University of Wisconsin-Extension

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

3817 Mineral Point Road
Madison, WI 53705-5100
Tel • 608.262.1705
Fax • 608.262.8086
Wisconsin Relay • 711
WisconsinGeologicalSurvey.org

KENNETH R. BRADBURY
DIRECTOR AND STATE GEOLOGIST

Elemental chemostratigraphy of the Cottage Grove Hole MP-18 core: Implications for litho- and hydrostratigraphy in southcentral Wisconsin

James J. Zambito IV
Patrick I. McLaughlin
Sarah E. Bremmer

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James J. Zambito IV*, Patrick I. McLaughlin, and Sarah E. Bremmer

Wisconsin Geological and Natural History Survey
University of Wisconsin – Extension
3817 Mineral Point Road, Madison, Wisconsin 53705

*corresponding author: jay.zambito@wgnhs.uwex.edu

Introduction

Since 2013, the Wisconsin Geological and Natural History Survey (WGNHS) has been developing a chemostratigraphic methodology for using a portable x-ray fluorescence (pXRF) elemental analyzer to characterize sample elemental composition, and by proxy, mineralogical and quantitative lithologic variability within stratigraphic successions. In this open-file report, we present an example of this type of data set from the drill core Cottage Grove Hole MP-18 (WGNHS ID# 13001216). We briefly discuss the data set and implications for lithologic interpretations, subsurface lithostratigraphic correlations, and hydrostratigraphic frameworks.

Materials

This study focuses on the drill core Cottage Grove Hole MP-18 from Dane County, Wisconsin. This core was collected as part of an ongoing, long term groundwater research study led by Drs. Beth Parker and John Cherry (University of Guelph) and funded by a Natural Sciences and Engineering Research Council of Canada Industrial Research Chair awarded to Dr. Parker, Hydrite Chemical Co., and the University Consortium for Field-Focused Groundwater Contamination Research. The core was provided to, and is currently housed by, the WGNHS at its Mount Horeb Research Collections and Education Center to serve as a shared resource for facilitating ongoing geologic and hydrogeologic research.

Methods

The lithostratigraphy of the MP-18 core was measured and described by Zambito in 2014 as part of mapping that was being undertaken in Columbia County, in order to attempt correlation of better studied “offshore” successions with the “nearshore,” shallow-water deposited succession found on the Wisconsin Arch (Zambito and others, *in prep*). Photos of the core with the footages assigned during WGNHS study are provided in appendix A. Following on that, Zambito collected high-resolution pXRF elemental data at the contact interval between the Cambrian Jordan Formation (Trempealeau Group) and the overlying Ordovician Prairie du Chien Group as part of a study to recognize and interpret the Cambrian-Ordovician boundary on the Wisconsin Arch (Zambito and others, 2014). More recently, as part of a regional study on the Eau Claire Formation, McLaughlin and Bremmer collected pXRF at roughly 1-foot intervals through the lower portion of the core (Bremmer and others, 2015). The elemental data presented herein was collected using a Thermo Fisher Scientific Niton XL3t GOLDD+ Handheld XRF analyzer. Each analysis was run in the TestAllGeo mode for a total of 75 seconds (15 seconds on each of the main, low, and high filters, and 30 seconds on the light filter) using the instrument default calibration. It should be noted that error determined by pXRF analysis is an estimate of uncertainty in the measurement, which is different that accuracy or precision derived from study of the analysis of standards. Further details of the pXRF methodology used have been published as an open-file report (Zambito and others, 2016). The resulting lithologic log and pXRF data (appendix B; depth presented in feet, pXRF elemental data in ppm) is presented herein and compared to the natural gamma log (which was collected by the team from the University of Guelph and is available in the WGNHS geophysical data collections).

Results

The lithologic log and elemental profiles collected using pXRF are presented in figures 1 and 2. The gamma log was shifted about -3 feet to correspond to the lithostratigraphy of the core. As seen in figure 1, there is a strong correspondence between the gamma log, aluminum, and potassium, and, to a lesser degree, uranium and thorium values. Aluminum and potassium are positively correlated, with a r^2 value of 0.8978. Calcium and magnesium are positively correlated with a r^2 value of 0.8834. Calcium and silicon are negatively correlated with a r^2 value of 0.923. Figure 2, which focuses on the major rock-forming elements (aluminum, silicon, calcium, and magnesium), agrees well with the lithostratigraphy observed during core examination.

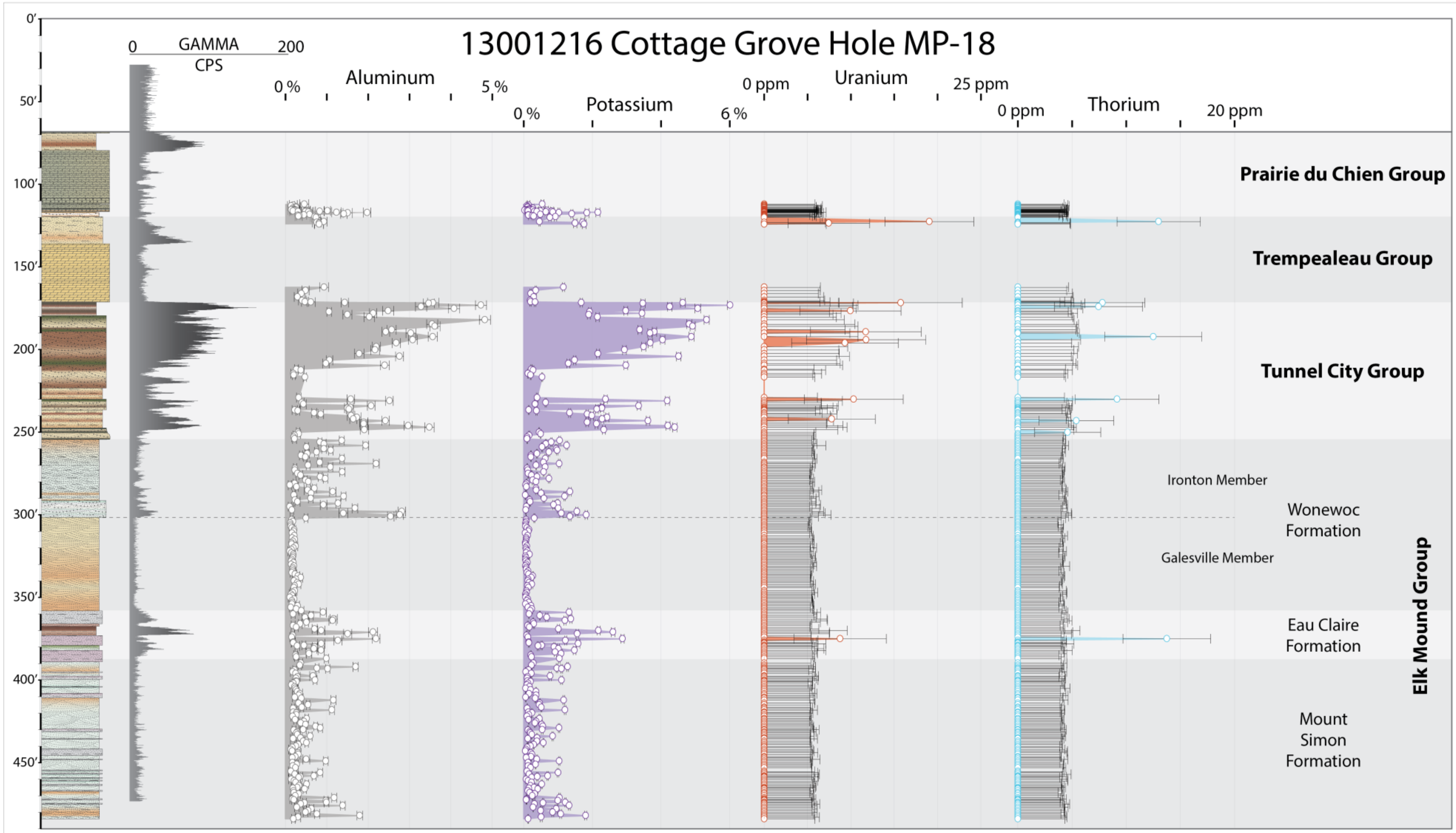

Figure 1: Lithologic log, natural gamma log, and profiles for elements (aluminum, potassium, uranium, and thorium) that are clay proxies and potential sources of natural gamma radiation for drill core Cottage Grove Hole MP-18 (WGNHS ID# 13001216).

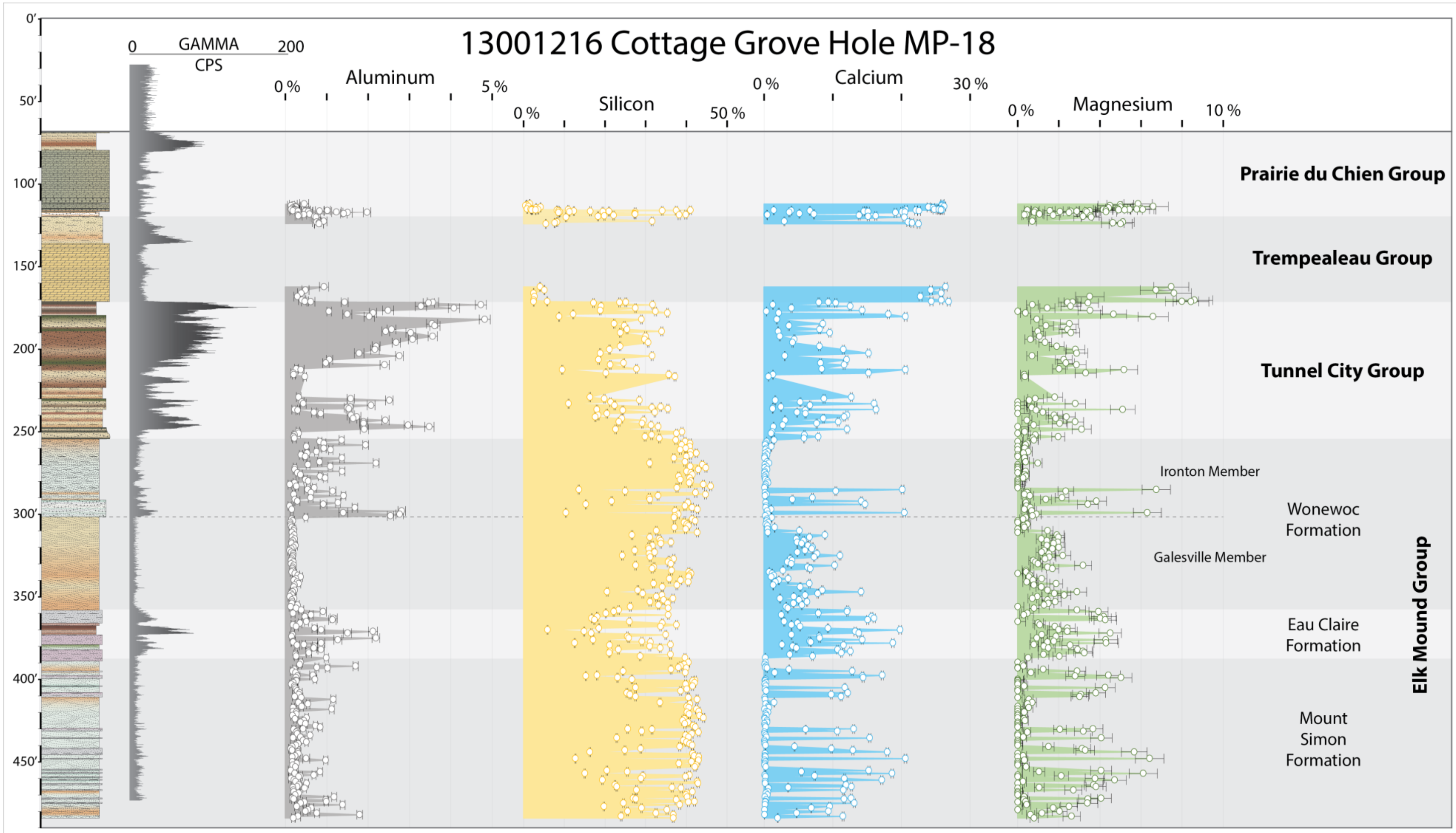

Figure 2: Lithologic log, natural gamma log, and profiles for elements (aluminum, silicon, calcium, and magnesium) that are proxies for clay, quartz, and carbonate content for drill core Cottage Grove Hole MP-18 (WGNHS ID# 13001216).

Discussion

The data presented provide new insights into lithologic interpretations, subsurface lithostratigraphic correlations, and hydrostratigraphic frameworks. The -3 foot shift applied to the gamma log is likely because the drilling crew only marked the footage of end runs on the core, which presumably corresponded to the true depth drilled, but in order to collect pXRF data at 1 foot or smaller resolution we had to interpret core footages between end runs which did not always have full recovery (these footages are marked in the photos presented in appendix A). Elemental patterns in figure 1 suggests that most of the natural gamma radiation recorded during logging is from potassium, though in parts of the Tunnel City Group and Eau Claire Formation, uranium and thorium concentrations are relatively elevated and correspond to gamma log increases. The reader is referred to Haas and others (2017) for further discussion about collecting and interpreting uranium and thorium data using pXRF. The clear relationship between potassium concentration and the gamma log suggests that in wells where there is not a gamma log, but core (or possibly even cuttings) is available, pXRF analysis can provide a quick means for generating a gamma log proxy that can be used for subsurface correlation with wells with geophysical data but lacking core/cuttings. Optimally, however, pXRF profiles are best interpreted when down-hole logs are available to account for intervals of poor or no recovery of geologic sample material.

Additionally, correspondence between the lithostratigraphic log and the pXRF data suggests that we can use aluminum as a proxy for clay, silicon as a proxy for quartz, and calcium and magnesium as proxies for carbonate. These carbonate proxies suggest that the gamma log alone may lead to misinterpretation of the position of the Birkmose Member (a dolomite-cemented, glauconitic sandstone) of the lowest Tunnel City Group, and the contact with the underlying Wonewoc Formation, which was identified during study of the core (lithologic logs shown in figs. 1 and 2; appendix A); this contact is clearly seen in changes in trends within elements signifying carbonate cement. Furthermore, the correspondence between calcium and magnesium throughout the succession suggests that most carbonate cement is dolomite. Although silicon is used herein as a proxy for quartz, it may be more appropriate to use a Si:Al ratio to account for the presence of silicon in clay minerals such as illite.

Subsurface stratigraphic correlation is also enhanced by use of pXRF elemental data. In the lower portion of the Cottage Grove Hole MP-18 core, the Eau Claire Formation, a regional aquitard, is present (figs. 1 and 2). The Eau Claire in this core is a sandstone-dominated unit with variable clay content, carbonate cement, and small amounts of glauconite. Based on our observations of the core, the gamma log, and the elemental patterns shown in figure 2, we place the strata between ~358 ft. and 386 ft. in the Eau Claire Formation; this thickness agrees with other recent regional studies of the Eau Claire (Aswasereelert and others, 2008). The basal contact of the Eau Claire is relatively sharp in the gamma log and carbonate proxies; there is a less obvious lithologic change in the core and the clay proxies. The top of the Eau Claire is gradational with the Wonewoc, representing a coarsening-upward transition to quartz-dominated sandstones based on the core and pXRF lithologic proxies. In the Wonewoc Formation, a regional aquifer, both our lithologic observations and the pXRF data agree with the gamma log, and clearly show, the contact between the Ironton-Galesville Members at 301.5 ft. (figs. 1 and 2; appendix A). An abrupt offset in the gamma log and corresponding increase in clay content and differences in carbonate cementation mark this contact (Sauk II–III unconformity of Runkel and others, 1998; 2007).

Finally, the elemental data set presented herein has important implications for constructing hydrostratigraphic models, as the pXRF data shows that some lithostratigraphic units are more heterolithic than others. For example, the sandstone of the Galesville Member has relatively little clay content, yet variable amounts of carbonate cement. In contrast, the overlying Ironton Member sandstones have variable clay content, and, with the exception of a few intervals in the lower portion of this unit, limited carbonate cements. We therefore predict groundwater in these aquifer units would behave differently because of differences in the presence and type of permeability and porosity. Further investigation of permeability and porosity would be best done by combining the elemental analysis presented herein with textural study and optical petrography because silica and potassium feldspar cements may be significant, but their presence difficult to determine from pXRF elemental data of sandstones. Additionally, hydrostratigraphy derived from pXRF elemental data may not provide an accurate indicator of subsurface fluid flow or storage capacity if fracture-dominated flow is present in these units. Regardless, the Tunnel City Group (with properties of both an aquitard and aquifer), and the Eau Claire Formation (a regional aquitard), and the Mount Simon (a regional aquifer) are all relatively heterolithic.

Acknowledgements

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Appendix A | Core photos


68.4'
START
77.95


85.0
83.0
81.30
79.60
77.95
77.95'
85
START
START
86.85'


86.85'
88.70
START
No Recov
START
89
87
91
91
92
90
96 or 97
95.45
95 or 96
1' missing somewhere this run
MISSING
99.0'


99.0´
START
No Recov
START
No Recov 2'
102
110
105
111.00´


139.5
137.8
134
132
142.4
133
135
137
139
142
134


START
START
A
151.35
146.0
144.0


151.35
Start
B
VOC
156
Start
160
157
160.8


168.55
166.65
164.65
162.75
160.8
MP-18
Start
Run # 22
169.0-174.0
167
165
163
F
E
NO RECOV
START
164
D
170
170.4


179.8
170.4
Start


187.8
179.8
186
185
START
189.7


199.7
START
START
199.60'


199.60'
209.2
START
Start
202
203
204
206
207


209.2'
No Recov


219'
228.1'
NO RECOV
START
AE
AD
AF
227
225
221
222
220
224


START
RUN # 35
228.1'
AJ
AK
235
237.8


237.8'
245
244
START
242
AL
238
AM
AN
Start
239
243
246.4'


246.9'
255
251
251
250
START
256.15'


256.15'
START
START
263
265
261
259
257
266
262
260
258


266'
269
270
275
277.4'
NO RECOV
NO RECOV


277.4
281.7
282
284
START
284
286
START 279
279
283
283
285
287


287'
293
291
295
No RECOV
Start
297'


297'
NO RECOV
START
299
298
Start 298
303
301
302
NO RECOV
START
304
306
306.6


306.6
316
314
309
310
317
315
308
MISSING
317.8'
No Recov


317.8'
NO RECOV
START
327.7'


327.7´
330
330
334
332
332
Start
336
334
329
Start
331
333
335
337.1´


337.1'
339
341
343
345
340
342
344
346
346.6'
Start


346.6'
347
Start
349
349
351
354
350
348
353
357
357.2'


357.2'
366.5'


366.5
367
371
372
373
377
377.5


377.5'
No Recov .1'
Start
382
380
386
384
383
381
379
Start
379
387
389'


389'
391
396
No Recov
Start
394
390
392
399
Start 397'
395'
No Recov 0.5
399.7'


399.7'
400
401
402
403
404
406
405
407
408
409
NO RECOV
Start
409.75'


409.75
410
411
412
415
416
414
419
No Recov 1'
420.3


420.3
421
422
423
424
425
426
428
429
430.2


432.2
430.2
439
437
435
433
431
440
438
No Recov .3'
Start
434
441


441'
450.9'
449
450
448
449
Start
446
447
444
Start
445
442


450.9'
453
No Recov 0.8'
Start 459
460
458
456
452
457
455
Start 459
461
459
461.3'


461.3'
462
463
464
Start 464
464
465
466
467
468
469
Start 469
471
470
471.3'


471.3
472
473
474
Start 474
474
478
Start 479
480
480.85
477


480.85'
483
482
484'