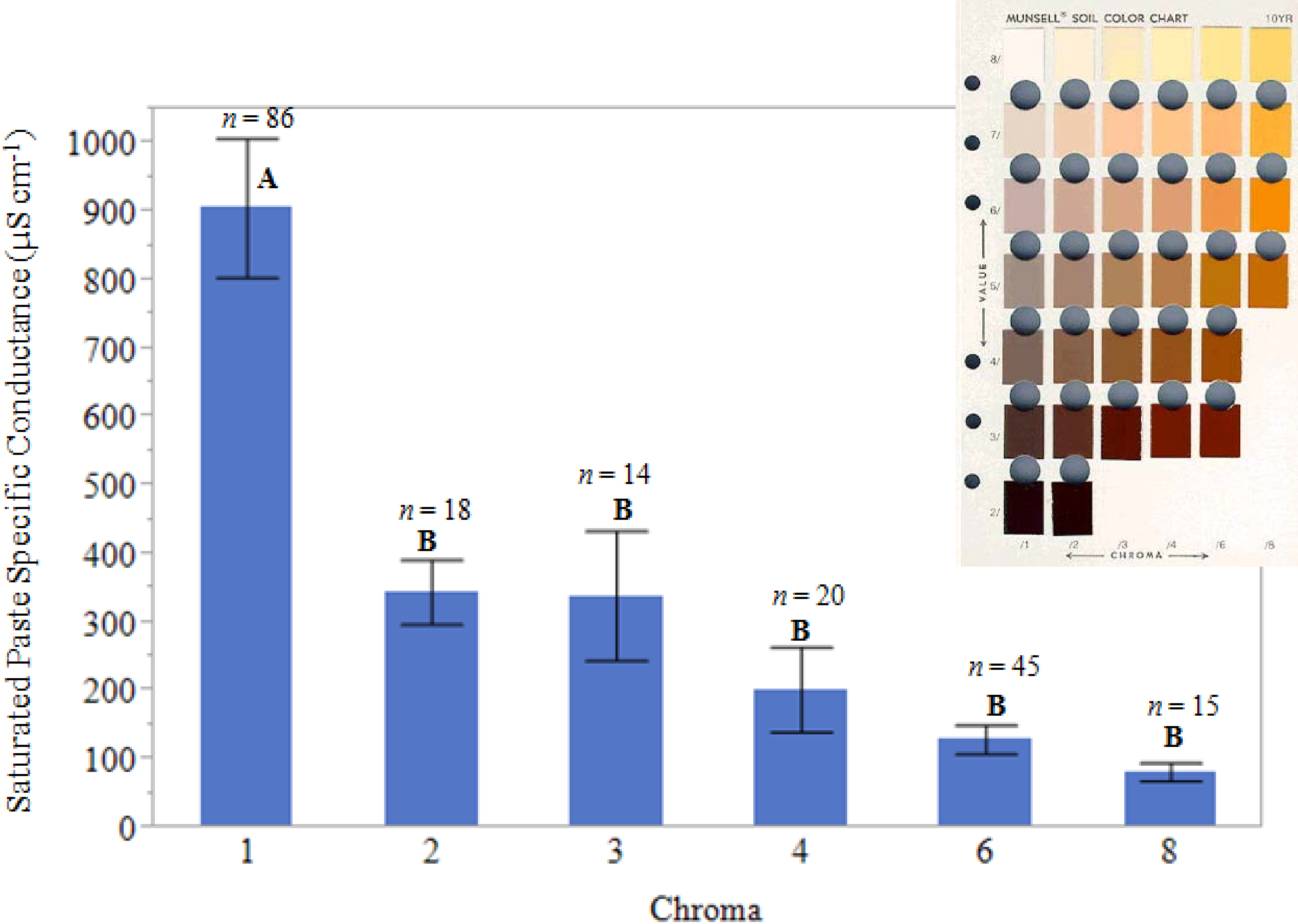
Sandstones – Thin Section Analysis

generally quartz rich subarkoses or sublitharenites

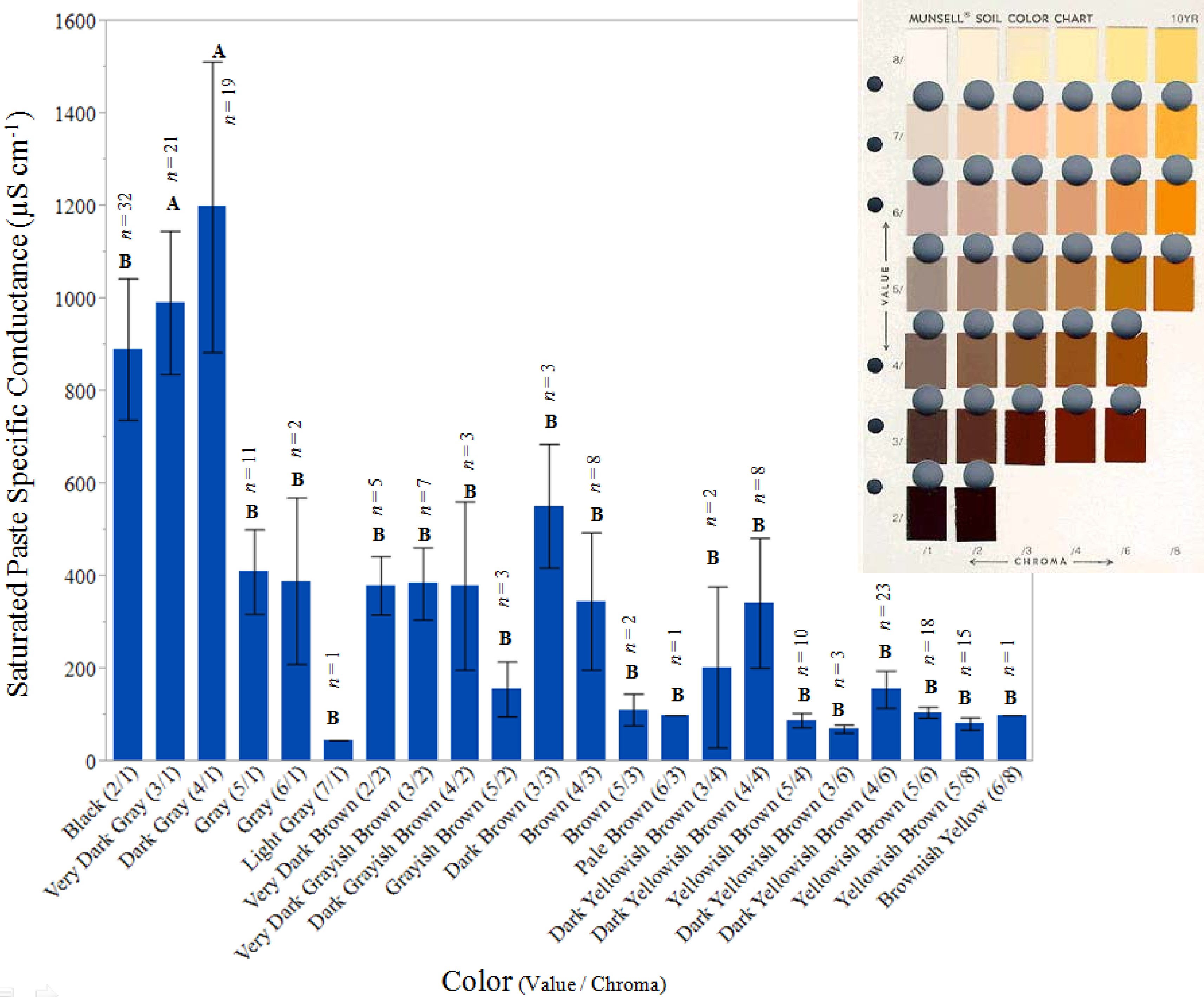
high in weatherable feldspars

Sample ID	Monocrystaline Quartz	Polycrystaline Quartz	K-spar	Altered K-spar	K-spar to Kaolinite	Plagioclase	Altered Plagioclase	Plagioclase to Kaolinite	Metamorphic Lithics	Sedimentary Lithics	Muscovite	Biotite	Chlorite	Chert	Limonite/Goethite	Pyrite	Heavies	Porosity	Sillimanite cement	Siderite	Carbonate cement/replacement	Kaolinite cement
1-10	191	25	21	4	1	5	14		23		9	1	7	3	4			3	1	5		3
1-11	183	20	21	1	3	10	34		19		7		9		7		1	8	2	7	2	2
1-12	204	12	11	2		13	34	1	17	2	12		3	6	3	1		1		4		6
1-13	174	18	9	1	1	8	21		25	1	14	3	12	2	2			17		6	4	1
1-14	159	4	6	3		11	41		48		12		4	2	6		1	16	1	2	1	
1-16	198	26	9		1	8	16		41	2	19	1	10		7	2		23		3	1	1
2a-5	166	14	11	2		7	17		65	1	20		9	5	9		1	13		6	3	
2a-6	181	7	7	4		17	30	1	51		23	1	5	6	9	1	1	17		8	1	2
4c-3	167	41	9		4	7	37	1	33	3	7		4	1	15			32	5	1	1	12
4c-5	159	43	10	2	6	3	31	4	39	1	9	1	5	2	11	1		19	2	4	1	19
6-2	171	55	11	1	11	5	49		20		11		7	2	16		1	40	7	7	1	22
6-3	157	52	8		12	1	31		40		21	2	5		10			32	3	7		13
9-2	189	31	9	41	30	3	4		50	1	10	2	8	2	2			30	1	2		19
9-3	199	23	13	34	27	5	1	1	44	1	17		4		5		1	41	3	8	4	14

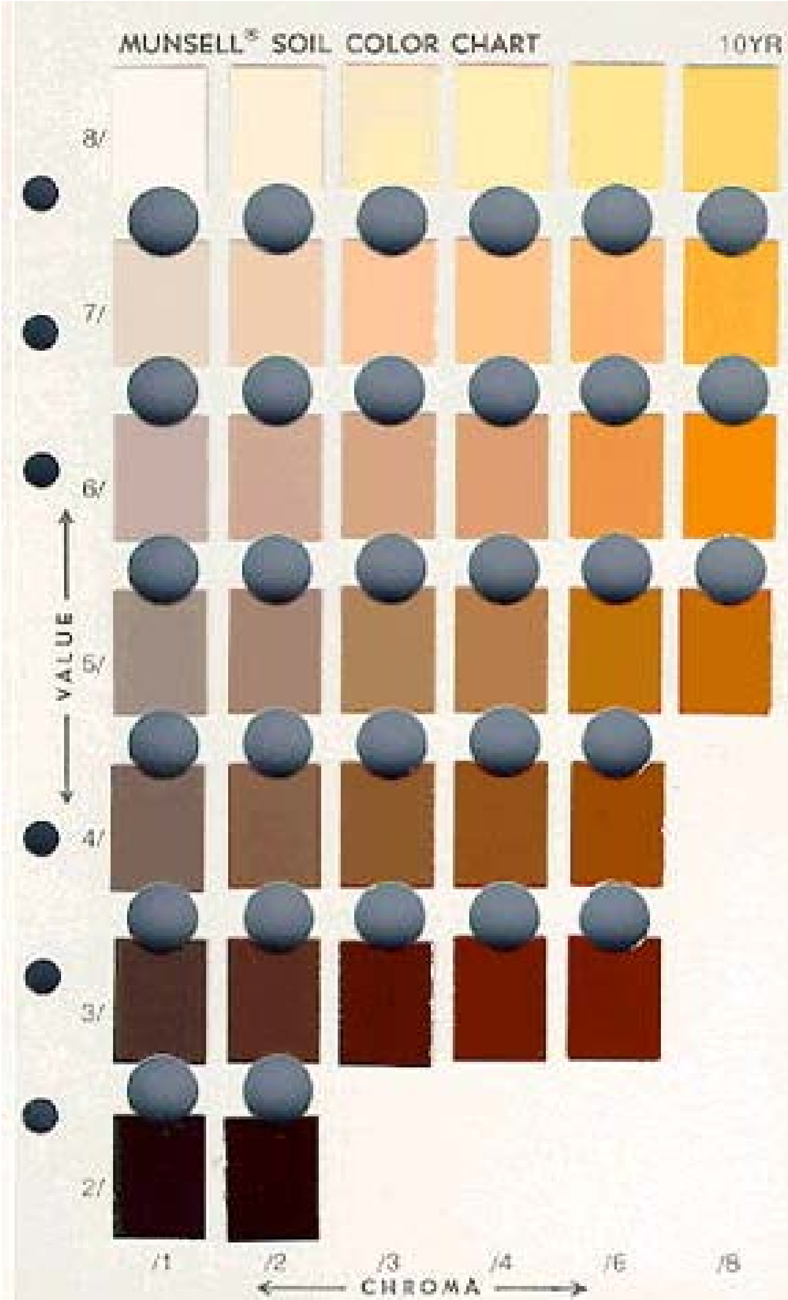

MUNSELL® SOIL COLOR CHART
10YR
8/
7/
6/
5/
4/
3/
2/
VALUE
/1
/2
/3
/4
/6
/8
CHROMA



MUNSELL® SOIL COLOR CHART
10YR
8/
7/
6/
5/
4/
3/
2/
VALUE
/1
/2
/3
/4
/6
/8
CHROMA
Saturated Paste Specific Conductance (µS cm-1)
1000
900
800
700
600
500
400
300
200
100
0
n = 86
A
n = 18
B
n = 14
B
n = 20
B
n = 45
B
n = 15
B
1
2
3
4
6
8
Chroma



Saturated Paste Specific Conductance (µS cm⁻¹)
0
200
400
600
800
1000
1200
1400
1600
Color (Value / Chroma)
Black (2/1)
Very Dark Gray (3/1)
Dark Gray (4/1)
Gray (5/1)
Gray (6/1)
Light Gray (7/1)
Very Dark Brown (2/2)
Very Dark Grayish Brown (3/2)
Dark Grayish Brown (4/2)
Grayish Brown (5/2)
Dark Brown (3/3)
Brown (4/3)
Brown (5/3)
Pale Brown (6/3)
Dark Yellowish Brown (3/4)
Dark Yellowish Brown (4/4)
Yellowish Brown (5/4)
Dark Yellowish Brown (3/6)
Dark Yellowish Brown (4/6)
Yellowish Brown (5/6)
Yellowish Brown (5/8)
Brownish Yellow (6/8)
n = 32 B
n = 21 A
n = 19 A
n = 11 B
n = 2 B
n = 1 B
n = 5 B
n = 7 B
n = 3 B
n = 3 B
n = 3 B
n = 8 B
n = 2 B
n = 1 B
n = 2 B
n = 8 B
n = 10 B
n = 3 B
n = 23 B
n = 18 B
n = 15 B
n = 1 B
MUNSELL® SOIL COLOR CHART
10YR
VALUE
CHROMA
8/
7/
6/
5/
4/
3/
2/
/1
/2
/3
/4
/6
/8

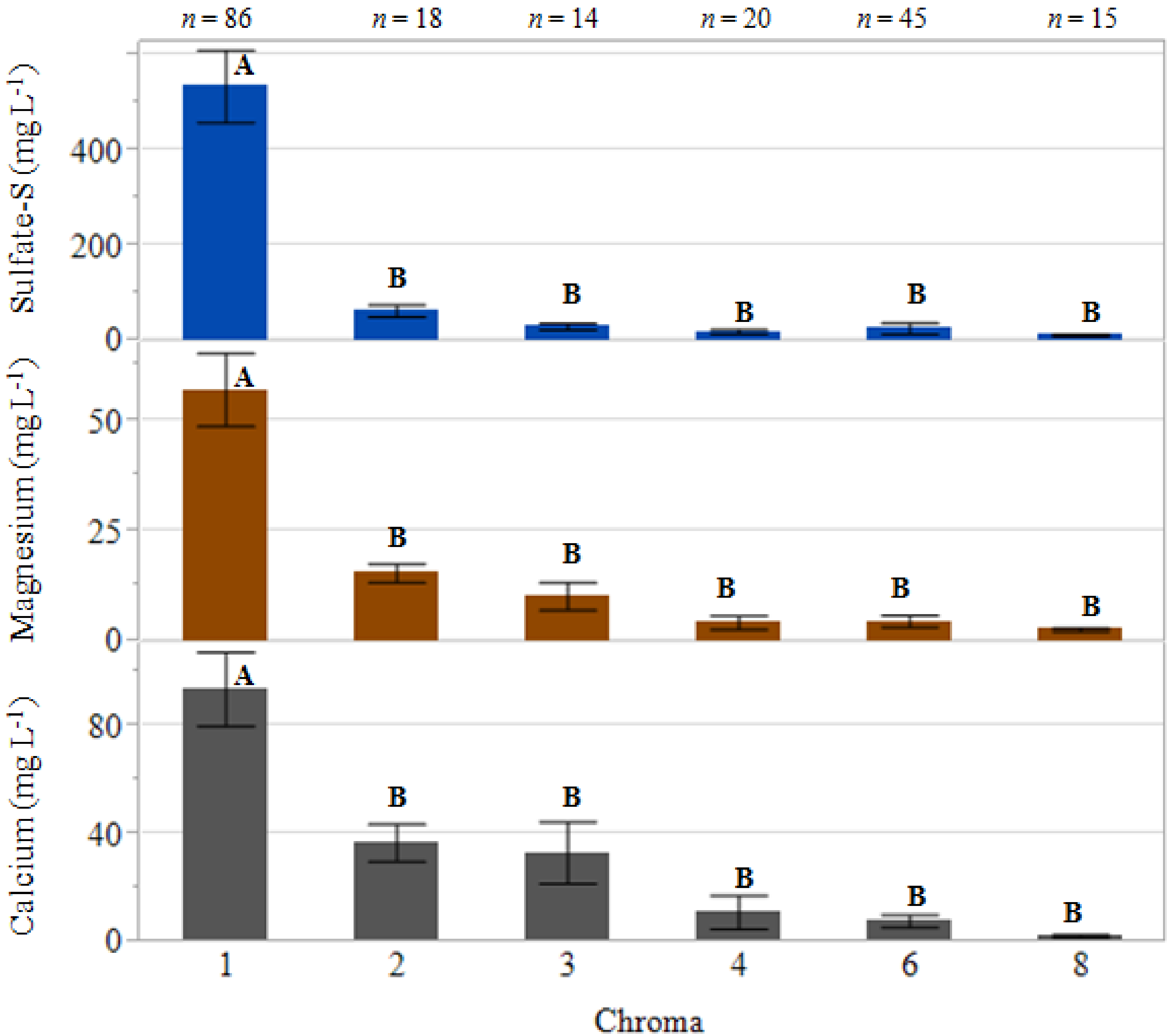


TDS Production Risk

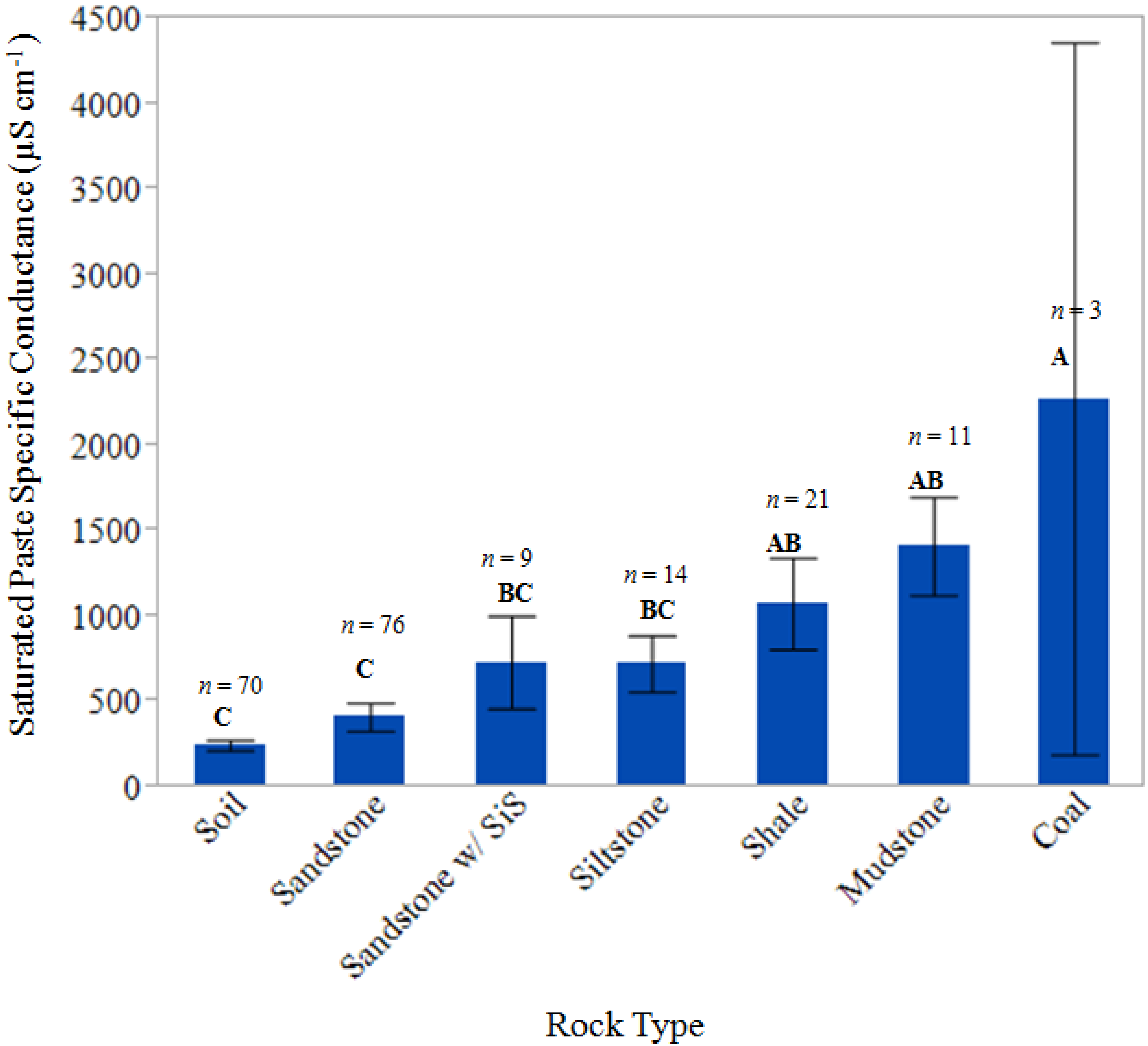
Value \ Chroma	/ 1	/ 2	/ 3	/ 4	/ 6	/ 8
8 /	-	-	-	-	-	-
7 /	45 µS cm^{-1} n = 1	-	-	-	-	-
6 /	390 µS cm^{-1} n = 2	-	100 µS cm^{-1} n = 1	-	-	100 µS cm^{-1} n = 1
5 /	410 µS cm^{-1} n = 11	157 µS cm^{-1} n = 3	113 µS cm^{-1} n = 2	90 µS cm^{-1} n = 10	107 µS cm^{-1} n = 18	82 µS cm^{-1} n = 15
4 /	1199 µS cm^{-1} n = 19	380 µS cm^{-1} n = 3	346 µS cm^{-1} n = 8	343 µS cm^{-1} n = 8	156 µS cm^{-1} n = 23	
3 /	992 µS cm^{-1} n = 21	385 µS cm^{-1} n = 7	553 µS cm^{-1} n = 3	204 µS cm^{-1} n = 2	71 µS cm^{-1} n = 3	
2 /	891 µS cm^{-1} n = 32	380 µS cm^{-1} n = 5				

Value

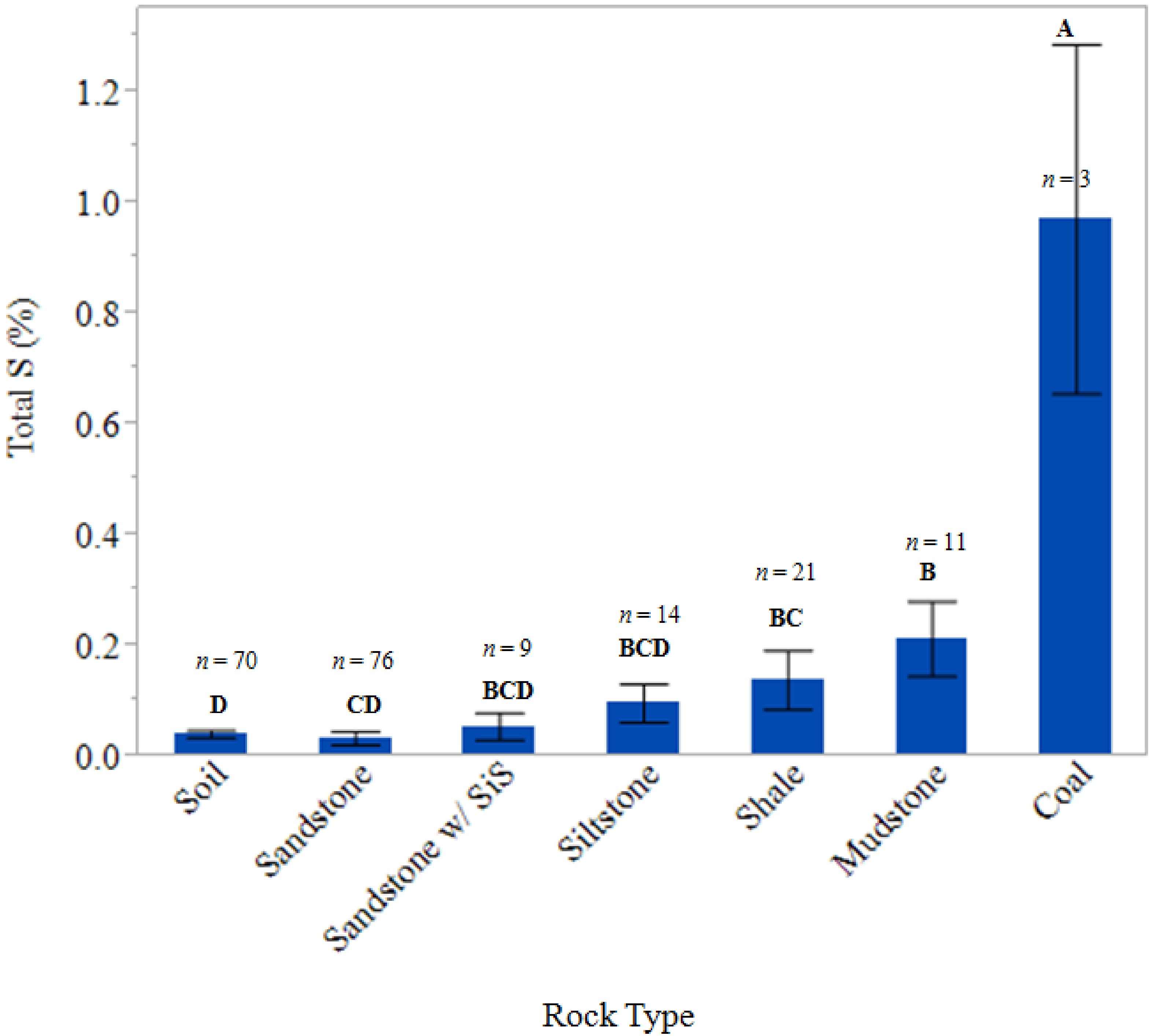
Chroma



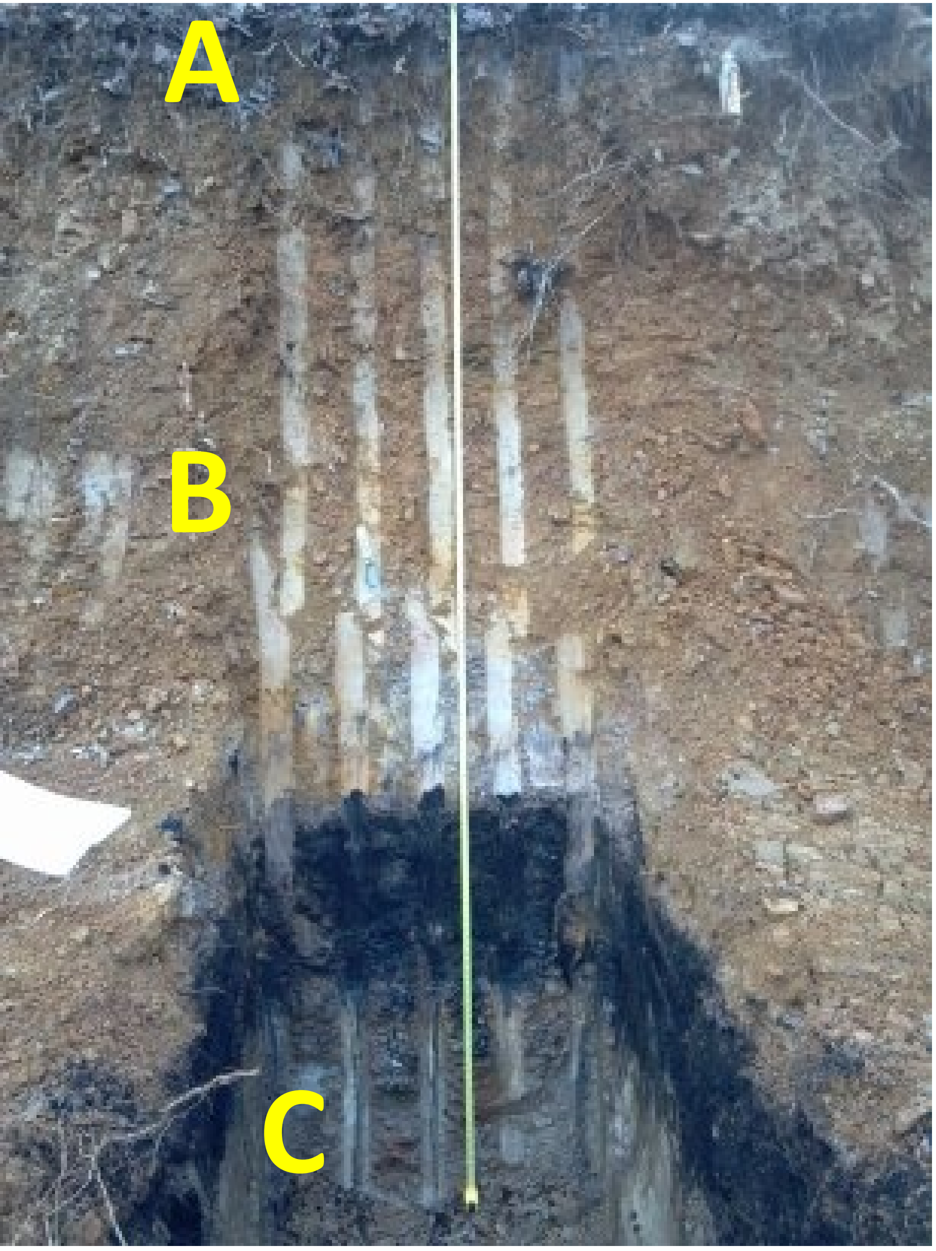
n = 86
n = 18
n = 14
n = 20
n = 45
n = 15
Sulfate-S (mg L-1)
400
200
0
Magnesium (mg L-1)
50
25
0
Calcium (mg L-1)
80
40
0
A
B
1
2
3
4
6
8
Chroma

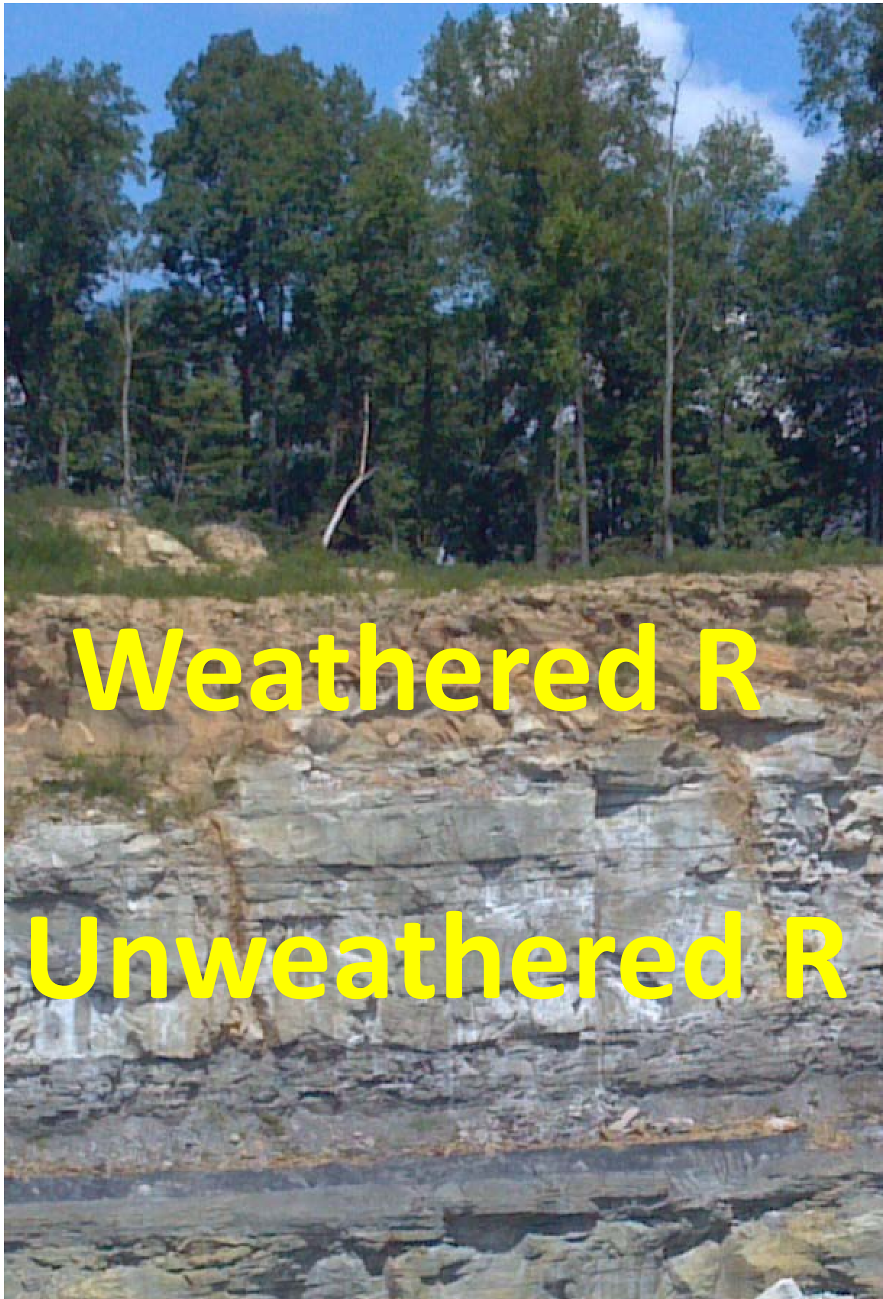


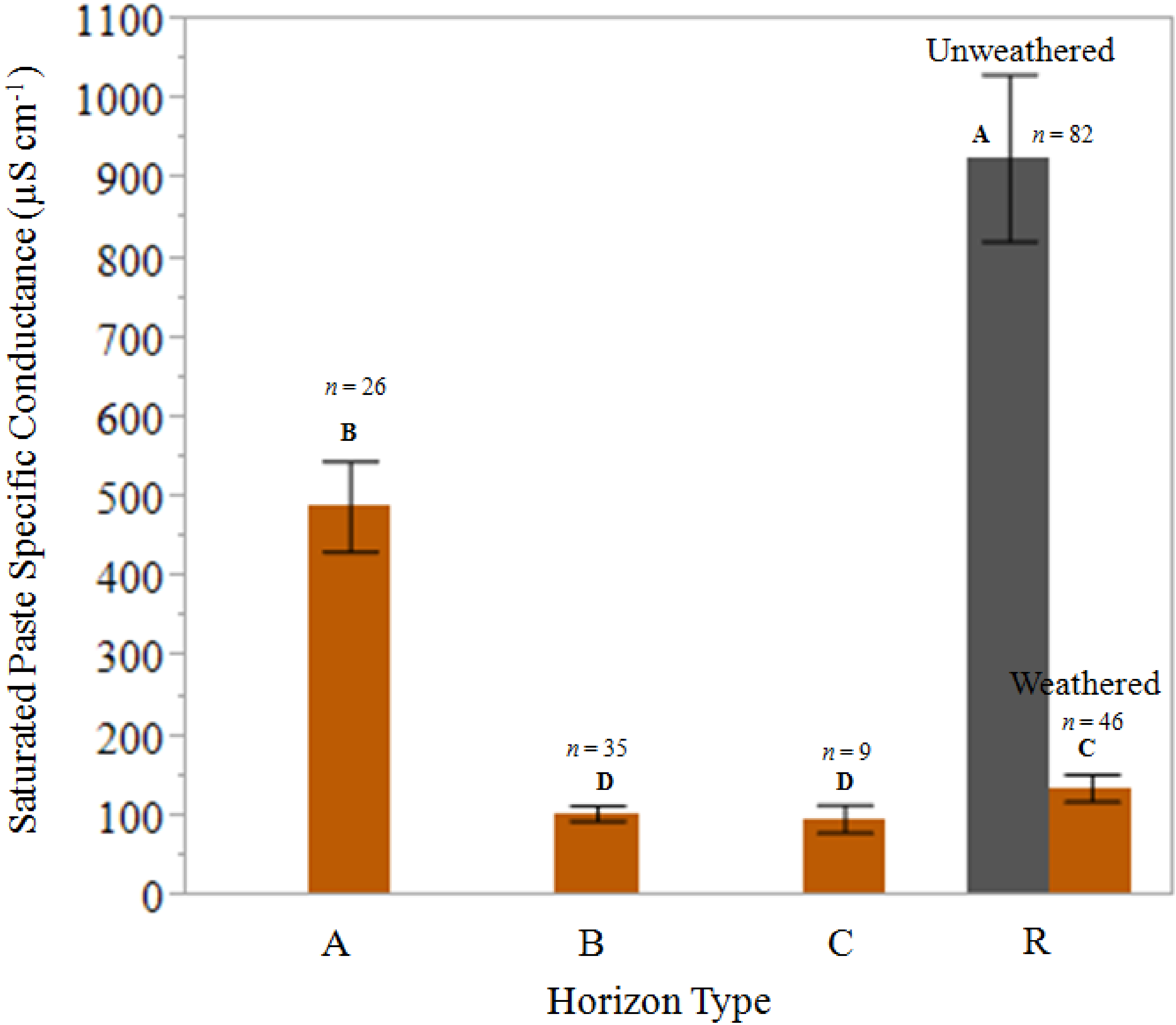
Saturated Paste Specific Conductance (µS cm-1)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
n = 70
C
n = 76
C
n = 9
BC
n = 14
BC
n = 21
AB
n = 11
AB
n = 3
A
Soil
Sandstone
Sandstone w/ SiS
Siltstone
Shale
Mudstone
Coal
Rock Type



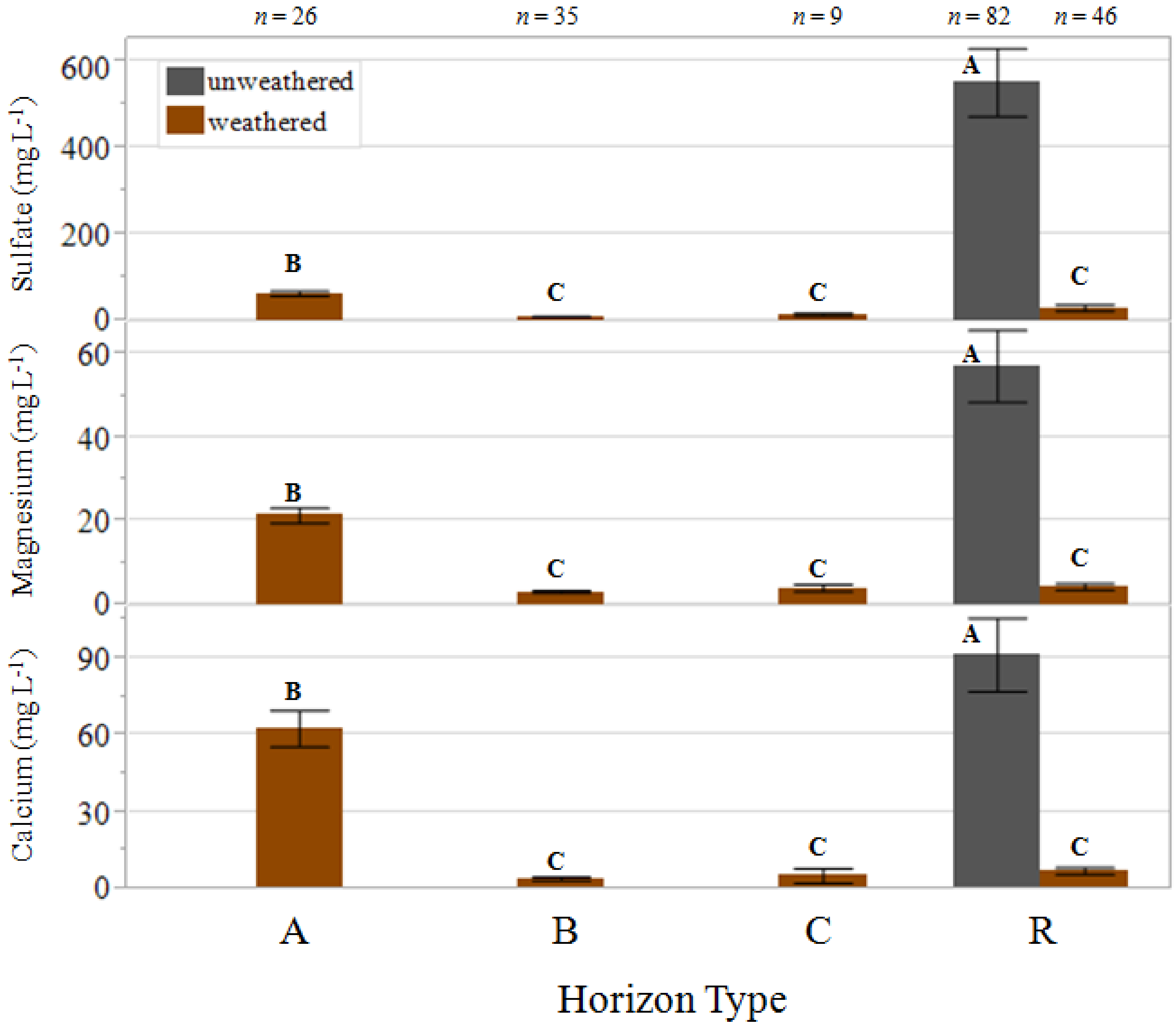
Total S (%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
A
n = 3
n = 11
B
n = 21
BC
n = 14
BCD
n = 9
BCD
n = 70
D
n = 76
CD
Soil
Sandstone
Sandstone w/ SiS
Siltstone
Shale
Mudstone
Coal
Rock Type


A
B
C

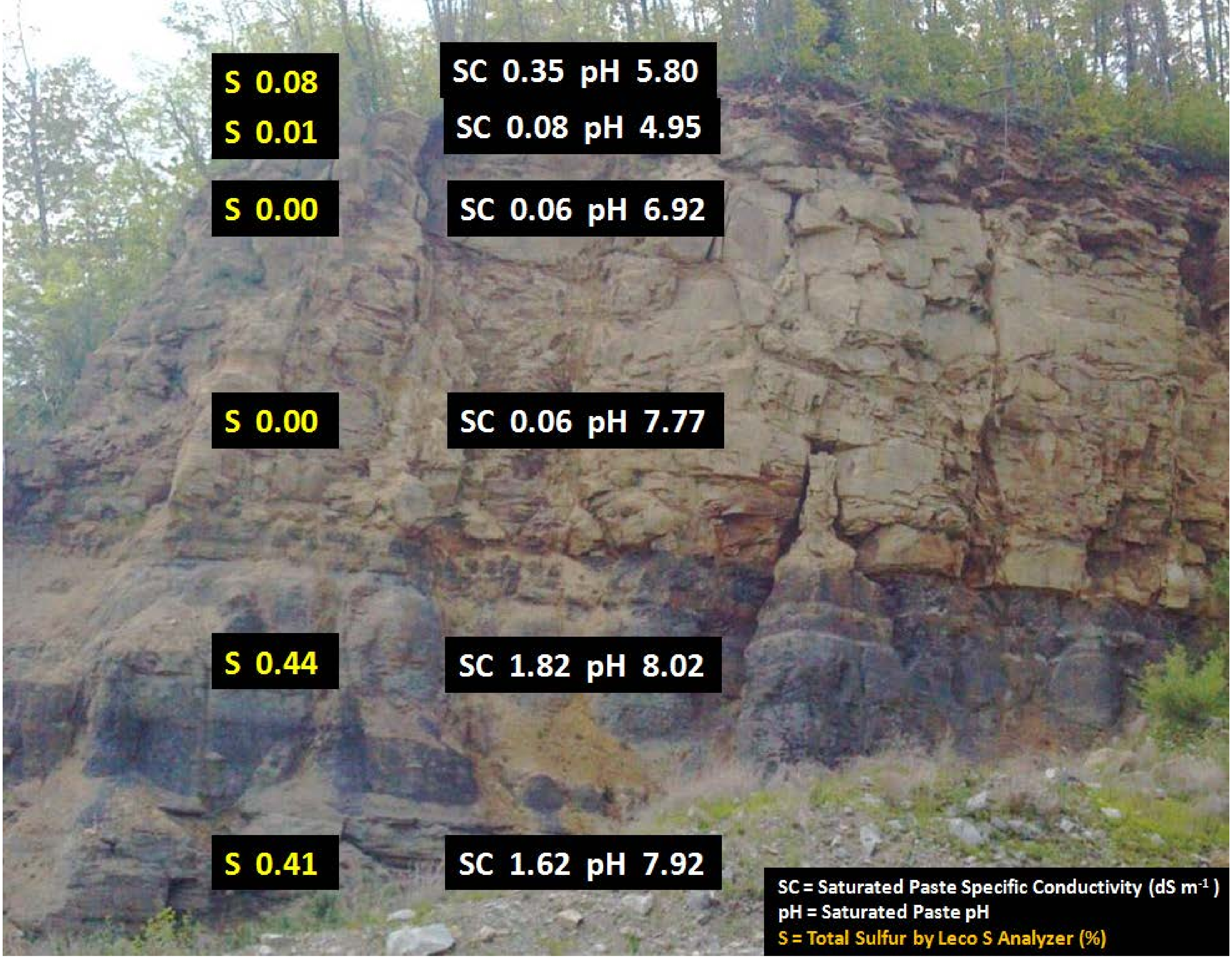

Weathered R
Unweathered R

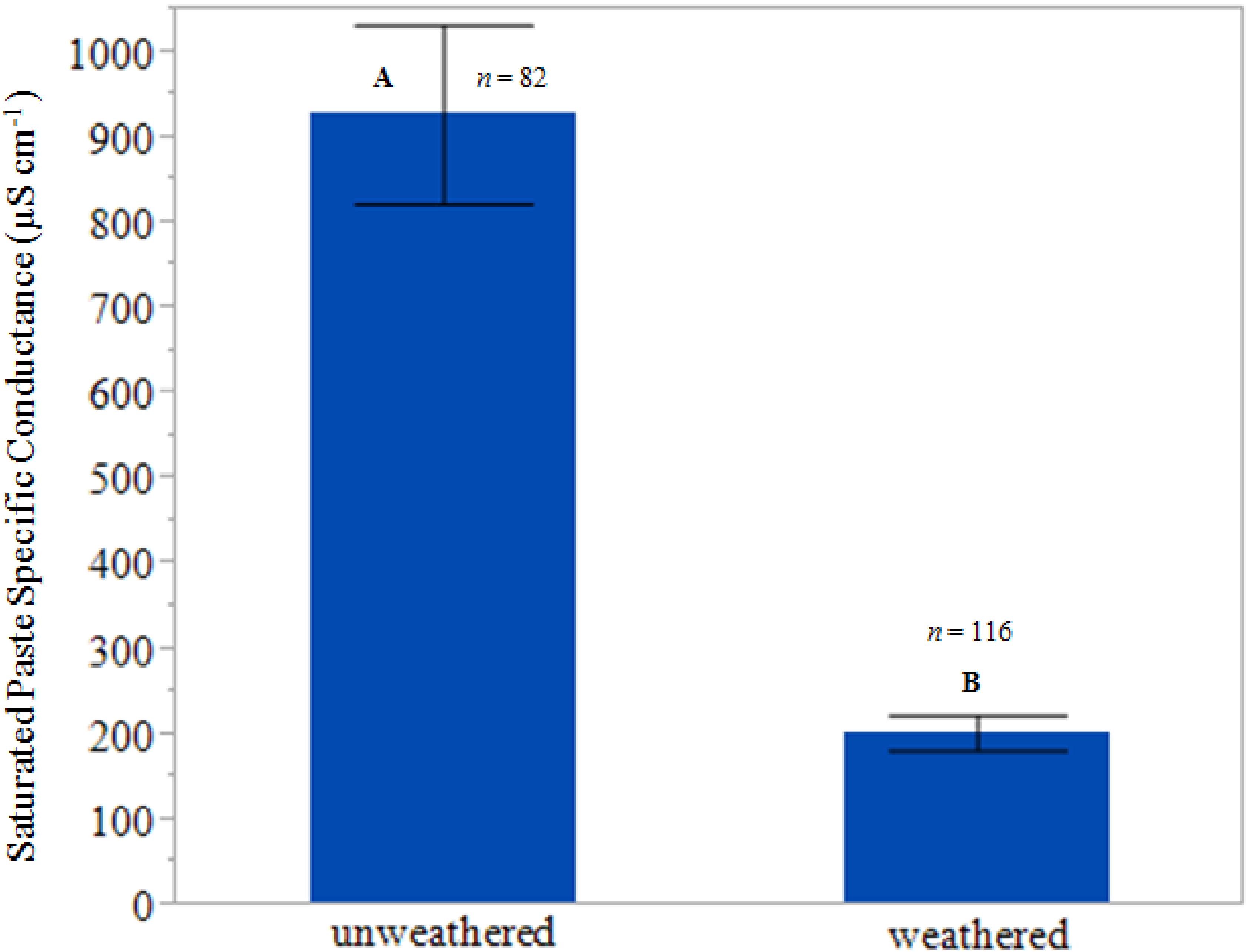


Saturated Paste Specific Conductance (µS cm-1)
1100
1000
900
800
700
600
500
400
300
200
100
0
Unweathered
A
n = 82
n = 26
B
Weathered
n = 46
C
n = 35
D
n = 9
D
A
B
C
R
Horizon Type

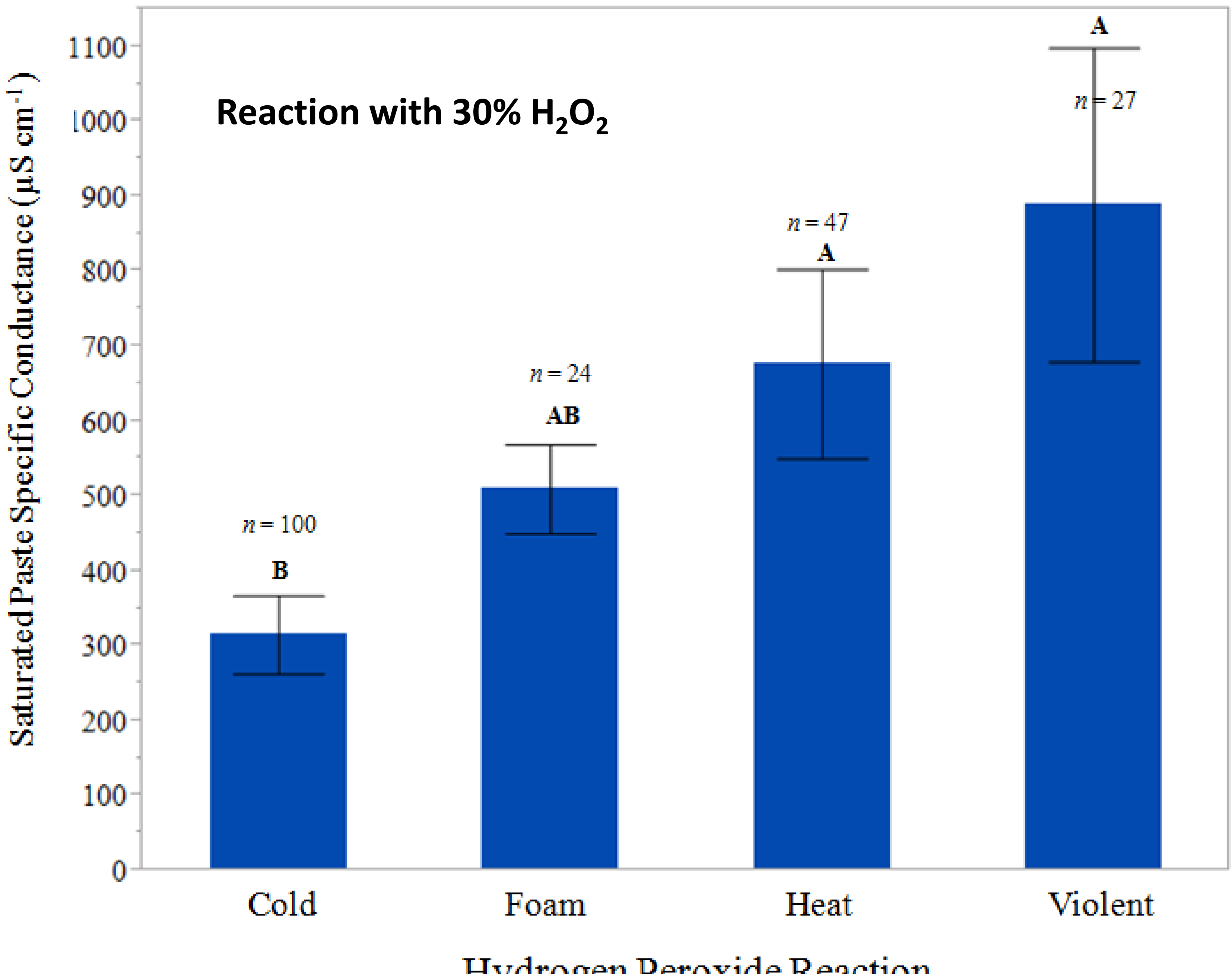


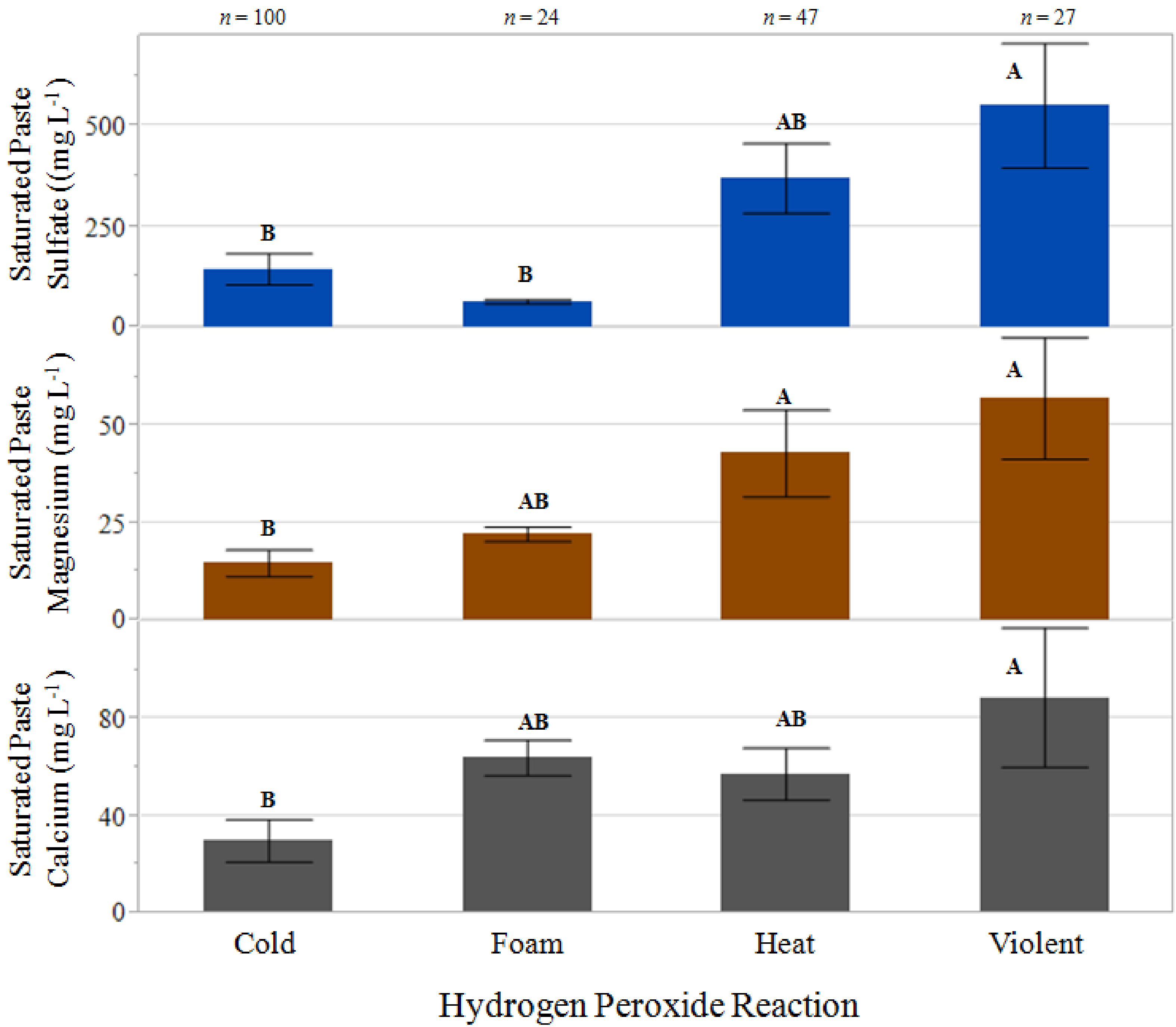
n = 26
n = 35
n = 9
n = 82
n = 46
unweathered
weathered
Sulfate (mg L-1)
Magnesium (mg L-1)
Calcium (mg L-1)
600
400
200
0
60
40
20
0
90
60
30
0
A
B
C
B
C
C
A
C
B
C
C
A
C
A
B
C
R
Horizon Type


S 0.08
S 0.01
SC 0.35 pH 5.80
SC 0.08 pH 4.95
S 0.00
SC 0.06 pH 6.92
S 0.00
SC 0.06 pH 7.77
S 0.44
SC 1.82 pH 8.02
S 0.41
SC 1.62 pH 7.92
SC = Saturated Paste Specific Conductivity (dS m-1)
pH = Saturated Paste pH
S = Total Sulfur by Leco S Analyzer (%)

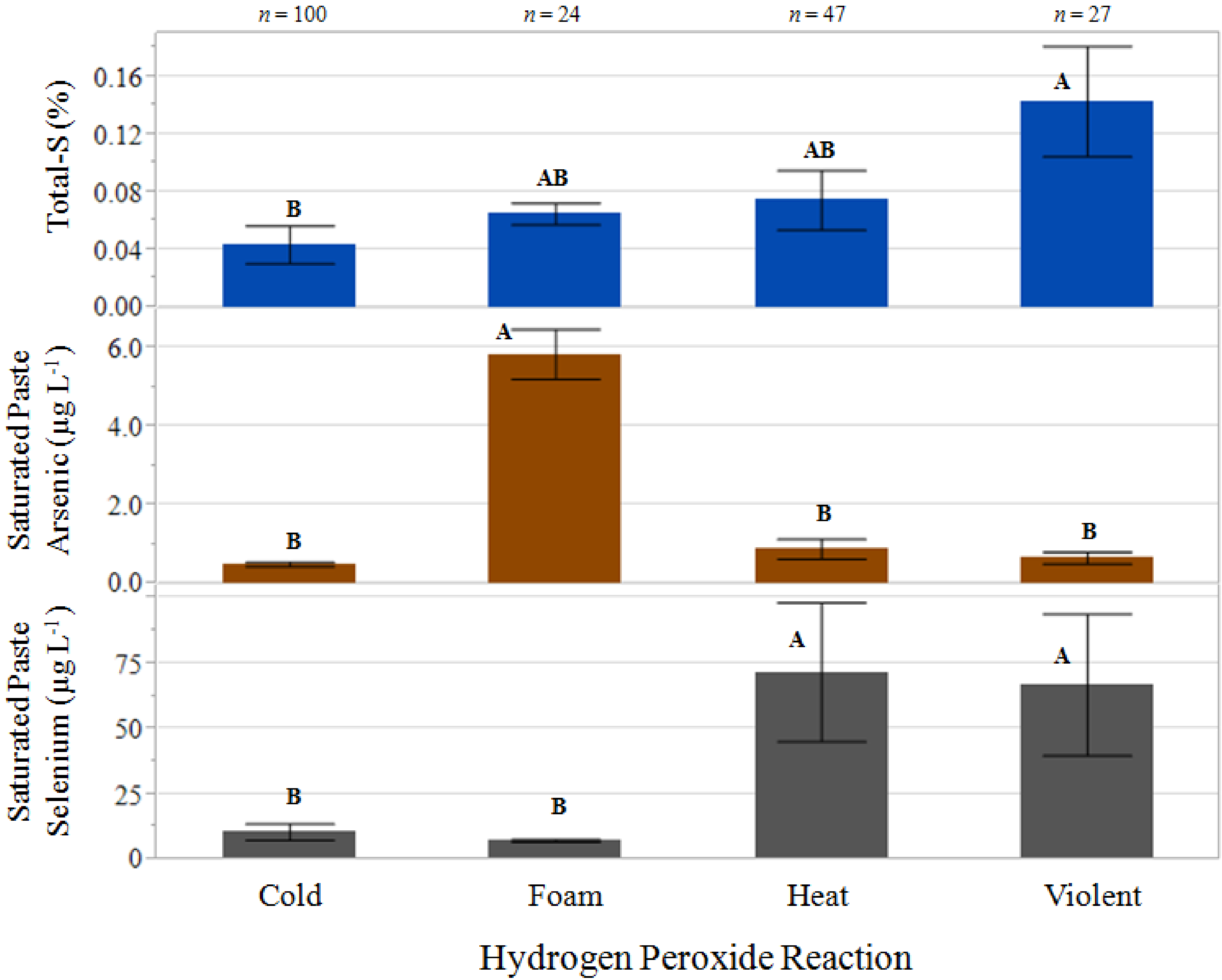


Saturated Paste Specific Conductance (μS cm-1)
1000
900
800
700
600
500
400
300
200
100
0
A
n = 82
B
n = 116
unweathered
weathered


Reaction with 30% H_2O_2
Saturated Paste Specific Conductance (µS cm⁻¹)
1100
1000
900
800
700
600
500
400
300
200
100
0
n = 100
B
n = 24
AB
n = 47
A
A
n = 27
Cold
Foam
Heat
Violent
Hydrogen Peroxide Reaction



n = 100
n = 24
n = 47
n = 27
Saturated Paste Sulfate ((mg L-1)
Saturated Paste Magnesium (mg L-1)
Saturated Paste Calcium (mg L-1)
500
250
0
50
25
0
80
40
0
B
B
AB
A
B
AB
A
A
B
AB
AB
A
Cold
Foam
Heat
Violent
Hydrogen Peroxide Reaction



n = 100
n = 24
n = 47
n = 27
Total-S (%)
0.00
0.04
0.08
0.12
0.16
B
AB
AB
A
Saturated Paste Arsenic (µg L-1)
0.0
2.0
4.0
6.0
A
B
B
B
Saturated Paste Selenium (µg L-1)
0
25
50
75
B
B
A
A
Cold
Foam
Heat
Violent
Hydrogen Peroxide Reaction

Summary

- ❑ SC had a very strong direct and linear relationship with the sum of all of the ions study… ~1:1 ratio

- ❑ Sulfate-S, Ca, and Mg dominated saturated paste SC for the samples studied

- ❑ Many other ions present in lower concentrations did not increase from low to high TDS samples (Se DID increase from low to high TDS)significantly

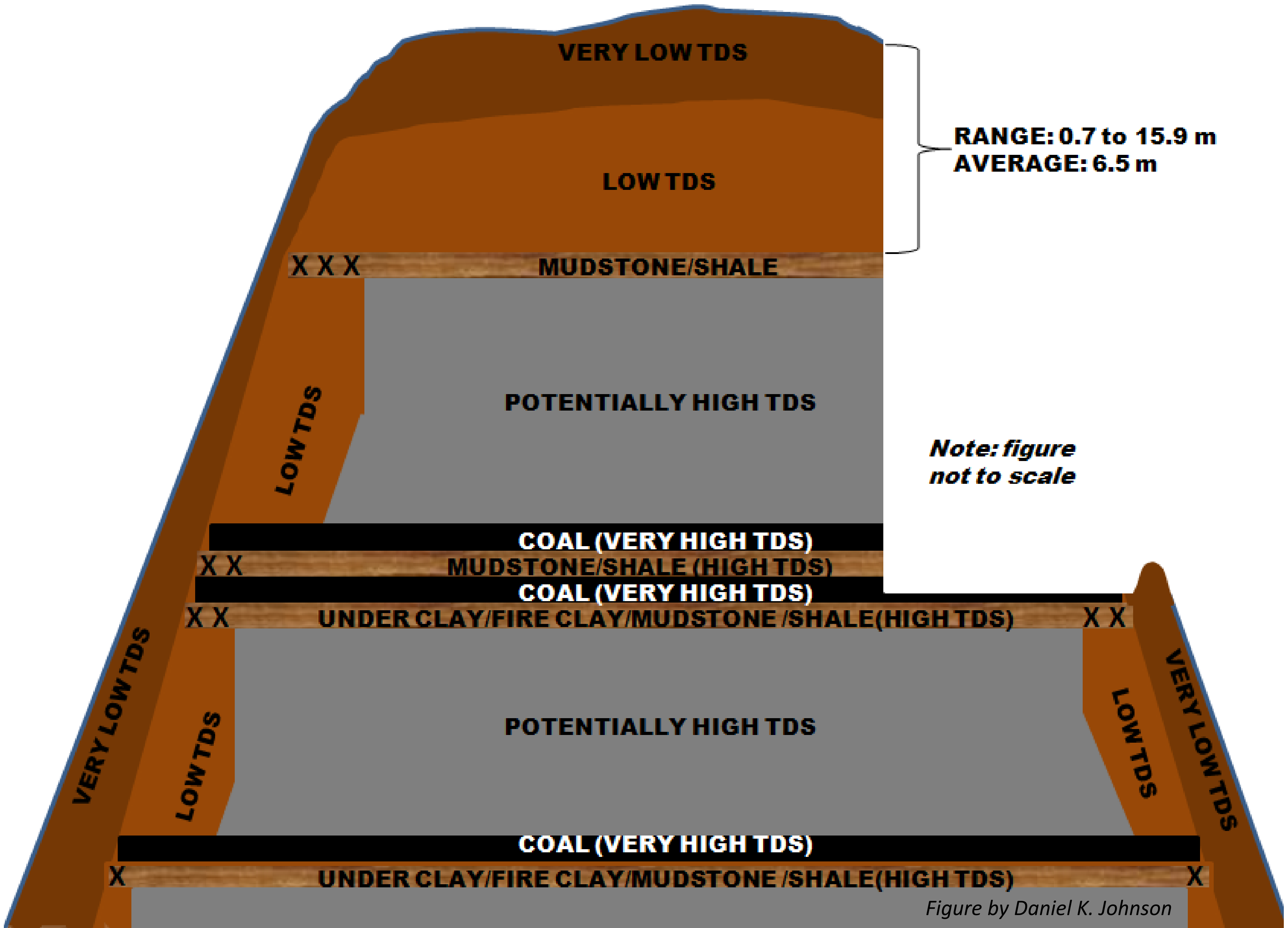
- ❑ Shallowest shale/mudstone layer forms boundary between weathered/unweathered spoils

- ❑ Unweathered samples lower in SC, Ca, Mg, and sulfate-S

- ❑ SC, sulfate-S, Ca, Mg, Se all higher in heat/violent H2O2 reaction samples

Low TDS Risk	**High TDS Risk**
Yellowish-brown	Dark gray, very dark gray, black
Soil, sandstone	Shale, mudstone, coal
Cold H_2O_2 reaction	Heat or violent H_2O_2 reaction
Low Se	High Se
Weathered – above SH/MS layer	Unweathered – below SH/MS layer

Recommendations



Recommendations

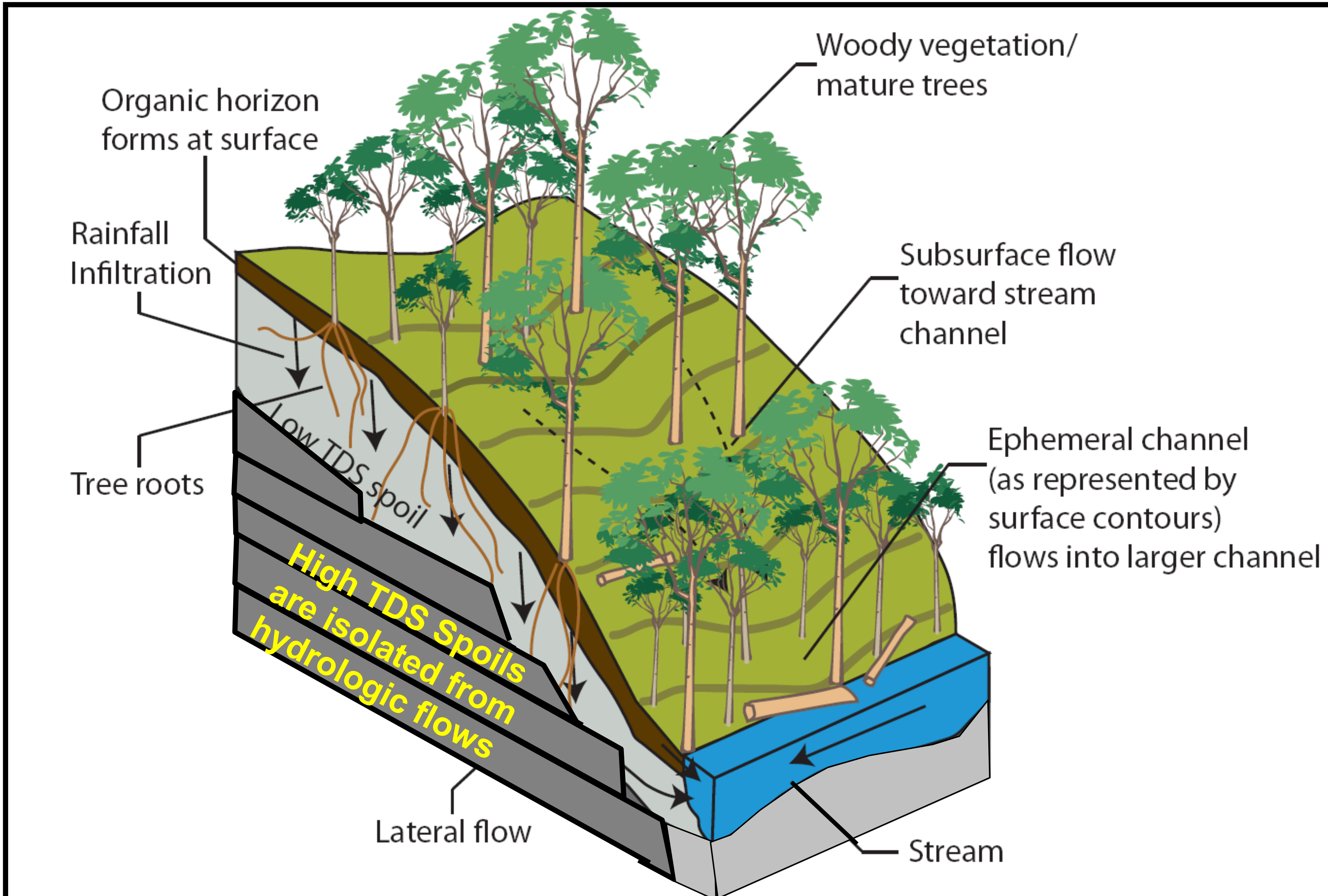


Figure and concept by Dr. Carl Zipper

Acknowledgements

Funding: Powell River Project

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