PS Hierarchical Clustering Analysis of the Green River Formation, Piceance Basin: A Useful Tool to Elucidate the Depositional Process of the Paleolake*

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Abstract

The Eocene Green River Formation (GRF) in the Piceance Basin (PB) of Colorado is estimated to contain the largest oil shale deposits in the world, and is a well-documented example of a lacustrine depositional system. Understanding the depositional environment and sedimentary processes in the basin depends upon detailed geochemical analysis across the basin. Quantitative analysis of the GRF can be achieved by detailed geochemical data derived from Inductively Coupled Plasma Optical Emission Spectroscopy and Mass Spectrometry (ICP-OES-MS). Sampling in the Douglass Pass area represents the basin margin and the basin center area is characterized by two complete cores, Shell 23X-2 and John Savage 24-1, sampled at the U.S. Geological Survey Core Research Center. Selected major and trace elements plus TOC values were input Minitab software and analyzed by multivariate statistical approach, which defined 5 clusters on both the basin margin and basin center, respectively. The newly formed clusters can be chemically distinct units, i.e., chemofacies. Five chemofacies were generated to characterize the depositional processes of the basin in the Eocene Epoch. For the basin margin, chemofacies 1 is characterized by high Si, Al, Fe, K, Ti, Zr and low Ca, Mg, S and Mo, representing siliciclastic with low redox; chemofacies 2 is characterized by high TOC, moderate high in Ca, Mg, Sr, Mn and low in S, implying carbonate with high TOC feature; chemofacies 3 is high in Ca, Mg, Sr, Mn, As and Mo, and low in Al, Si, Ti, K, marking carbonate under high redox; chemofacies 4 is characterized by high Si, K and low in S, Mo and TOC, showing the features of sandstone; chemofacies 5 is high in Si, Al, Ti, Fe, S, Co, Cr, C, Ni and low in Ca, Mg, Sr, Mo and TOC, representing pyritic siliciclastic facies with low TOC. In the basin center, the generated 5 chemofacies show different features from the margin. For Shell 23X-2, chemofacies 1 is high in Ca, Mg, P, Sr, Mn and moderate in Si, Al, Ti, Fe and K, representing siliceous dolomite; chemofacies 2 is high in Si, Al, Ti, K, Fe, Zr, S, Mo and low Ca, Mg, Na, showing siliciclastic with high redox feature; chemofacies 3 is high in As, S, Mo TOC and low in Na, Ca, and Mg, indicating high TOC with high redox condition; chemofacies 4 is high in TOC, Can and low in Fe, S, Mo, Cu, U, reflecting TOC with calcite rich, under low redox condition; chemofacies 5 is high in Na and low in other elements, marking high salinity facies. As for John Savage 24-1, it has similar features to Shell. Integrating basin margin and center together, it has been proved that hierarchical clustering analysis is a very useful tool to characterize the depositional process of the basin. The variations of chemofacies between the basin margin and the center are controlled by Early Eocene Climate Optimum (EECO).

References Cited

Tänavsuu-Milkeviciene, K., and J.F. Sarg, 2012, Evolution of an organic-rich lake basin– stratigraphy, climate and tectonics: Piceance Creek basin, Eocene Green River Formation: Sedimentology, v. 59, p. 1735–1768.

Boak, J., and S. Poole, 2015, Mineralogy of the Green River Formation in the Piceance Creek Basin, Colorado: Stratigraphy and Paleolimnology of the Green River Formation, Western USA, Springer, p. 183-209.

Hierarchical Clustering Analysis of the Green River Formation, Piceance Basin: an useful tool to elucidate the depositional process of the Paleolake

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1. Abstract

The Eocene Green River Formation (GRF) in the Piceance Basin (PB) of Colorado is estimated to contain the largest oil shale deposits in the world, and is a well-documented example of a lacustrine depositional system. Understanding the depositional environment and sedimentary processes in the basin depends upon detailed geochemical analysis across the basin. Quantitative analysis of the GRF can be achieved by detailed geochemical data derived from Inductively Coupled Plasma Optical Emission Spectroscopy and Mass Spectrometry (ICP-OES-MS). Sampling in the Douglass Pass area represents the basin margin and the basin center area is characterized by two complete cores, Shell 23X-2 and John Savage 24-1, sampled at the U.S. Geological Survey Core Research Center.

Selected major & trace elements plus TOC values were input Minitab software and analyzed by multivariate statistical approach, which defined 5 clusters on both the basin margin and basin center, respectively. The newly-formed clusters can be considered to be chemically distinct units, i.e., chemofacies. 5 chemofacies were generated to characterize the depositional processes of the basin in the Eocene Epoch. For the basin margin, chemofacies 1 is characterized by high Si, Al, Fe, K, Ti, Zr and low Ca, Mg, S and Mo, representing siliciclastic with low redox; chemofacies 2 is characterized by high TOC, moderate high in Ca, Mg, Sr, Mn and low in S, implying carbonate with high TOC feature; chemofacies 3 is high in Ca, Mg, Sr, Mn, As and Mo, and low in Al, Si, Ti, K, marking carbonate under high redox; chemofacies 4 is characterized by high Si, K and low in S, Mo and TOC, showing the features of sandstone; chemofacies 5 is high in Si, Al, Ti, Fe, S, Co, Cr, C, Ni and low in Ca, Mg, Sr, Mo and TOC, representing pyritic siliciclastic facies with low TOC.

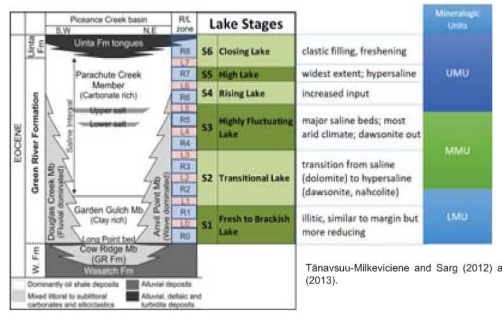
In the basin center, the generated 5 chemofacies show different features from the margin. For Shell 23X-2, chemofacies 1 is high in Ca, Mg, P, Sr, Mn and moderate in Si, Al, Ti, Fe and K, representing silicious dolomite; chemofacies 2 is high in Si, Al, Ti, K, Fe, Zr, S, Mo and low Ca, Mg, Na, showing siliciclastic with high redox feature; chemofacies 3 is high in As, S, Mo TOC and low in Na, Ca, and Mg, indicating high TOC with high redox condition; chemofacies 4 is high in TOC, Can and low in Fe, S, Mo, Cu, U, reflecting TOC with calcite rich, under low redox condition; chemofacies 5 is high in Na and low in other elements, marking high salinity facies. As for John Savage 24-1, it has similiar features to Shell. Integrating basin margin and center together, it has been proved that hierarchical clustering analysis is a very useful tool to characterize the depositional process of the basin. The variations of chemofacies between the basin margin and the center are controlled by Early Eocene Climate Optimum (EECO).

2. Objectives

a. To identify the most appropriate chemofacies by hierarchical clustering analysis on both the basin margin and basin center;

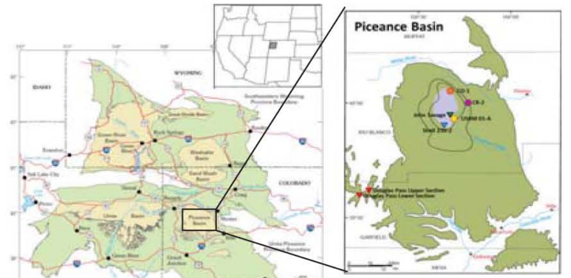
b. To figure out how chemofacies relates to depositional environment of the basin;

3. Geologic Setting



Tänavsuu-Milkeviciene and Sarg (2012) and Boak et al. (2013).

4. Datasets and Methods



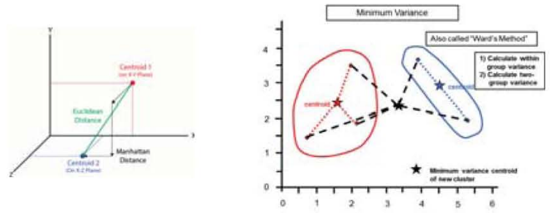
Datasets:

Douglas Pass area: 186 samples analyzed by ICP-OES-MS (Basin Margin area)

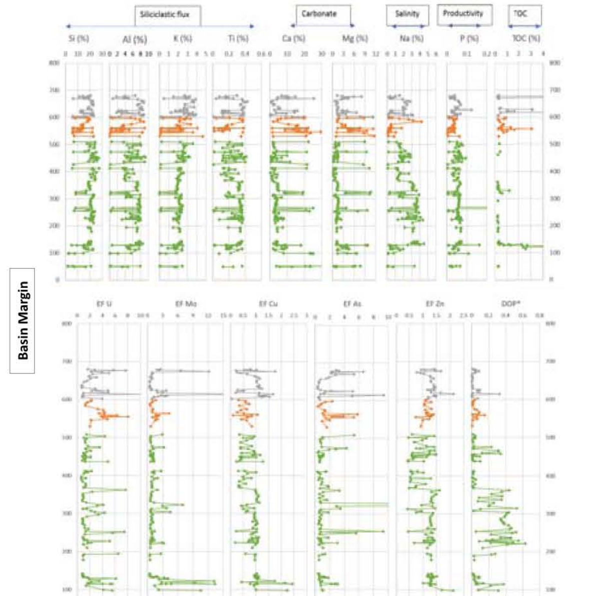
Shell 23X-2: 90 samples analyzed by ICP-OES-MS (Basin Center)

John Savage 24-1 cores: 100 samples analyzed by ICP-OES-MS (Basin Center)

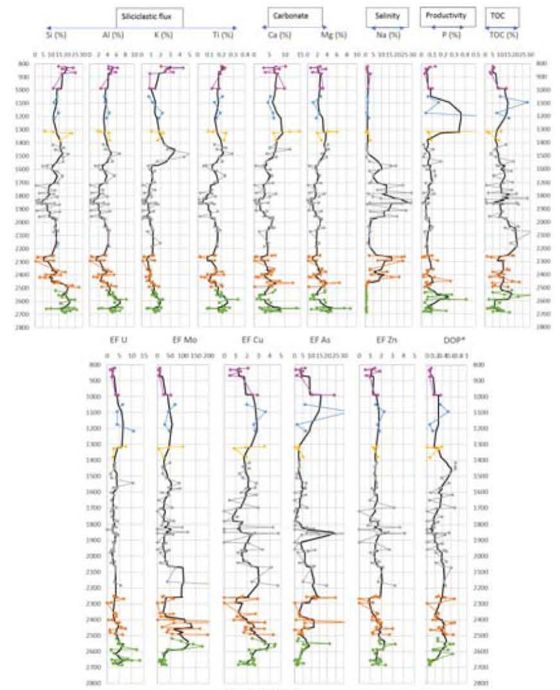
Hierarchical Clustering Analysis (HCA)



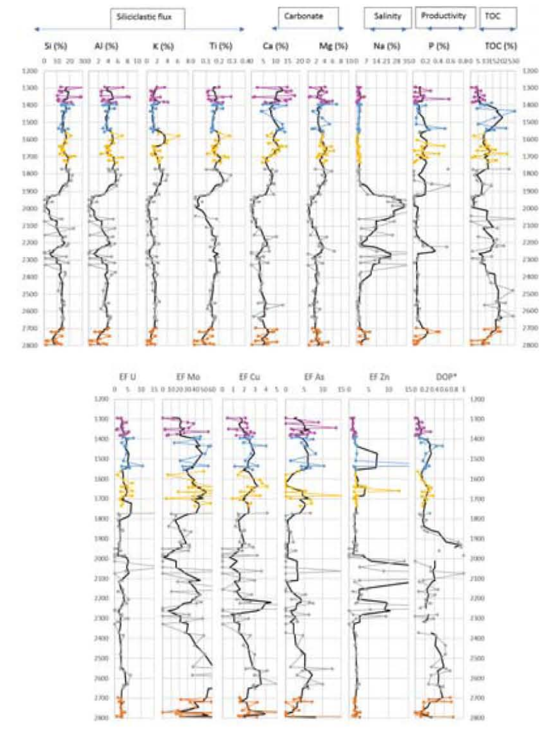
5.1 Geochemistry in the margin



5.2 Geochemistry in Basin Center



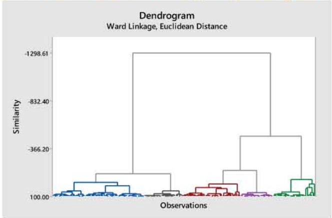
Shell 23X-2

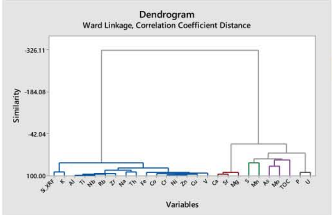


John Savage 24-1

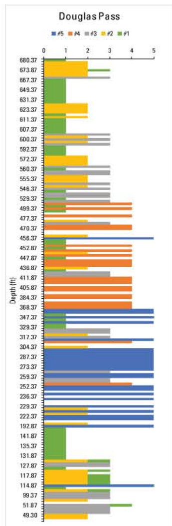
6. HCA of Green River Formation

6.1 In the basin margin (Douglas Pass)

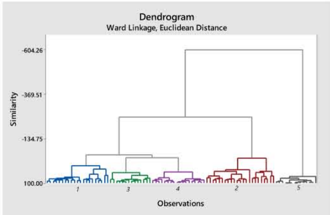


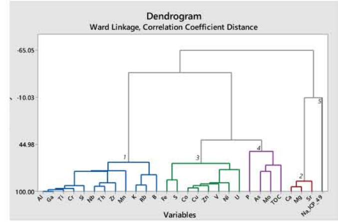


Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Si	1.17	0.86	0.37	1.38	1.18
Al	1.44	0.76	0.10	0.85	1.42
Ca	0.41	1.41	2.81	0.23	0.44
Fe	1.39	0.72	0.51	0.45	1.49
K	1.32	1.01	0.11	1.16	1.07
Mg	0.48	1.26	2.86	0.18	0.48
Na	1.42	0.45	0.13	0.84	1.92
S	0.48	0.56	0.51	0.07	4.24
Ti	1.47	0.73	0.08	0.77	1.49
As	0.70	0.99	1.85	0.73	1.01
Co	1.39	0.72	0.30	0.63	1.58
Cr	1.43	0.89	0.18	0.42	1.53
Cu	1.60	0.66	0.03	0.44	1.61
Mn	0.93	1.16	1.32	0.44	1.04
Mo	0.37	0.76	3.85	0.24	0.37
Nb	1.46	0.79	0.09	0.71	1.48
Ni	1.44	0.78	0.24	0.45	1.58
P	1.15	0.77	0.88	0.91	1.20
Rb	1.38	0.83	0.09	1.00	1.35
Sr	0.41	1.39	2.78	0.31	0.43
Th	1.30	0.81	0.46	0.72	1.41
U	0.90	1.21	1.19	0.42	1.20
V	1.33	0.97	0.39	0.41	1.45
Zn	1.52	0.74	0.17	0.43	1.56
Zr	1.38	0.93	0.16	0.70	1.38
TOC	0.55	3.44	0.22	0.00	0.11

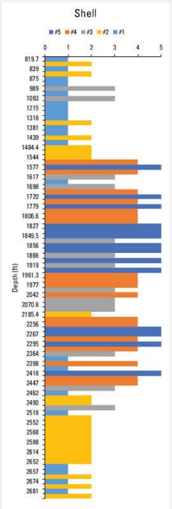


6.2 In the basin center (Shell 23X-2)

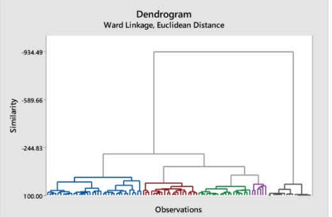


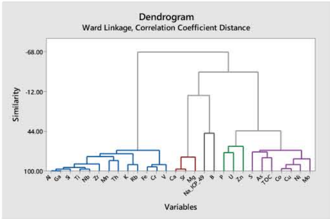


Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Si	1.03	1.54	1.11	0.84	0.16
Al	1.08	1.58	1.04	0.82	0.12
Ti	1.15	1.52	1.02	0.84	0.11
K	1.09	1.66	0.96	0.71	0.19
Ca	1.85	0.80	0.81	1.05	0.18
Mg	1.70	0.99	0.80	0.97	0.19
Fe	1.08	1.62	1.16	0.58	0.25
S	0.53	1.83	1.67	0.51	0.30
P	1.54	1.14	0.82	0.98	0.18
Na	0.34	0.15	0.33	0.93	4.15
As	0.66	1.34	1.90	0.75	0.38
B	0.94	2.06	0.89	0.50	0.10
Co	0.83	1.68	1.47	0.62	0.15
Cr	1.17	1.58	1.04	0.81	0.00
Cu	0.89	1.76	1.36	0.57	0.10
Ga	1.11	1.55	1.04	0.82	0.13
Mn	1.35	1.25	0.96	0.98	0.13
Mo	0.63	1.95	1.41	0.46	0.27
Nb	1.19	1.62	0.96	0.76	0.03
Ni	0.95	1.65	1.25	0.69	0.15
Rb	1.08	1.61	1.06	0.77	0.12
Sr	1.89	0.88	0.76	0.96	0.15
Th	1.19	1.57	1.00	0.74	0.12
U	1.16	1.69	1.10	0.55	0.12
V	1.02	1.64	1.18	0.69	0.14
Zn	0.95	1.64	1.29	0.70	0.12
Zr	0.97	1.93	0.83	0.67	0.11
TOC	0.71	0.95	1.83	1.37	0.20

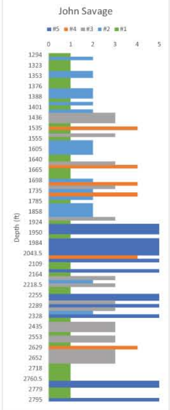


6.3 In the basin center (John Savage 24-1))

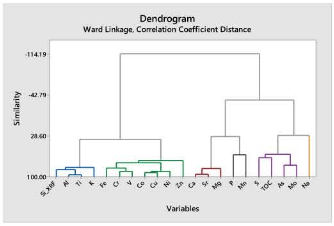




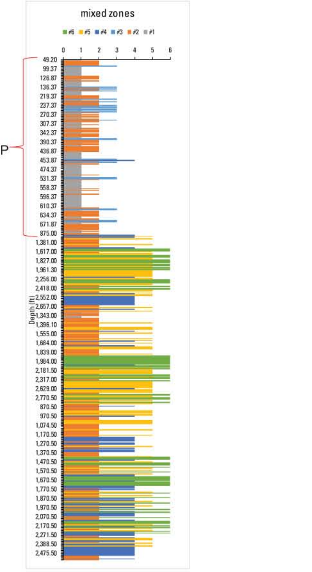
Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Al	0.92	1.68	1.13	1.32	0.07
Ca	1.50	1.01	0.88	0.90	0.11
Fe	0.92	1.53	1.15	1.67	0.09
K	0.86	1.89	1.01	1.15	0.12
Mg	1.41	1.18	0.90	0.73	0.14
P	1.35	0.89	0.80	2.47	0.11
S	0.70	0.79	2.19	1.88	0.19
Si	0.98	1.61	1.13	1.14	0.10
Na	0.56	0.31	0.44	0.26	3.70
Ti	0.96	1.60	1.14	1.32	0.06
As	0.70	0.89	1.75	3.39	0.03
B	1.20	1.58	0.70	0.90	0.25
Co	0.82	1.37	1.38	2.19	0.06
Cr	0.97	1.57	1.19	1.39	0.00
Cu	0.90	1.29	1.36	2.02	0.07
Ga	0.94	1.65	1.13	1.28	0.07
Mn	1.14	1.48	0.97	1.14	0.09
Mo	0.76	0.88	1.59	3.46	0.09
Nb	0.94	1.75	1.07	1.25	0.02
Ni	0.86	1.26	1.37	2.04	0.17
Rb	1.00	1.55	1.17	1.15	0.06
Sr	1.53	0.98	0.77	1.17	0.11
Th	1.00	1.58	0.97	1.62	0.10
U	0.83	1.26	1.20	3.04	0.07
V	0.93	1.38	1.34	1.59	0.09
Zn	0.72	1.15	0.99	4.67	0.12
Zr	0.96	1.61	1.12	1.31	0.08
TOC	1.00	0.67	1.78	2.15	0.09



6.4.Mixed zone (DP+Shell+JS+USBM01A)



Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Si	1.49	1.06	0.48	1.17	1.04	0.17
Al	1.80	0.92	0.09	1.27	0.94	0.25
Ti	2.08	0.90	0.08	1.04	0.90	0.23
K	1.58	1.15	0.10	1.03	0.86	0.31
Ca	0.49	1.45	3.31	0.68	0.89	0.30
Mg	0.50	1.31	3.38	0.86	0.97	0.34
Fe	1.66	0.88	0.40	1.51	0.90	0.28
S	1.41	0.52	0.38	1.57	1.77	0.38
P	3.25	1.18	0.46	0.03	0.00	0.00
Na	0.63	0.43	0.04	0.50	0.52	4.21
As	0.54	0.75	0.50	2.65	1.31	0.37
Co	1.32	0.79	0.24	1.84	1.20	0.28
Cr	1.54	0.94	0.16	1.46	1.01	0.25
Cu	1.06	0.73	0.00	2.21	1.34	0.30
Mn	1.44	1.20	1.49	0.85	0.74	0.24
Mo	0.08	0.64	0.06	3.28	1.54	0.46
Ni	1.24	0.80	0.18	1.90	1.17	0.34
Sr	0.48	[illegible]	[illegible]	0.74	0.86	0.28
V	1.24	0.89	0.38	1.69	1.16	0.29
Zn	1.38	0.77	0.12	1.92	1.08	0.35
TOC	0.07	0.60	0.02	1.17	3.16	0.70



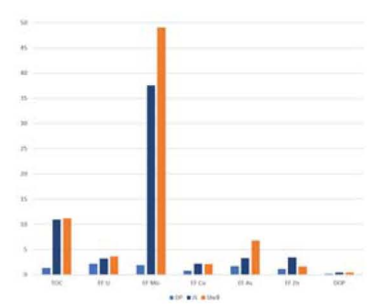
Summary:

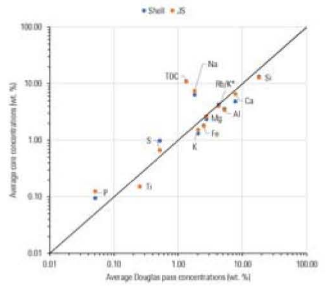
1.For the basin margin, Chemofacies 1, 2 and 3 are dominant in DP only;

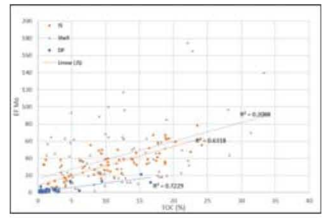
2. Chemofacies 4, 5, 6 are dominant in the basin center only;

3. The sharp distinction between the basin margin and basin center could be better quantified in terms of HCA

6.5. Enrichment factors







8. Conclusion

1) Our study demonstrates that major and trace metal elements can serve as useful proxies for clastic sediments carbonate, redox condition, paleoproductivity and salinity in a lacustrine system;

2) the variations of detrital inputs and salinity across the the PB is mainly controlled by climatic variations around EECO;

3) HCA is an useful tool to quantify the chemofacies across the basin;

4) 5 chemofacies were identified from the basin margin to the basin center based on HCA, demontrating different features;

5) The sharp distinction of the chemofacies across the basin supports the stratified lake model.

Reference

Tänavsuu-Milkeviciene, K., and Sarg, J.F., 2012. Evolution of an organic-rich lake basin– stratigraphy, climate and tectonics: Piceance Creek basin, Eocene Green River Formation Sedimentology, 59, p. 1735–1768.

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Acknowledgement

Oklahoma Geological Survey

U.S.Geological Survey

Total

Shell