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minerals at the McArthur River deposit, Saskatchewan**

A. Acevedo and T.K. Kyser

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A. Acevedo¹ and T.K. Kyser¹

¹ Queen's University, Kingston, Ontario

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Introduction

Canada was the world's largest producer of uranium until 2009 when production from sandstone-hosted deposits in Kazakhstan exceeded production from Canadian unconformity-related deposits. All of Canada's current uranium production comes from the Athabasca Basin, mainly from the McArthur River mine, the world's largest high-grade uranium mine. With an area of over 85,000 km² the Athabasca Basin hosts about 96% of its known uranium reserves at the shallow (~500 m depth) eastern margin, along a small mineralized corridor (Jefferson et al., 2007). Recent discoveries demonstrate significant potential for deeper places within the basin, where conventional exploration techniques are not a viable option due to cost, so that new tools for exploration are needed. Exploration has expanded beyond the present limits of the Athabasca Basin as new basement-hosted mineralization has been discovered (e.g. Patterson Lake South; Ainsworth et al., 2012). The diagnostic low-temperature alteration for these basement-hosted deposits is superimposed on metamorphic assemblages making it more challenging to find these targets, also calling for new and better exploration tools.

As part of the Targeted Geoscience Initiative Four (TGI-4) uranium ore systems project, the purpose of this activity is to examine the isotopic composition of Fe and Mg in chlorite and illite precipitated during formation of unconformity-related uranium deposits. Given that these minerals are directly associated with ore alteration (Alexandre et al., 2005), changes in alteration- and ore-forming processes may be recorded in their Fe and Mg isotopic compositions.

Methods

40 samples from 13 diamond drill holes from the McArthur River Zone 4 (Figure 1) were selected for this project as representative of the alteration geology (Figure 2). Samples are separated by alteration geology as:

- T1 + Kln (K1, K2) + I1 ± (C1, ICML)
- C1 + Kln (K1, K2) + T1 + (I1, ICML)
- I1 + ICML
- I1
- I1 + Dkt (K1)
- T1 + I1 + K2
- C2 ± C3 + I1 + K2
- I1^{bsmt} + C2^{bsmt}
- I1^{bsmt} + C1^{bsmt}
-

T1= Tourmaline, Kln= kaolinite, I1= Illite, C1= Sudoite, ICML= Illite-Chlorite mixed-layered clay mineral, Dkt= Dickite (K1), K2= post ore Kaolinite, C2= Mg-Fe-rich Sudoite (pre-ore), C3= Fe-Mg-rich Sudoite (syn-ore), I1bsmt= Illite in the altered basement, C1 bsmt= Clinochlore in the altered basement, C2 bsmt= Mg-Sudoite in the altered basement. Another criteria to choose these samples was the availability of ⁵⁷Fe Mössbauer spectroscopy data, since under equilibrium conditions, Fe minerals that are entirely Fe³⁺ have higher δ⁵⁶Fe values than those of mixed Fe³⁺-Fe²⁺ oxidation state.

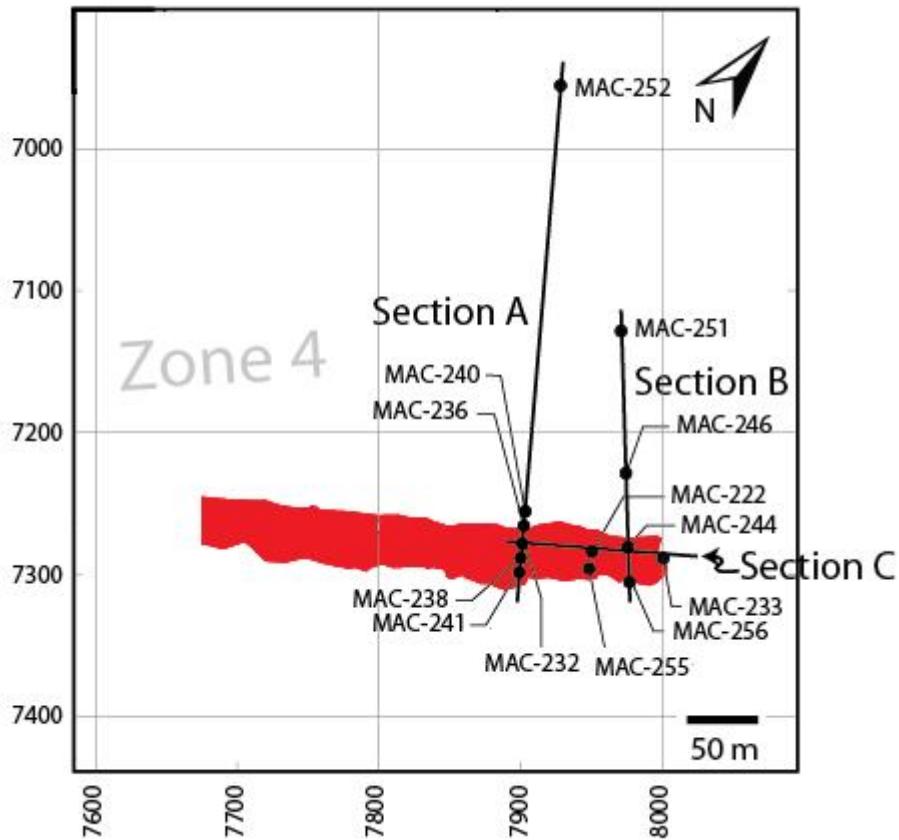


Figure 1. Drill holes included in this project, from the McArthur River Zone 4 ore body. Details of the two NE-SW oriented transects (Sections A-B) and one transect oriented NW-SE (Section C) are illustrated in Figure 3. Modified from Ng (2012).

Project status

Splits of the samples have been analyzed with the Thermo-Fisher Element 2 XR high-resolution ICP-MS for trace element concentrations and lead ratios, and the Thermo-Fisher iCAP ICP-OES for major elements, showing anomalous values for light rare earth elements (LREE) in some of the samples (Appendix C). The biggest concern was that the high concentrations of LREE were contained in chlorite and illite, a potential hindrance for Mg and Fe isotopic studies. A set of 12 samples were examined with a Scanning Electron Microscope (SEM) to verify the minerals hosting LREE's, revealing the presence of both monazite and APS crystals associated with trioctahedral chlorite, and sudoite as noted by Gaboreau et al., (2007) (Fig.2).

After analyzing samples on the SEM, it was found that the LREE's are contained in monazite present as euhedral crystals mostly in a matrix of chlorite and in aluminium phosphate-sulphate (APS) minerals present mostly in the edges of larger illite crystals. Both minerals were present in trace concentrations in the samples. Although these phases host the REEs, their effect on Mg and Fe isotopic compositions is minimal.

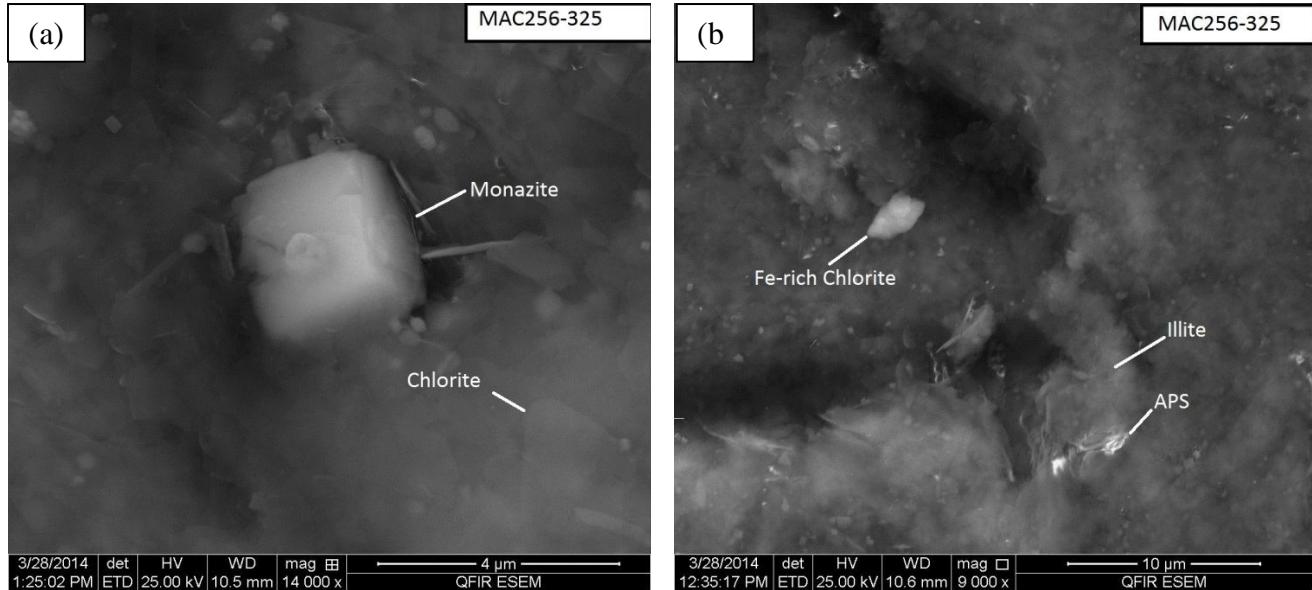


Figure 2. SEM images of sample MAC 256-325 from the Manitou Falls Formation showing the presence of both (a) monazite and (b) APS minerals in a chlorite and illite matrix.

Isotopic Analyses

A number of tests were completed using a prep-FAST sample/standard dilution system to verify complete separation of our elements of interest but also to validate that there were no problems with isotopic fractionation in the process. All samples were dissolved in HF + HNO₃, evaporated, dissolved in 10M HCl and finally loaded in a prep-FAST sample/standard dilution system.

For internal control on isotopic results two synthetic standards have been created representing both extremes in Fe and Mg contents. One has low Fe and Mg contents, comparable to the I1 Illite (Fe: 0.6 wt.%, Mg: 0.29 wt.%), and another with higher Fe and Mg contents, analogous to the C2 Sudoite (Fe: 7.1 wt.%, Mg: 7.0 wt.%).

Fe isotopes: Using both synthetic standards (C2-I1), Fe ion chromatography has been adapted for the needs of the project and after a number of tests, full Fe recovery was achieved without isotopic fractionation during this process. In the method, sets of 5 samples, 2 standards (C2-I1), and 1 blank were processed using the prep-FAST system using a strong anion exchange resin (AG MP-1) and once the sets of samples were ready, isotopic values obtained using a ThermoFinnigan Neptune high-resolution multi-collector ICP-MS.

Mg isotopes: The ion chromatography process was adapted for Mg separation, and after a number of tests was successful. Samples consisted of the eluted matrix from the Fe separation, containing other major elements.

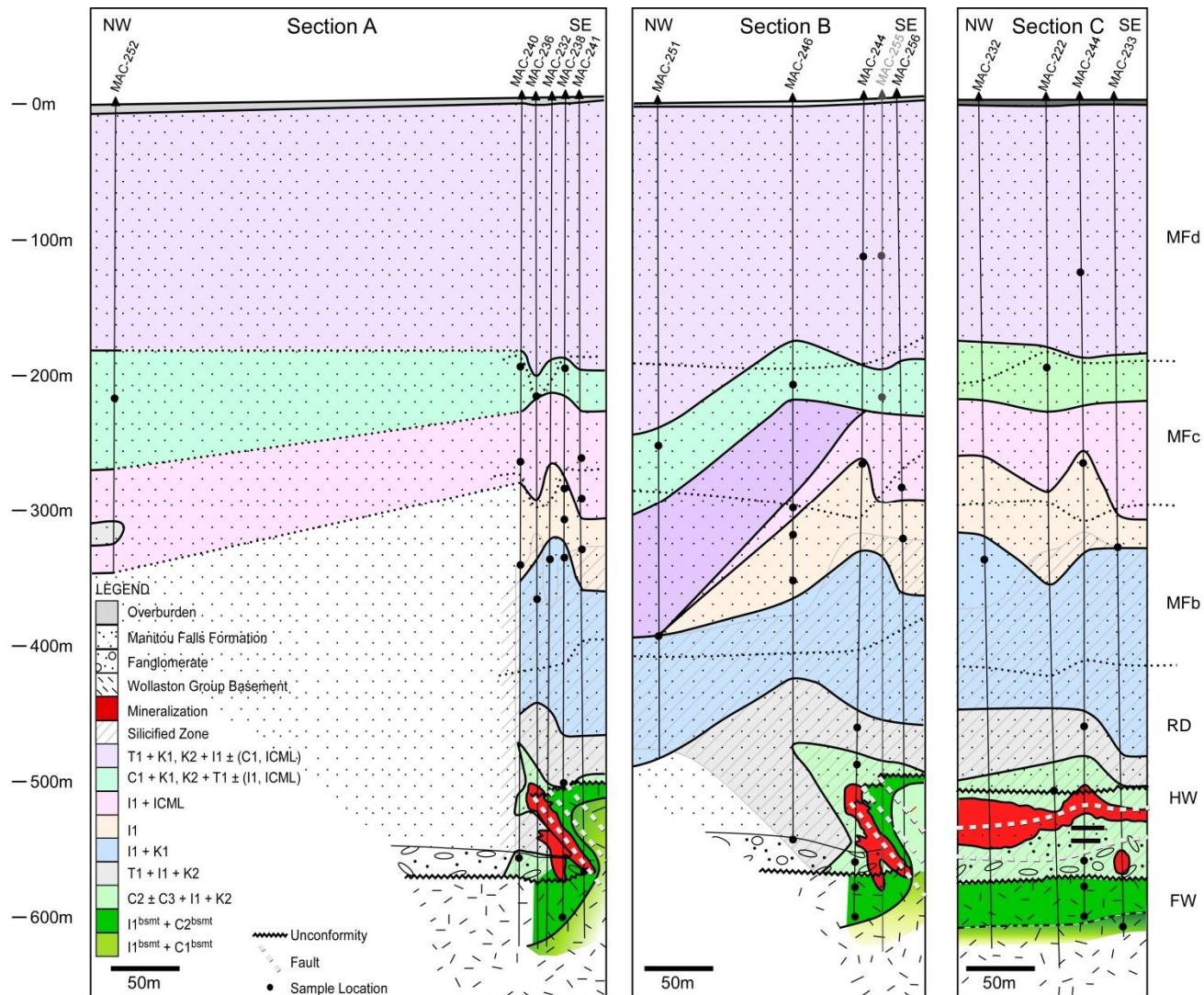


Figure 3. Sample locations and spatial distribution of alteration minerals within the Manitou Falls Formation, Read Formation and Wollaston Group basement at McArthur River Zone 4. Abbreviations: Dkt=dickite, Kln=kaolinite, ICML=illite-chlorite mixed layer clay. Members of the Manitou Fall Formation (MF) rocks: MFd = Dunlop Member, MFc = Collins Member, MFb = Bird Member. RD = Read Formation, HW = Hanging wall basement rocks, FW = Footwall basement rocks. Modified from Ng et al. (2013).

References

- Ainsworth, G.P., McElroy, R., Ashley, R., Ainsworth, B., 2012. A Convenient Joint Venture - Patterson Lake South; Open House 2012 Abstract Volume, Saskatchewan Geological Survey, p.10.
- Alexandre, P., Kyser, K., Polito, P., and Thomas, D., 2005. Alteration mineralogy and stable isotope geochemistry of Paleoproterozoic basement-hosted unconformity-type uranium deposits in the Athabasca Basin, Canada; *Economic Geology*, v. 100, p. 1547–1563.
- Gaboreau, S., Cuney, M., Quirt, D., Beaufort, D., Patrier, P. and Mathieu, R., 2007. Significance of aluminum phosphate-sulfate minerals associated with unconformity-type deposits: The Athabasca basin, Canada; *American Mineralogist*, v. 92, p. 267–280.
- Jefferson, C.W., Thomas, D.J., Gandhi, S.S., Ramaekers, P., Delaney, G., Brisbin, D., Cutts, C., Portella, P. and Olson, R.A., 2007a. Unconformity-associated uranium deposits of the Athabasca basin, Saskatchewan and Alberta; in EXTECH IV: Geology and Uranium EXploration TECHnology of the Proterozoic Athabasca Basin, Saskatchewan and Alberta, C.W. Jefferson and G. Delaney (eds.); Geological Survey of Canada Bulletin 588, p. 23–67.
- Ng, R., 2012. Geochemical and mineralogical evolution of the McArthur River Zone 4 unconformity-related uranium ore body and application of iron oxidation state in clay alteration as indicator of uranium mineralization; Unpublished MSc thesis, Queen's University, Kingston, 220 p.
- Ng, R., Alexandre, P. and Kyser, T.K., 2013. Mineralogical and Geochemical Evolution of the Unconformity-Related McArthur River Zone 4 Orebody in the Athabasca Basin, Canada: Implications of a Silicified Zone; *Economic Geology*, v. 108, p. 1657–1689.

Appendix A

Modal abundance of clay minerals from McArthur River Zone 4 by XRD semi-quantitative analysis using relative intensity ratio method

Sample	% dravite	% illite	% ICML	% sudsite	% clinochlore	% kaolinite	% dickite	% quartz	% APS
MAC222-197	52	17		18		11		3	
MAC222-509	2	6		51		43			
MAC232-339		83					17		
MAC233-315		100							
MAC233-612		9			91				
MAC236-256	3	68	28			1			
MAC236-368	1	15				2	82		
MAC238-199	56	19		10		11		3	
MAC238-287	2	90						8	trace
MAC238-311		100							
MAC238-339		83					17		
MAC238-505	5	39				47		9	
MAC238-523	4	26			66	3			
MAC238-604		88			4	8			
MAC240-197	31	11		37		20			
MAC240-267	3	60	37						
MAC240-344		100							
MAC240-560	9	39		52					
MAC241-265	3	72	25						
MAC241-295		66	33	2					
MAC241-333		100							
MAC241-569	5	26			60	8			
MAC244-128	5	39	40	16					
MAC244-269		100							
MAC244-464		79				16	5		
MAC244-569	6	33			55	6			
MAC244-581		61			39				
MAC244-603		34			62	4			
MAC246-209	16	34	37		12				
MAC246-300		67	32	1					
MAC246-320	3	100							
MAC246-354		100							
MAC246-545	1	79		9		11			
MAC251-252	10	11		26	52				
MAC252-215				35	65				
MAC255-128	5	40	48	7					
MAC255-220	5	70		6	14	6			
MAC255-504	1	25		54	14	7			
MAC256-287	3	67	29						
MAC256-325		100							

APS= aluminum phosphate-sulfate minerals

ICML= illite-chlorite mixed-layer clay

Appendix B

Pb and U isotopic ratios of clay separates from McArthur River Zone 4

Sample	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{208}\text{Pb}/^{206}\text{Pb}$	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{208}\text{Pb}/^{232}\text{Th}$	$^{238}\text{U}/^{232}\text{Th}$
MAC_222_197	0.65	2.03	25.33	16.57	51.30	0.81	73.95	0.74	0.45
MAC_222_509	0.02	0.06	777.46	18.20	42.77	0.47	1.58	0.14	5.48
MAC_232_339	0.75	2.04	20.84	15.57	42.54	1.18	118.71	1.14	0.47
MAC_233_315	0.58	1.74	28.69	16.57	49.80	0.12	9.55	4.04	19.82
MAC_233_612	0.29	1.03	68.44	19.54	70.71	0.40	17.14	0.06	0.15
MAC_236_256	0.59	2.17	28.72	16.82	62.28	0.12	10.21	0.11	0.41
MAC_236_368	0.82	2.05	19.58	15.99	40.07	1.36	156.13	1.94	0.70
MAC_238_199	0.59	2.04	29.12	17.15	59.26	0.44	37.26	0.17	0.19
MAC_238_287	0.81	2.17	20.07	16.19	43.62	0.43	51.21	2.78	2.95
MAC_238_311	0.58	1.48	29.69	17.11	43.88	0.09	7.78	0.45	3.38
MAC_238_339	0.66	2.22	24.66	16.36	54.77	0.45	42.57	0.72	0.73
MAC_238_505	0.24	0.78	76.43	18.52	59.36	0.28	10.32	2.27	10.57
MAC_238_523	0.01	0.03	1769.12	20.26	49.07	0.80	1.37	0.51	22.87
MAC_238_604	0.67	2.08	27.04	18.00	56.17	1.44	145.92	1.15	0.38
MAC_240_197	0.75	1.99	23.21	17.37	46.16	0.52	59.33	0.56	0.54
MAC_240_267	0.38	0.99	47.13	17.94	46.50	0.31	17.25	0.50	1.60
MAC_240_344	0.75	2.15	21.41	16.08	45.98	0.24	26.90	3.54	6.95
MAC_240_560	0.50	1.51	31.70	15.77	47.93	0.22	15.90	0.37	1.13
MAC_241_265	0.62	2.12	25.55	15.83	54.16	0.51	45.81	0.42	0.39
MAC_241_295	0.59	2.54	26.83	15.95	68.17	0.19	16.47	0.45	0.94
MAC_241_333	0.69	2.34	23.76	16.28	55.54	0.07	7.58	1.17	6.89
MAC_241_569	0.07	0.18	243.73	17.28	44.92	0.86	9.03	0.14	0.89
MAC_244_128	0.61	2.04	26.94	16.55	55.08	0.18	16.96	0.43	1.19
MAC_244_269	0.58	1.74	28.66	16.68	49.76	0.41	36.03	1.81	2.56
MAC_244_464	0.67	1.65	22.51	15.16	37.09	0.35	33.39	2.05	3.60
MAC_244_569	0.19	0.63	86.81	16.90	54.36	0.12	3.59	0.08	1.02
MAC_244_581	0.79	1.95	20.40	16.06	39.85	1.22	143.97	1.17	0.49
MAC_244_603	0.72	2.08	22.29	16.04	46.32	0.36	35.55	0.31	0.42
MAC_246_209	0.84	2.22	21.03	17.57	46.60	0.34	46.06	0.29	0.38
MAC_246_300	0.51	3.42	33.44	17.03	114.34	0.20	14.96	0.12	0.18
MAC_246_320	0.72	2.30	22.49	16.18	51.69	0.14	16.02	0.21	0.62
MAC_246_354	0.65	2.02	25.16	16.33	50.72	0.73	66.90	9.72	6.59
MAC_246_545	0.77	1.99	21.26	16.35	42.19	0.75	82.48	2.22	1.50
MAC_251_252	0.63	1.74	27.73	17.35	48.13	0.25	23.13	0.15	0.34
MAC_252_215	0.84	2.22	19.34	16.28	42.89	1.26	158.98	0.26	0.09
MAC_255_128	0.71	2.10	23.87	16.92	50.09	0.27	29.75	0.24	0.41
MAC_255_220	0.64	1.97	24.58	15.75	48.37	0.49	42.51	0.38	0.40
MAC_255_504	0.10	0.44	172.32	17.42	76.42	0.87	13.41	0.18	0.47
MAC_256_287	0.56	1.71	32.64	18.14	55.71	0.15	13.41	0.53	2.06
MAC_256_325	0.58	2.04	27.32	15.89	55.84	0.40	34.44	2.99	3.67

Appendix C

Element concentrations of clay separates from McArthur River Zone 4

Sample	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
MAC_222_197	19.05	DL	10505.04	192.72	6.67	0.36	2601.50	0.16	356.40	2.55	43.76	0.21	169.60	7.55	3.09
MAC_222_509	16.03	1.03	660.16	39.89	24.27	0.94	1552.55	0.14	74.89	52.61	161.46	0.47	92.22	4.74	2.16
MAC_232_339	23.67	0.22	788.34	52.19	1.53	0.12	2921.52	0.44	69.03	1.13	31.48	0.59	89.81	1.23	0.70
MAC_233_315	16.67	0.38	455.98	34.96	1.30	0.06	1457.62	0.46	1.59	1.18	21.80	0.41	74.51	DL	DL
MAC_233_612	2.80	1.86	157.43	7.90	3.69	0.01	737.27	DL	58.16	17.66	68.45	0.85	13.37	1.25	0.65
MAC_236_256	15.50	0.97	960.67	123.79	2.62	0.26	1942.52	0.45	150.27	1.03	41.98	0.54	47.83	4.78	2.35
MAC_236_368	22.29	0.12	2025.55	9.90	1.76	0.14	1682.71	0.44	17.04	1.48	37.34	DL	363.99	0.24	0.09
MAC_238_199	17.86	0.31	3746.59	203.98	9.08	0.40	2293.03	0.57	197.20	4.17	65.70	DL	166.83	5.82	2.92
MAC_238_287	30.23	0.67	892.29	44.06	2.75	0.16	2166.30	0.22	11.15	0.94	40.74	0.03	94.10	0.22	0.09
MAC_238_311	35.08	0.75	770.65	90.81	1.82	3.18	2378.24	0.80	60.36	1.62	64.84	0.26	109.87	4.18	2.56
MAC_238_339	8.31	0.24	263.62	13.32	0.61	0.64	1043.79	0.08	21.42	0.35	11.25	DL	19.41	0.35	0.15
MAC_238_505	14.89	0.45	2724.48	17.54	7.06	0.86	755.14	0.19	17.85	7.29	179.32	DL	78.08	1.20	0.69
MAC_238_523	30.44	0.60	2742.46	44.31	6.81	0.80	885.36	0.02	168.12	25.76	5.76	0.33	2740.16	1.76	0.83
MAC_238_604	1.19	0.72	446.11	74.18	3.56	0.04	1344.98	0.08	29.68	11.73	90.77	4.01	26.44	1.02	0.54
MAC_240_197	26.04	0.54	9502.25	291.13	10.59	0.63	3056.43	0.28	269.75	6.15	156.84	0.08	181.48	8.00	3.21
MAC_240_267	24.99	0.75	260.92	60.28	1.14	0.10	1463.37	0.27	41.84	0.83	19.77	0.34	118.28	1.37	0.70
MAC_240_344	12.70	1.48	712.47	66.88	0.85	0.06	2747.57	0.37	9.40	0.72	41.43	DL	128.06	0.23	DL
MAC_240_560	8.42	1.52	1500.41	35.08	2.12	0.15	644.70	0.21	202.48	18.12	132.81	0.32	166.70	1.98	1.20
MAC_241_265	21.87	0.54	821.85	147.92	3.21	0.18	2392.79	0.71	9.00	1.15	34.05	0.13	34.97	0.49	0.29
MAC_241_295	9.09	0.58	245.46	44.61	0.82	0.10	935.75	0.16	6.17	0.66	18.82	0.34	21.80	0.32	0.19
MAC_241_333	30.71	1.07	685.11	30.60	1.95	0.20	2054.41	0.89	5.53	2.19	25.47	0.10	89.26	0.20	DL
MAC_241_569	1.02	1.19	516.38	55.78	6.01	0.12	420.68	0.07	82.97	25.97	25.95	0.68	79.18	1.63	0.93
MAC_244_128	9.44	0.64	750.18	62.83	1.61	0.22	935.28	0.28	45.04	1.11	37.42	0.42	45.89	2.74	1.29
MAC_244_269	30.77	0.48	570.27	48.00	1.26	0.10	1437.42	0.25	11.65	0.50	24.86	DL	45.83	0.22	DL
MAC_244_464	2.54	0.53	256.46	21.75	0.21	0.04	127.24	0.10	18.45	0.26	11.55	DL	186.30	0.31	0.18
MAC_244_569	1.64	1.66	1231.89	38.97	2.68	0.32	656.39	0.12	134.74	15.16	38.68	0.27	77.60	2.54	1.06
MAC_244_581	1.26	1.06	222.16	26.51	1.00	0.05	454.91	0.11	62.88	1.26	19.12	0.48	17.43	2.56	1.25
MAC_244_603	0.68	1.23	179.21	88.95	3.69	0.03	698.09	0.03	44.76	22.56	64.24	3.17	34.39	3.38	1.94
MAC_246_209	6.39	1.30	3291.35	110.05	1.59	0.36	857.71	0.10	277.79	0.81	16.84	0.24	47.27	4.89	1.87
MAC_246_300	7.06	0.71	214.57	58.33	1.28	0.12	1280.40	0.41	24.37	1.52	10.88	0.45	34.90	1.75	1.11
MAC_246_320	15.32	0.58	175.23	21.64	0.54	0.10	1261.30	0.34	10.34	0.69	14.82	0.01	73.56	0.32	0.16
MAC_246_354	12.00	1.08	876.19	10.02	1.21	0.17	750.78	0.26	1.10	1.87	26.69	0.06	102.32	DL	DL
MAC_246_545	0.94	0.23	113.73	12.47	0.22	0.06	320.72	0.05	8.13	0.43	23.87	DL	90.66	0.49	0.34
MAC_251_252	6.58	1.28	587.69	37.11	0.74	0.13	1992.40	0.08	116.45	1.42	19.51	0.20	29.50	1.38	0.51
MAC_252_215	4.70	1.38	462.29	58.35	1.14	0.17	1121.59	DL	178.55	1.66	20.41	0.20	20.87	2.19	0.84
MAC_255_128	25.18	1.62	900.01	162.98	2.34	0.27	1833.45	0.48	291.54	1.31	25.88	0.84	99.48	8.97	3.57
MAC_255_220	4.04	0.54	1132.58	8.80	0.64	0.03	476.99	0.07	66.64	0.26	16.09	DL	22.20	1.43	0.68
MAC_255_504	20.54	0.58	228.24	44.07	3.05	0.51	567.16	0.13	216.13	10.45	58.20	DL	81.62	2.37	1.14
MAC_256_287	55.61	1.55	1050.40	168.08	3.31	0.27	5514.07	2.56	23.00	2.44	119.51	0.20	174.94	1.88	0.92
MAC_256_325	3.19	0.35	286.49	10.11	0.43	0.07	1001.72	0.10	5.12	0.47	21.35	DL	17.39	0.11	DL

Sample	Eu	Ga	Gd	Ge	Hf	Hg	Ho	La	Li	Lu	Mn	Mo	Na	Nb	Nd	Ni
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
MAC_222_197	3.04	47.82	14.08	DL	14.65	0.26	1.28	139.16	88.49	0.45	17.82	1.53	6133.60	12.58	127.65	48.68
MAC_222_509	1.14	63.36	4.69	DL	7.77	0.43	0.85	23.06	1346.98	0.28	53.50	9.64	1069.47	3.26	40.15	289.85
MAC_232_339	0.44	44.80	2.63	0.82	20.10	0.12	0.24	23.12	122.55	0.15	36.37	0.96	904.27	4.64	28.43	6.23
MAC_233_315	DL	32.31	DL	DL	12.87	0.26	DL	0.69	177.24	DL	72.51	3.89	1154.65	4.52	0.79	13.76
MAC_233_612	0.44	17.12	1.64	DL	0.60	0.36	0.22	28.54	227.42	DL	32.28	DL	544.04	2.11	21.20	43.26
MAC_236_256	1.67	46.35	8.58	DL	22.71	0.08	0.89	51.92	251.62	0.46	40.06	1.89	1034.85	2.95	56.93	26.88
MAC_236_368	0.20	28.23	0.86	DL	14.71	0.11	0.04	5.54	54.80	0.02	14.86	1.48	982.24	3.70	7.53	9.18
MAC_238_199	2.04	42.61	9.40	DL	30.36	0.09	1.05	69.26	57.12	0.55	16.05	1.50	6356.91	59.33	80.83	38.23
MAC_238_287	0.12	62.69	0.55	1.47	9.95	0.06	DL	3.69	216.05	DL	15.34	1.08	725.99	1.28	4.42	20.77
MAC_238_311	1.01	44.40	5.20	DL	38.30	0.03	0.86	19.89	149.90	0.50	27.88	1.85	1752.80	2.75	26.46	15.72
MAC_238_339	0.27	17.64	1.04	0.77	4.43	0.07	0.06	7.21	102.57	0.04	3.78	0.31	438.15	0.38	9.63	2.44
MAC_238_505	0.17	36.85	0.93	DL	7.09	0.09	0.22	9.22	130.24	0.10	10.22	8.52	2021.34	3.56	6.30	22.99
MAC_238_523	0.59	27.14	2.82	DL	0.69	DL	0.32	132.96	379.51	0.10	17.23	3.63	1381.89	DL	41.29	33.35
MAC_238_604	0.56	44.09	1.83	DL	1.15	0.43	0.19	8.21	107.69	0.11	32.98	0.50	3869.63	7.29	13.95	49.47
MAC_240_197	3.01	115.42	13.93	DL	21.86	0.06	1.30	86.11	321.87	0.45	33.17	2.29	9495.20	22.11	111.54	135.38
MAC_240_267	0.49	29.34	2.43	1.19	9.04	DL	0.25	12.98	170.01	0.11	22.96	3.37	224.08	3.52	17.39	26.93
MAC_240_344	0.11	41.86	0.53	DL	21.45	0.11	DL	2.75	186.97	0.02	9.97	7.02	635.22	3.72	3.56	7.35
MAC_240_560	0.98	27.77	5.37	DL	7.59	DL	0.40	86.32	123.04	0.35	37.59	1.28	1408.25	0.98	70.62	76.33
MAC_241_265	DL	42.93	0.63	DL	29.06	DL	0.10	3.26	270.08	0.06	16.68	DL	2511.05	6.11	4.13	32.57
MAC_241_295	0.07	27.32	0.46	DL	8.27	0.01	0.07	2.19	207.78	0.05	11.00	0.59	360.35	2.64	2.97	22.41
MAC_241_333	0.06	36.29	0.32	1.65	26.39	0.14	DL	2.21	153.39	DL	32.29	7.78	1921.41	11.68	2.61	17.68

Sample	Eu ppm	Ga ppm	Gd ppm	Ge ppm	Hf ppm	Hg ppm	Ho ppm	La ppm	Li ppm	Lu ppm	Mn ppm	Mo ppm	Na ppm	Nb ppm	Nd ppm	Ni ppm
MAC_244_269	0.12	45.14	0.52	1.67	7.31	DL	DL	3.62	131.96	DL	10.11	3.22	1041.98	2.30	4.93	14.90
MAC_244_464	0.14	5.33	0.76	DL	4.88	DL	0.06	6.73	31.10	0.05	5.78	0.90	135.68	3.88	4.92	2.81
MAC_244_569	1.04	24.27	4.28	DL	4.69	0.12	0.44	62.11	207.78	0.17	11.82	1.98	791.45	2.30	49.65	75.95
MAC_244_581	0.94	24.81	3.89	DL	4.18	0.03	0.47	34.17	92.69	0.17	4.16	0.29	356.82	1.58	28.78	36.02
MAC_244_603	0.61	22.09	2.97	DL	0.73	DL	0.70	23.65	196.95	0.29	19.14	0.80	699.61	1.90	19.20	134.53
MAC_246_209	2.36	21.62	10.32	DL	6.95	DL	0.78	105.50	84.33	0.26	5.41	DL	1144.40	1.15	94.57	23.80
MAC_246_300	0.39	26.69	2.25	DL	22.80	0.07	0.36	7.62	137.69	0.24	77.94	0.96	410.25	5.25	11.97	22.85
MAC_246_320	0.15	18.98	0.73	DL	13.20	0.04	0.06	3.65	107.44	DL	8.06	2.42	390.46	5.03	4.67	11.40
MAC_246_354	DL	55.33	DL	DL	13.58	0.07	DL	0.41	170.94	DL	9.87	1.52	2109.59	4.38	0.49	11.11
MAC_246_545	0.15	6.87	0.86	DL	1.72	0.04	0.10	2.74	20.48	0.09	31.30	1.13	143.85	0.97	4.14	4.49
MAC_251_252	0.82	20.11	3.50	DL	2.53	0.08	0.23	45.56	91.32	0.08	35.45	0.39	9118.27	0.51	35.81	35.12
MAC_252_215	1.27	21.03	4.72	DL	3.77	DL	0.35	77.41	103.70	0.12	7.35	DL	7654.46	1.66	56.32	43.56
MAC_255_128	3.21	38.45	13.68	DL	18.45	DL	1.50	112.49	343.62	0.56	15.88	2.85	1131.42	1.02	104.38	42.24
MAC_255_220	0.47	16.74	2.91	DL	3.96	DL	0.25	25.33	43.33	0.11	2.95	0.46	1288.46	3.40	24.93	3.40
MAC_255_504	1.20	25.10	7.89	DL	5.53	0.14	0.39	108.52	165.88	0.21	6.87	21.08	555.66	9.44	88.15	63.84
MAC_256_287	0.45	134.18	2.77	DL	92.76	0.08	0.33	6.88	930.93	0.16	34.83	3.46	2473.62	10.72	10.56	116.05
MAC_256_325	0.06	17.54	0.28	DL	4.96	DL	DL	1.88	151.47	DL	4.34	0.82	309.87	4.86	2.31	4.77
Sample	P ppm	Pb ppm	Pd ppm	Pr ppm	Pt ppm	Rb ppm	Re ppm	S ppm	Sb ppm	Sc ppm	Se ppm	Si ppm	Sm ppm	Sn ppm	Sr ppm	
MAC_222_197	2346.10	137.20	0.60	34.58	DL	0.75	DL	573.75	0.41	6.58	DL	153.16	20.54	7.56	1908.86	
MAC_222_509	556.06	104.04	DL	9.56	DL	1.67	DL	190.24	DL	17.29	DL	17.74	7.31	7.81	310.43	
MAC_232_339	1876.99	60.18	DL	7.33	DL	40.92	DL	338.93	0.36	6.80	DL	36.59	4.26	20.74	2691.03	
MAC_233_315	1598.89	12.78	DL	0.20	DL	28.50	DL	176.00	0.52	1.67	DL	15.95	DL	4.90	925.95	
MAC_233_612	158.41	2.26	DL	6.16	DL	18.81	DL	100.20	2.68	10.18	DL	13.37	2.75	3.53	31.87	
MAC_236_256	1846.05	33.51	DL	14.91	DL	27.70	DL	261.08	0.58	7.73	DL	12.13	10.66	6.39	1783.26	
MAC_236_368	2016.69	68.88	DL	1.89	DL	3.64	DL	518.08	0.62	2.47	DL	119.45	1.31	36.45	1832.64	
MAC_238_199	2696.52	85.30	0.41	20.70	DL	0.31	DL	592.71	2.56	11.25	DL	95.75	13.78	14.61	2466.86	
MAC_238_287	2677.41	49.36	DL	1.14	DL	34.57	DL	452.90	0.22	1.84	DL	32.25	0.87	4.09	2120.56	
MAC_238_311	1795.78	41.74	0.29	6.13	DL	52.98	DL	439.91	0.53	9.32	DL	33.72	6.17	5.70	1654.26	
MAC_238_339	654.83	14.26	DL	2.39	DL	11.55	DL	106.91	DL	1.82	DL	9.33	1.69	1.00	889.74	
MAC_238_505	759.72	175.25	DL	1.74	DL	6.42	DL	2459.57	0.80	10.15	DL	36.87	1.13	9.26	600.30	
MAC_238_523	833.23	30.68	0.28	13.66	DL	20.48	DL	1363.86	0.34	5.04	DL	15.77	4.07	1.50	657.03	
MAC_238_604	623.82	5.12	DL	3.17	DL	41.99	DL	1698.65	DL	12.87	DL	14.10	2.91	3.37	277.10	
MAC_240_197	4119.46	141.04	0.51	27.93	DL	0.59	DL	580.91	0.87	9.92	DL	834.47	19.56	31.54	3027.24	
MAC_240_267	1598.31	31.13	DL	4.22	DL	13.53	DL	155.26	0.64	3.50	DL	49.87	3.34	4.54	1286.99	
MAC_240_344	1386.06	35.29	DL	0.84	DL	34.96	DL	279.13	0.41	1.73	DL	12.75	0.76	9.77	1853.50	
MAC_240_560	646.96	30.14	DL	19.88	DL	6.26	DL	89.68	DL	10.23	DL	4.02	10.40	11.45	282.98	
MAC_241_265	2928.26	30.44	DL	0.99	DL	23.01	DL	161.69	0.67	3.41	DL	16.09	0.79	5.83	1358.00	
MAC_241_295	707.79	12.45	DL	0.72	DL	15.38	DL	48.47	0.23	2.08	DL	31.71	0.59	4.40	540.39	
MAC_241_333	2154.29	29.13	DL	0.63	DL	28.97	DL	248.13	1.15	2.52	DL	DL	0.44	17.81	1021.27	
MAC_241_569	262.22	34.06	DL	8.12	DL	8.93	DL	74.15	0.80	13.65	DL	DL	3.33	9.66	115.59	
MAC_244_128	1037.64	46.05	DL	4.72	DL	8.51	DL	86.12	1.23	3.75	DL	14.36	4.12	2.95	490.25	
MAC_244_269	1533.66	29.18	DL	1.18	DL	27.26	DL	216.13	0.85	1.99	DL	13.22	0.83	3.31	1234.49	
MAC_244_464	156.16	9.95	DL	1.36	DL	4.09	DL	DL	DL	0.45	DL	DL	0.88	13.87	80.58	
MAC_244_569	361.77	25.78	DL	14.10	DL	13.25	DL	76.08	0.49	10.62	DL	DL	7.26	7.94	209.39	
MAC_244_581	193.53	5.60	0.28	7.41	DL	26.37	DL	37.32	DL	17.59	DL	DL	5.02	5.91	131.00	
MAC_244_603	196.28	6.14	0.48	5.39	DL	42.07	DL	98.33	DL	14.80	DL	DL	3.15	4.52	105.94	
MAC_246_209	1097.78	47.45	DL	25.89	DL	5.86	DL	124.55	DL	3.09	DL	DL	15.12	4.44	753.20	
MAC_246_300	770.46	16.64	DL	2.83	DL	13.25	DL	68.19	0.47	2.93	DL	8.21	2.61	4.83	641.95	
MAC_246_320	867.04	16.95	DL	1.15	DL	18.50	DL	85.43	0.64	2.91	DL	13.48	1.04	6.60	892.92	
MAC_246_354	983.40	18.74	DL	0.11	DL	42.67	DL	152.73	0.74	3.12	DL	17.57	DL	7.70	351.69	
MAC_246_545	295.29	8.85	DL	0.97	DL	7.28	DL	62.56	0.18	0.92	DL	DL	0.97	6.85	210.63	
MAC_251_252	431.96	13.30	DL	9.91	DL	7.19	DL	2701.83	DL	1.87	DL	DL	5.66	3.73	335.07	
MAC_252_215	590.68	26.33	DL	16.24	DL	6.50	DL	2319.31	DL	1.62	DL	DL	7.76	2.00	388.00	
MAC_255_128	1802.27	72.74	0.92	27.53	DL	23.63	DL	219.95	DL	6.42	DL	2.69	18.52	4.43	1047.30	
MAC_255_220	497.90	9.15	DL	6.60	DL	17.29	DL	75.32	0.32	1.31	DL	DL	4.01	2.73	484.48	
MAC_255_504	950.63	45.54	DL	24.09	DL	2.40	DL	1403.22	0.86	6.55	DL	19.44	14.59	11.96	521.52	
MAC_256_287	5870.52	83.62	DL	2.52	DL	53.38	DL	345.99	1.94	10.09	DL	123.69	2.65	8.89	3601.75	
MAC_256_325	728.05	14.83	DL	0.57	DL	10.73	DL	77.76	0.23	2.11	DL	99.10	0.44	3.04	536.95	

Sample	Tb ppm	Te ppm	Th ppm	Tl ppm	Tm ppm	U ppm
MAC_222_197	1.58	DL	90.74	0.04	0.42	33.92
MAC_222_509	0.76	DL	78.79	0.06	0.34	429.66
MAC_232_339	0.28	DL	41.97	0.08	0.12	18.42
MAC_233_315	DL	DL	1.80	0.10	DL	30.75
MAC_233_612	0.20	DL	14.32	0.06	0.10	1.70
MAC_236_256	0.95	DL	151.44	0.08	0.39	50.89
MAC_236_368	0.07	DL	23.13	0.03	0.02	14.26
MAC_238_199	1.15	DL	286.52	0.03	0.45	46.89
MAC_238_287	0.06	DL	10.26	0.10	DL	25.98
MAC_238_311	0.70	DL	41.41	0.09	0.44	116.52
MAC_238_339	0.10	DL	12.15	0.04	0.03	7.62
MAC_238_523	0.18	DL	36.58	0.10	0.09	342.56
MAC_238_604	0.29	DL	1.55	0.13	0.10	29.64
MAC_240_197	0.21	DL	2.76	0.64	0.10	0.91
MAC_240_267	1.61	DL	108.10	0.06	0.45	47.13
MAC_240_344	0.30	DL	36.19	0.06	0.10	52.77
MAC_240_560	DL	DL	5.12	0.08	DL	29.64
MAC_241_265	0.44	DL	47.66	0.04	0.22	47.27
MAC_241_295	0.09	DL	52.68	0.06	0.05	18.29
MAC_241_333	0.06	DL	20.11	0.06	0.03	16.52
MAC_241_569	0.04	DL	12.77	0.40	DL	72.35
MAC_244_128	0.28	DL	43.36	0.04	0.15	34.13
MAC_244_269	0.46	DL	47.60	0.05	0.20	45.64
MAC_244_464	0.06	DL	8.15	0.06	DL	17.47
MAC_244_569	0.08	DL	3.83	0.02	0.03	12.96
MAC_244_581	0.49	DL	121.94	0.06	0.16	107.32
MAC_244_603	0.45	DL	2.56	0.04	0.16	1.07
MAC_246_209	0.48	DL	11.00	0.15	0.28	3.91
MAC_246_300	1.07	DL	59.81	0.03	0.27	17.31
MAC_246_320	0.31	DL	119.23	0.09	0.18	19.06
MAC_246_354	0.07	DL	46.65	0.11	0.03	24.62
MAC_246_545	DL	DL	1.04	0.11	DL	5.78
MAC_251_252	0.10	DL	1.83	0.01	0.07	2.26
MAC_252_215	0.36	DL	31.88	0.03	0.07	8.39
MAC_255_128	0.48	DL	40.76	0.03	0.12	3.02
MAC_255_220	1.72	DL	199.68	0.06	0.50	72.12
MAC_255_504	0.30	DL	15.95	0.04	0.10	5.60
MAC_256_287	0.65	DL	82.95	0.05	0.18	33.58
MAC_256_325	0.37	DL	70.96	0.09	0.13	119.90