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## **Chemical and Radiochemical Background Concentrations of Geologic Materials Beneath Fermilab**

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### **ABSTRACT**

This document consists of a group of tables containing chemical and radiochemical analytical results of samples of geologic materials at Fermi National Accelerator Laboratory. The results are for materials from ground surface to approximately 375 feet below ground surface. The results are from materials obtained from previously undisturbed areas and represent background values. Material for analyses were taken from boreholes drilled as part of the NuMI ground water monitoring network.

The current methodology in use at Fermilab for estimating radionuclide production in soil or rock and migration in the saturated zone to the regulated ground water, is the Concentration Model. Malensek, et al. (Fermilab-TM-1851), proposed this model in 1993 as a new approach over the previously used Single Resident Well Model (Jonckheere, December 1978). EP Note 8 (Cossairt, December 1994), summarized the principal conclusions and made a specific recommendation to the Fermilab Director concerning the application of the results to the future design of targets and absorbers at Fermilab. Subsequently, clarification and modification of aspects of the model were done (Cossairt et al., EP Note 17) and its application for unique conditions addressed (Grossman et al., Fermilab-TM-2103).

One of the parameters of the Concentration Model is the average star density ( $\langle S \rangle$ ) in the geologic material outside of the targeting enclosure. This value is determined from a Monte Carlo computer program for the simulation of hadronic and electromagnetic cascades. Input to the program can be for generic material or can include specific chemical compositions. Part of the output of this program is tables and contour plots of star density for the composition and geometry of the area. In the determination of shielding and operational design, the composition of the formation outside of the production area may be an important factor when calculating residual dose rates.

The chemical composition of soil outside of a beam enclosure has been made for limited cases along with activation products from soil and rock (Fairman, et al. 1970, Awschalom 1971, Borak et al. 1972, Gollon 1978, Cupps 1998). Chemical analyses of Illinois limestones and dolomites have been compiled to present information regarding the various rock formations for use in evaluating the chemical character of these resources by the Illinois State Geological Survey (1957). This report focuses on the background chemical and radiochemical composition of samples of geologic materials from the ground surface to approximately 375 feet below ground surface<sup>1</sup>. The materials consist of the consolidated bedrock formations that make up the upper bedrock aquifer and the unconsolidated glacial deposits that confine them. Samples of geologic material were taken from cores that were drilled during the initial ground water monitoring network installation for the NuMI project. Radiochemical analysis was performed at the onsite Activation Analysis Laboratory<sup>2</sup> and chemical analysis was performed at an offsite vendor, Actlabs-Skyline, Tucson, AZ<sup>3</sup>. Detailed descriptions of the stratigraphy are documented (Rust 1996, STS 1997 and Earth Tech 1999.) With this information on the background chemical and radiochemical composition of geologic materials, comparisons can be made between dose rates obtained using "standard" geologic material compositions and the actual chemical compositions.

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<sup>1</sup> The last sample was taken from 340.5 feet below ground surface, however the borehole extended to 375 feet with a similar lithology from 340 to the bottom of the core.

<sup>2</sup> Radiochemical analysis was for gammas only. The samples were crushed and transferred to a poly bottle prior to counting. Each sample was then counted for 14,400 seconds at 1.2234 cm on detector Ge(Li)#1. The total gross counts for each sample was measured in the energy range of 20-3050 keV. The background counts were subtracted from the sample counts prior to the activities being calculated. Activities were corrected back to the time of sampling. Water was not driven off of the samples for tritium analysis.

<sup>3</sup> Samples were analyzed at research grade using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Instrumental Neutron Activation Analysis (INAA), and Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) technologies.

## References:

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13. RUST Environment and Infrastructure, "NS1 and NS2 Hydrogeologic Site Characterization and Monitoring Well Installation." December 1996.
14. STS Consultants, Ltd., "Hydrogeological Evaluation Report Neutrino Main Injector (NuMI)." April 1997.

Table of Background Radiochemical Analytical Results for Soil Units

Depth (feet bgs)	Unit/Formation	Soil Type	Radiochemical (pCi/g)				
			<sup>40</sup> K	<sup>7</sup> Be	<sup>22</sup> Na	<sup>54</sup> Mn	<sup>60</sup> Co
4	Yorkville Member, Resedimented Facies	clay	12.8 +/- 2.5	0 +/- 1.15	0 +/- 0.22	0 +/- 0.16	0 +/- 0.23
6	Yorkville Member, Resedimented Facies	clay	16.7 +/- 3.2	0 +/- 1.11	0 +/- 0.22	0 +/- 0.16	0 +/- 0.21
8	Yorkville Member, Resedimented Facies	silt	17.7 +/- 3.4	0 +/- 1.02	0 +/- 0.20	0 +/- 0.15	0 +/- 0.19
10	Yorkville Member, Facies A	clay	14.6 +/- 2.8	0 +/- 1.01	0 +/- 0.21	0 +/- 0.16	0 +/- 0.20
12	Yorkville Member, Facies A	clay	24.7 +/- 4.6	0 +/- 1.08	0 +/- 0.21	0 +/- 0.16	0 +/- 0.20
14	Yorkville Member, Facies A	clay	25.0 +/- 4.6	0 +/- 1.15	0 +/- 0.21	0 +/- 0.16	0 +/- 0.22
16	Yorkville Member, Facies A	clay	21.5 +/- 4.0	0 +/- 1.11	0 +/- 0.21	0 +/- 0.15	0 +/- 0.19
18	Yorkville Member, Facies A	clay	15.9 +/- 3.0	0 +/- 1.06	0 +/- 0.20	0 +/- 0.15	0 +/- 0.20
20	Yorkville Member, Facies A	clay	20.4 +/- 3.7	0 +/- 1.20	0 +/- 0.21	0 +/- 0.14	0 +/- 0.19
22	Yorkville Member, Facies B	silt	17.2 +/- 3.2	0 +/- 1.11	0 +/- 0.19	0 +/- 0.14	0 +/- 0.19
24	Yorkville Member, Facies B	clay	10.2 +/- 2.0	0 +/- 1.01	0 +/- 0.17	0 +/- 0.13	0 +/- 0.18
26	Yorkville Member, Facies B	clay	12.7 +/- 2.4	0 +/- 1.08	0 +/- 0.17	0 +/- 0.14	0 +/- 0.18
28	Yorkville Member, Facies B	clay	15.7 +/- 3.0	0 +/- 1.07	0 +/- 0.19	0 +/- 0.15	0 +/- 0.19
30	Yorkville Member, Facies B	clay	17.9 +/- 3.3	0 +/- 1.06	0 +/- 0.17	0 +/- 0.14	0 +/- 0.18
32	Yorkville Member, Facies B	clay	16.9 +/- 3.2	0 +/- 1.08	0 +/- 0.19	0 +/- 0.15	0 +/- 0.20
34	Yorkville Member, Facies B	clay	24.6 +/- 4.6	0 +/- 1.16	0 +/- 0.21	0 +/- 0.15	0 +/- 0.21
36	Yorkville Member, Facies C	clay	26.4 +/- 4.8	0 +/- 1.25	0 +/- 0.21	0 +/- 0.15	0 +/- 0.20
38	Yorkville Member, Facies C	clay	18.9 +/- 3.5	0 +/- 1.17	0 +/- 0.20	0 +/- 0.15	0 +/- 0.20
40	Yorkville Member, Facies C	clay	7.8 +/- 1.5	0 +/- 1.11	0 +/- 0.19	0 +/- 0.14	0 +/- 0.18
42	Yorkville Member, Facies C	clay	15.1 +/- 2.9	0 +/- 1.09	0 +/- 0.18	0 +/- 0.14	0 +/- 0.18
44	Yorkville Member, Facies C	clay	18.9 +/- 3.5	0 +/- 1.17	0 +/- 0.19	0 +/- 0.14	0 +/- 0.20
46	Yorkville Member, Facies C	clay	16.7 +/- 3.2	0 +/- 1.17	0 +/- 0.19	0 +/- 0.14	0 +/- 0.20
48	Yorkville Member, Facies C	clay	24.3 +/- 4.5	0 +/- 1.23	0 +/- 0.19	0 +/- 0.15	0 +/- 0.21
50	Yorkville Member, Facies C	clay	16.2 +/- 3.0	0 +/- 1.21	0 +/- 0.19	0 +/- 0.16	0 +/- 0.20
52	Batestown Member	silty sand	7.5 +/- 1.4	0 +/- 1.18	0 +/- 0.18	0 +/- 0.14	0 +/- 0.19
54	Batestown Member	silty sand	8.1 +/- 1.6	0 +/- 1.07	0 +/- 0.18	0 +/- 0.14	0 +/- 0.18
56	Batestown Member	sand	7.5 +/- 1.5	0 +/- 1.09	0 +/- 0.16	0 +/- 0.13	0 +/- 0.16
58	Batestown Member	sandy silt	10.4 +/- 2.0	0 +/- 1.12	0 +/- 0.17	0 +/- 0.13	0 +/- 0.17
60	Batestown Member	clay	6.1 +/- 1.3	0 +/- 1.14	0 +/- 0.18	0 +/- 0.13	0 +/- 0.16
61	Batestown Member	clay	11.6 +/- 2.2	0 +/- 1.17	0 +/- 0.18	0 +/- 0.13	0 +/- 0.19
63	Batestown Member	clay	7.5 +/- 1.6	0 +/- 1.34	0 +/- 0.20	0 +/- 0.14	0 +/- 0.20
65	Batestown Member	gravel	5.7 +/- 1.3	0 +/- 1.15	0 +/- 0.17	0 +/- 0.13	0 +/- 0.17

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)

uncertainties are calculated from error values of efficiency, absorption correction and geometry

Table of Background Radiochemical Analytical Results for Rock Units

Depth (feet bgs)	Unit/Formation	Rock Type	Radiochemical (pCi/g)							
			<sup>40</sup> K	<sup>7</sup> Be	<sup>22</sup> Na	<sup>54</sup> Mn	<sup>60</sup> Co	<sup>212</sup> Pb	<sup>214</sup> Pb	<sup>214</sup> Bi
69.0	Silurian/Niagran	Dolomite	4.74 +/- 0.95	0 +/- 2.87	0 +/- 0.14	0 +/- 0.12	0 +/- 0.13	0.17 +/- 0.04	0.26 +/- 0.06	0.21 +/- 0.07
94.5	Silurian/Niagran	Dolomite	10.4 +/- 2.0	0 +/- 2.98	0 +/- 0.15	0 +/- 0.13	0 +/- 0.14	0.36 +/- 0.08	0.23 +/- 0.06	+/-
105.0	Silurian/Niagran	Dolomite	9.46 +/- 1.81	0 +/- 3.02	0 +/- 0.15	0 +/- 0.14	0 +/- 0.13	0.25 +/- 0.06	0.23 +/- 0.07	0.22 +/- 0.07
107.0	Silurian/Niagran	Dolomite	6.53 +/- 1.32	0 +/- 3.17	0 +/- 0.14	0 +/- 0.13	0 +/- 0.13	0.18 +/- 0.05	0.35 +/- 0.07	0.15 +/- 0.05
130.0	Silurian/Alexandrian	Dolomite	2.43 +/- 0.73	0 +/- 2.87	0 +/- 0.13	0 +/- 0.13	0 +/- 0.13	+/-	0.31 +/- 0.07	0.12 +/- 0.06
138.0	Silurian/Alexandrian	Dolomite	3.02 +/- 0.66	0 +/- 2.84	0 +/- 0.12	0 +/- 0.12	0 +/- 0.13	+/-	0.43 +/- 0.08	0.24 +/- 0.07
150.0	Silurian/Alexandrian	Dolomite	32.5 +/- 6.0	0 +/- 4.23	0 +/- 0.21	0 +/- 0.20	0 +/- 0.22	1.66 +/- 0.32	1.76 +/- 0.24	1.54 +/- 0.26
160.5	Silurian/Alexandrian	Dolomite	1.08 +/- 0.34	0 +/- 2.95	0 +/- 0.13	0 +/- 0.13	0 +/- 0.13	+/-	0.58 +/- 0.11	0.51 +/- 0.11
162.0	Silurian/Alexandrian	Dolomite	1.49 +/- 0.4	0 +/- 3.28	0 +/- 0.14	0 +/- 0.14	0 +/- 0.14	+/-	0.43 +/- 0.08	0.34 +/- 0.08
180.5	Silurian/Alexandrian	Dolomite	2.98 +/- 0.83	0 +/- 3.32	0 +/- 0.15	0 +/- 0.14	0 +/- 0.14	0.19 +/- 0.05	0.15 +/- 0.04	0.24 +/- 0.06
194.5	Ordovician/Maquoketa	Dolomite	1.3 +/- 0.59	0 +/- 2.93	0 +/- 0.12	0 +/- 0.12	0 +/- 0.12	+/-	0.23 +/- 0.05	+/-
208.5	Ordovician/Maquoketa	Dolomite/Shale	12.4 +/- 2.3	0 +/- 3.35	0 +/- 0.14	0 +/- 0.13	0 +/- 0.13	0.39 +/- 0.08	0.23 +/- 0.06	0.28 +/- 0.06
268.5	Ordovician/Maquoketa	Siltstone	6.26 +/- 1.24	0 +/- 3.58	0 +/- 0.15	0 +/- 0.14	0 +/- 0.15	0.13 +/- 0.04	+/-	0.24 +/- 0.06
340.5	Ordovician/Galena	Dolomite	2.51 +/- 0.82	0 +/- 3.31	0 +/- 0.15	0 +/- 0.13	0 +/- 0.13	+/-	0.13 +/- 0.05	0.18 +/- 0.05

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)

uncertainties are calculated from error values of efficiency, absorption correction and geometry

Table of Background Trace Elements from Soil and Rock Samples using Fusion Inductively Coupled Plasma Mass

Depth (feet bgs)	Unit/Formation	Material Type	Ga ppm	Ge ppm	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	Mo ppm	In ppm
7 - 11	Quaternary	Diamicton	-1	-0.5	13	70	6.7	40	2.1	-2	-0.1
11 - 14	Quaternary	Diamicton	-1	-0.5	29	82	8.9	40	4	-2	-0.1
28 - 35	Quaternary	Resedimented	2	-0.5	32	86	8.9	39	4.7	-2	-0.1
39 - 42	Quaternary	Diamicton	1	-0.5	25	104	10.4	34	3.9	-2	-0.1
42 - 53	Quaternary	Diamicton	-1	-0.5	5	89	4.1	19	1	-2	-0.1
54 - 58	Quaternary	Diamicton	-1	-0.5	15	99	6.5	26	2.6	-2	-0.1
58 - 65	Quaternary	Diamicton	18	1.7	162	112	22.5	236	21.4	-2	-0.1
69.0	Silurian/Niagran	Dolomite	-1	-0.5	-2	76	6.3	16	0.7	-2	-0.1
94.5	Silurian/Niagran	Dolomite	-1	-0.5	4	68	6.1	15	1	-2	-0.1
105.0	Silurian/Niagran	Dolomite	-1	-0.5	11	64	7	20	1.7	-2	-0.1
107.0	Silurian/Niagran	Dolomite	-1	-0.5	3	50	8.6	15	0.6	-2	-0.1
130.0	Silurian/Alexandrian	Dolomite	-1	-0.5	47	88	12.8	54	5.7	-2	-0.1
138.0	Silurian/Alexandrian	Dolomite	-1	-0.5	53	89	12.8	62	5.8	-2	-0.1
150.0	Silurian/Alexandrian	Dolomite	-1	-0.5	4	55	7.2	12	0.8	-2	-0.1
160.5	Silurian/Alexandrian	Dolomite	4	1	88	82	20.3	115	9.5	5	-0.1
162.0	Silurian/Alexandrian	Dolomite	6	0.9	86	89	19	133	9.4	4	-0.1
180.5	Silurian/Alexandrian	Dolomite	9	1	106	95	20.5	114	11.5	5	-0.1
194.5	Ordovician/Maquoketa	Dolomite	5	0.6	68	95	15.1	107	6.8	3	-0.1
208.5	Ordovician/Maquoketa	Dolomite/Shale	10	1	125	121	21	130	11.3	5	-0.1
268.5	Ordovician/Maquoketa	Siltstone	-1	0.7	36	103	12.9	96	4.2	-2	-0.1
340.5	Ordovician/Galena	Dolomite	-1	-0.5	35	106	12.4	115	5.2	-2	-0.1

Negative values equal not detected at that lower limit.

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)

Table of Background Trace Elements from Soil and Rock Samples using Fusion Inductively Coupled Plasma Mass Spectroscopy

Depth (feet bgs)	Unit/Formation	Material Type	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
			ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
7 - 11	Quaternary	Diamicton	8.79	10	1.61	6.15	1.07	0.248	1.09	0.16	0.94	0.2	0.56	0.077
11 - 14	Quaternary	Diamicton	15	22.9	2.63	9.65	1.68	0.357	1.5	0.24	1.36	0.28	0.81	0.111
28 - 35	Quaternary	Resedimented	13.6	17.8	2.36	8.63	1.62	0.334	1.42	0.21	1.23	0.26	0.76	0.108
39 - 42	Quaternary	Diamicton	18.4	21	2.76	10.1	1.77	0.372	1.73	0.26	1.43	0.29	0.81	0.11
42 - 53	Quaternary	Diamicton	6.62	8	1.08	4.21	0.72	0.172	0.7	0.11	0.59	0.13	0.34	0.045
54 - 58	Quaternary	Diamicton	9.18	12.6	1.57	6.14	1.03	0.223	0.97	0.17	0.9	0.19	0.54	0.075
58 - 65	Quaternary	Diamicton	49.2	78.3	8.7	30.3	4.44	0.869	3.46	0.54	3.37	0.74	2.46	0.379
69.0	Silurian/Niagran	Dolomite	3.18	5.6	0.66	2.9	0.7	0.178	0.78	0.14	0.79	0.15	0.43	0.056
94.5	Silurian/Niagran	Dolomite	3.7	6.6	0.79	3.11	0.76	0.178	0.88	0.14	0.82	0.16	0.45	0.062
105.0	Silurian/Niagran	Dolomite	6.1	11.2	1.33	5.43	1.17	0.249	1.13	0.19	1	0.2	0.55	0.074
107.0	Silurian/Niagran	Dolomite	5.41	9	1.29	5.28	1.11	0.252	1.29	0.18	1.05	0.23	0.64	0.09
130.0	Silurian/Alexandrian	Dolomite	15	25.6	3.11	12.2	2.4	0.518	2.11	0.36	1.98	0.42	1.27	0.178
138.0	Silurian/Alexandrian	Dolomite	15.2	25.5	3.11	12.3	2.29	0.505	2.16	0.34	2	0.41	1.22	0.184
150.0	Silurian/Alexandrian	Dolomite	5.73	6.3	0.84	3.51	0.67	0.151	0.74	0.13	0.8	0.17	0.51	0.074
160.5	Silurian/Alexandrian	Dolomite	26.6	52.5	5.85	21.9	4.1	0.913	3.92	0.63	3.63	0.73	2.06	0.303
162.0	Silurian/Alexandrian	Dolomite	22.9	45.1	5.01	19.1	3.72	0.801	3.17	0.54	3.1	0.66	1.97	0.274
180.5	Silurian/Alexandrian	Dolomite	27.2	54.4	6.05	22.6	4.25	0.898	3.84	0.62	3.65	0.73	2.1	0.306
194.5	Ordovician/Maquoketa	Dolomite	18.1	35.3	4.03	15.6	2.98	0.691	2.71	0.45	2.5	0.53	1.55	0.223
208.5	Ordovician/Maquoketa	Dolomite/Shale	29.1	57.2	6.24	23.3	4.22	0.948	3.73	0.62	3.49	0.74	2.16	0.32
268.5	Ordovician/Maquoketa	Siltstone	12	23	2.86	11.5	2.39	0.603	2.29	0.41	2.13	0.45	1.31	0.184
340.5	Ordovician/Galena	Dolomite	14.2	26.3	3.17	12.1	2.26	0.564	2.19	0.36	2.08	0.42	1.27	0.18

Negative values equal not detected at that lower limit.

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)



Table of Background Trace Elements from Soil and Rock Samples using Fusion Inductively Coupled Plasma Mass Spectroscopy

Depth (feet bgs)	Unit/Formation	Material Type	Yb	Lu	Hf	Ta	W	Tl	Bi	Th	U
			ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
7 - 11	Quaternary	Diamicton	0.46	0.071	0.7	-0.1	0.3	-0.05	-0.06	1.19	0.24
11 - 14	Quaternary	Diamicton	0.7	0.116	1	0.2	1.1	0.11	-0.06	3.21	0.34
28 - 35	Quaternary	Resedimented	0.65	0.103	1	0.3	0.9	0.21	-0.06	3.77	0.41
39 - 42	Quaternary	Diamicton	0.69	0.099	0.8	0.2	0.9	0.11	-0.06	3.64	0.34
42 - 53	Quaternary	Diamicton	0.24	0.034	0.4	-0.1	-0.2	-0.05	-0.06	0.7	0.43
54 - 58	Quaternary	Diamicton	0.45	0.072	0.6	0.1	0.3	-0.05	-0.06	1.34	0.65
58 - 65	Quaternary	Diamicton	2.6	0.413	6.5	1.4	3.2	0.55	0.19	10.7	5.83
69.0	Silurian/Niagran	Dolomite	0.35	0.046	0.2	-0.1	-0.2	-0.05	-0.06	0.56	1.1
94.5	Silurian/Niagran	Dolomite	0.36	0.055	0.3	-0.1	0.2	-0.05	-0.06	0.73	0.99
105.0	Silurian/Niagran	Dolomite	0.46	0.073	0.5	-0.1	0.2	-0.05	-0.06	1.19	0.51
107.0	Silurian/Niagran	Dolomite	0.5	0.071	0.3	-0.1	-0.2	-0.05	-0.06	0.48	0.42
130.0	Silurian/Alexandrian	Dolomite	1.11	0.17	1.5	0.4	0.7	0.11	-0.06	3.4	0.74
138.0	Silurian/Alexandrian	Dolomite	1.17	0.169	1.6	0.4	0.8	0.16	-0.06	3.4	0.75
150.0	Silurian/Alexandrian	Dolomite	0.4	0.054	0.3	-0.1	0.2	-0.05	-0.06	0.48	0.51
160.5	Silurian/Alexandrian	Dolomite	2.01	0.302	3.5	0.7	1.6	0.25	-0.06	6.82	3.24
162.0	Silurian/Alexandrian	Dolomite	1.76	0.27	3.5	0.6	1.7	0.66	-0.06	5.89	3.29
180.5	Silurian/Alexandrian	Dolomite	2.05	0.307	3.2	0.8	2	0.35	-0.06	7.65	3.85
194.5	Ordovician/Maquoketa	Dolomite	1.38	0.222	2.8	0.5	1.3	0.37	-0.06	4.7	2.71
208.5	Ordovician/Maquoketa	Dolomite/Shale	2.07	0.309	3.7	0.8	1.9	0.29	-0.06	7.96	4.64
268.5	Ordovician/Maquoketa	Siltstone	1.17	0.172	2.5	0.3	1.3	0.26	-0.06	2.6	1.04
340.5	Ordovician/Galena	Dolomite	1.17	0.179	3	0.3	0.7	0.2	-0.06	3.17	1.16

Negative values equal not detected at that lower limit.

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)

Table of Background Chemicals from Soil and Rock Samples using Instrumental Neutron Activation Analysis

Depth (feet bgs)	Unit/Formation	Material Type	Au ppb	As ppm	Br ppm	Co ppm	Cr ppm	Hg ppm	Ir ppb	Mo ppm	Sb ppm	Sc ppm	Se ppm	Mass g
7 - 11	Quaternary	Diamicton	<2	10	2.9	13.1	58.7	<1	<2	7	0.8	10.4	<0.5	1.637
11 - 14	Quaternary	Diamicton	<2	9	3.6	12.8	52.1	<1	<2	7	0.7	9.44	<0.5	1.433
28 - 35	Quaternary	Resedimented	<2	9	2.2	16.7	74.1	<1	<2	7	0.9	12.8	<0.5	1.285
39 - 42	Quaternary	Diamicton	<2	9	4.2	9.6	43.6	<1	<2	4	0.5	7.68	<0.5	1.44
42 - 53	Quaternary	Diamicton	<2	9	2.1	16.1	76.7	<1	<2	10	0.7	12.9	<0.5	1.317
54 - 58	Quaternary	Diamicton	<2	5	6.1	9.6	41.4	<1	<2	<2	0.3	7.35	<0.5	1.853
58 - 65	Quaternary	Diamicton	<2	5	7.1	5.4	26.3	<1	<2	<2	0.3	4.29	<0.5	1.736
69.0	Silurian/Niagran	Dolomite	2	<1	20.4	1.6	45.8	<1	<2	<2	<0.1	1.72	<0.5	1.497
94.5	Silurian/Niagran	Dolomite	<2	2	16.1	6.6	11.4	<1	<2	<2	0.4	3.5	<0.5	1.623
105.0	Silurian/Niagran	Dolomite	2	1	20.5	2.4	12.3	<1	<2	<2	1	4.38	<0.5	1.691
107.0	Silurian/Niagran	Dolomite	3	1	26.4	2.1	9.4	<1	<2	<2	0.3	4.43	<0.5	1.594
130.0	Silurian/Alexandrian	Dolomite	<2	<1	30.2	1.7	3.2	<1	<2	<2	<0.1	0.81	<0.5	1.509
138.0	Silurian/Alexandrian	Dolomite	<2	<1	19.1	2	9.3	<1	<2	<2	<0.1	1.53	<0.5	1.778
150.0	Silurian/Alexandrian	Dolomite	<2	4	1.5	4.4	85.8	<1	<2	<2	0.7	13.1	<0.5	1.893
160.5	Silurian/Alexandrian	Dolomite	<2	2	7.1	1.9	4.5	<1	<2	2	0.2	1	<0.5	1.712
162.0	Silurian/Alexandrian	Dolomite	2	1	6.8	1.9	4.8	<1	<2	<2	0.2	0.79	<0.5	1.762
180.5	Silurian/Alexandrian	Dolomite	<2	<1	3	0.9	9.8	<1	<2	<2	<0.1	1.33	<0.5	1.88
194.5	Ordovician/Maquoketa	Dolomite	<2	1	4.2	3.7	2.8	<1	<2	<2	<0.1	0.76	<0.5	1.775
208.5	Ordovician/Maquoketa	Dolomite/Shale	<2	<1	2.8	2.9	22	<1	<2	<2	0.2	4.95	<0.5	1.694
268.5	Ordovician/Maquoketa	Siltstone	<2	1	1.2	2.5	10.2	<1	<2	<2	<0.1	2.3	<0.5	1.755
340.5	Ordovician/Galena	Dolomite	<2	5	1.6	1	4.8	<1	<2	<2	0.1	0.73	<0.5	1.694

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)

Table of Background Chemicals from Soil and Rock Samples using Total Digestion Inductively Coupled Plasma

Depth (feet bgs)	Unit/Formation	Material Type	Sr ppm	Be ppm	V ppm	Cu ppm	Pb ppm	Zn ppm	Ag ppm	Ni ppm	Cd ppm	Bi ppm
7 - 11	Quaternary	Diamicton	92	2	83	21	17	49	<0.4	40	<0.5	<5
11 - 14	Quaternary	Diamicton	96	1	71	19	16	52	<0.4	29	<0.5	<5
28 - 35	Quaternary	Resedimented	113	2	98	20	17	56	<0.4	48	<0.5	<5
39 - 42	Quaternary	Diamicton	92	1	56	18	11	42	<0.4	18	<0.5	<5
42 - 53	Quaternary	Diamicton	116	2	99	23	14	56	<0.4	47	0.5	5
54 - 58	Quaternary	Diamicton	99	<1	50	22	7	45	0.6	29	0.7	<5
58 - 65	Quaternary	Diamicton	110	<1	27	12	7	22	<0.4	18	<0.5	<5
69.0	Silurian/Niagran	Dolomite	83	<1	8	3	<5	12	<0.4	3	<0.5	<5
94.5	Silurian/Niagran	Dolomite	90	<1	12	5	6	10	<0.4	7	<0.5	<5
105.0	Silurian/Niagran	Dolomite	89	<1	12	6	<5	162	<0.4	10	<0.5	<5
107.0	Silurian/Niagran	Dolomite	109	<1	15	4	<5	10	<0.4	10	<0.5	<5
130.0	Silurian/Alexandrian	Dolomite	95	<1	<5	3	<5	9	<0.4	2	<0.5	<5
138.0	Silurian/Alexandrian	Dolomite	99	<1	8	2	<5	11	<0.4	8	<0.5	<5
150.0	Silurian/Alexandrian	Dolomite	121	2	109	21	8	13	<0.4	29	<0.5	<5
160.5	Silurian/Alexandrian	Dolomite	73	<1	9	4	<5	9	<0.4	7	<0.5	<5
162.0	Silurian/Alexandrian	Dolomite	70	<1	16	6	<5	15	<0.4	11	<0.5	<5
180.5	Silurian/Alexandrian	Dolomite	69	<1	8	4	<5	9	<0.4	7	<0.5	<5
194.5	Ordovician/Maquoketa	Dolomite	52	<1	<5	6	<5	10	<0.4	2	<0.5	<5
208.5	Ordovician/Maquoketa	Dolomite/Shale	92	<1	28	5	<5	14	<0.4	14	<0.5	<5
268.5	Ordovician/Maquoketa	Siltstone	88	<1	14	10	<5	14	<0.4	4	<0.5	<5
340.5	Ordovician/Galena	Dolomite	57	<1	7	8	<5	17	<0.4	2	<0.5	<5

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)

Table of Background Major Elements from Soil and Rock Samples using Fusion ICP

Depth (feet bgs)	Unit/Formation	Material Type	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	LOI*	TOTAL
			%	%	%	%	%	%	%	%	%	%	%	%
7 - 11	Quaternary	Diamicton	45.29	10.59	4.24	0.054	7.11	10.97	0.52	3.40	0.576	0.06	18.13	100.94
11 - 14	Quaternary	Diamicton	41.80	9.08	3.66	0.061	8.39	12.82	0.50	2.99	0.501	0.06	20.07	99.93
28 - 35	Quaternary	Resedimented	47.54	12.55	4.77	0.062	5.84	8.68	0.49	3.92	0.652	0.06	15.59	100.15
39 - 42	Quaternary	Diamicton	39.46	7.01	3.05	0.053	9.32	14.69	0.46	2.25	0.364	0.09	21.68	98.43
42 - 53	Quaternary	Diamicton	44.01	12.33	4.33	0.055	6.81	9.52	0.42	3.58	0.575	0.09	16.93	98.65
54 - 58	Quaternary	Diamicton	40.66	5.14	3.58	0.083	10.46	16.30	0.65	1.37	0.274	0.09	20.16	98.77
58 - 65	Quaternary	Diamicton	35.50	4.51	1.77	0.041	11.53	17.59	0.53	1.55	0.276	0.09	25.42	98.81
69.0	Silurian/Niagran	Dolomite	8.18	1.38	0.50	0.018	19.29	26.86	0.07	0.76	0.073	0.03	42.28	99.44
94.5	Silurian/Niagran	Dolomite	15.69	3.06	0.98	0.043	16.61	23.47	0.06	1.54	0.159	0.04	37.19	98.84
105.0	Silurian/Niagran	Dolomite	13.26	3.18	0.98	0.028	16.92	23.67	0.07	1.80	0.172	0.02	38.41	98.51
107.0	Silurian/Niagran	Dolomite	11.63	2.85	0.95	0.028	17.55	24.69	0.07	1.51	0.144	0.02	39.19	98.63
130.0	Silurian/Alexandrian	Dolomite	2.09	0.50	0.49	0.039	20.66	29.13	0.05	0.27	0.024	0.10	45.96	99.31
138.0	Silurian/Alexandrian	Dolomite	5.46	1.33	0.63	0.035	20.11	28.55	0.05	0.59	0.082	<0.01	41.64	98.48
150.0	Silurian/Alexandrian	Dolomite	63.82	18.36	2.05	0.007	1.92	0.72	0.14	5.07	0.923	0.07	6.98	100.06
160.5	Silurian/Alexandrian	Dolomite	3.04	0.26	0.58	0.018	20.94	29.30	0.06	0.07	0.012	0.01	44.80	99.09
162.0	Silurian/Alexandrian	Dolomite	3.41	0.47	1.48	0.022	20.85	29.17	0.06	0.16	0.029	0.01	43.03	98.69
180.5	Silurian/Alexandrian	Dolomite	5.84	1.27	0.73	0.043	19.53	27.62	0.05	0.51	0.066	0.05	43.09	98.80
194.5	Ordovician/Maquoketa	Dolomite	1.70	0.35	1.21	0.109	19.96	29.41	0.06	0.10	0.016	0.28	45.25	98.45
208.5	Ordovician/Maquoketa	Dolomite/Shale	23.96	4.75	1.42	0.031	14.03	20.33	0.10	1.86	0.242	0.32	31.81	98.85
268.5	Ordovician/Maquoketa	Siltstone	18.31	2.14	1.75	0.049	16.36	23.73	0.07	0.78	0.104	0.14	34.35	97.78
340.5	Ordovician/Galena	Dolomite	1.79	0.49	1.06	0.056	20.97	29.30	0.06	0.23	0.029	0.06	44.43	98.48

\* Lost on Ignition (LOI) is a measure of the CO<sub>2</sub> and moisture content. This is usually high in MgO and CaO deposits.

bgs = below ground surface (ground surface is approximately 740 feet Mean Sea Level)