Geochemical Analysis of Speleothems in Bristol Caverns using XRF.

Couch, Clay, ETSU, Couchc1@etsu.edu

Abstract

The study of chromophores in speleothems is often conducted to identify paleoclimatic indicators or trace contaminants in watersheds. The geochemical analysis of speleothems has been done using mass spectrometry and XRF, as seen in papers by Turner (2002) and Vlieghe et al., (2026). Photographic methods in the existing literature remain inconsistent. This study aims to establish a framework for a photographic method to study speleothem chromophores using a color card, consistent lighting, along with marking the XRF test location on a sample's photograph. The samples for this study were obtained from Bristol Caverns, TN, a cave found in the Knox Group stratigraphic unit. This location was used because it was easily accessible and contains speleothems of unique coloration. The results of 136 XRF measurements taken from 47 speleothems show a correlation between speleothems with over ~3,5000 PPM iron content and an orange to red coloration, with several samples of similar color being less than 1,000 PPM iron content, implying the presence of another chromophore that is non-metallic. The small amount of data regarding magnesium hints at a connection between magnesium and sections of darker color.

Introduction

The cause of coloration in speleothems has been attributed to many different variables such as metal ions like nickel, zinc or lead causing greens and blues (Vlieghe et al., 2023; Vlieghe et al., 2025), sediment buildup causing browns, anthropogenic influence causing black (Hill and Forti, 1997; Jeong et al., 2003), and organic substances such as humic and fulvic acids (Hill and Forti, 1997; White et al., 2019).

As part of the examination of chromophores, a myriad of testing methods have been tried: pXRF (Finné et al., 2015) looking at different elements heaver that magnesium that may influence coloration, electron scanning microscopes and optical microscopy (Beck, 1978), both of which examined crystal size as a factor of color, and mass spectrometry looking at the amount of lighter elements such as sulfur as a cause of color.

When discussing color, it is important to have a standard way to describe it; this can be problematic if no photos were taken, as “green” has a wide variety of shades and tones. Using the Munsell soil chart is an ideal way to fix this, but it will not work for many of the more dramatically colored formations. Another problem can arise when photographs are taken, but the light and camera used are not named, as some LEDs are known to tend towards green or red tints and will change the color of the photos taken. Certain cameras tend towards warm or cold photos, further complicating color fidelity. A solution to this is to include a standard color checker card.

The objective of this paper is to explore the possible link between metallic ions and coloration and to establish a standard method for color photography in the study of speleothem chromophores.

Geologic setting

Bristol Caverns formed within the Knox Group Carbonates in northeastern Tennessee. The cave has formed along vertical bedding planes (as it is situated between an anticline and a syncline) and so has a high number of speleothems. The water responsible for formation growth in Bristol Caverns is meteoric in origin, and no stratigraphic units overlay the cave.

Methods:

Sample Collection

Broken speleothems were taken from Bristol Caverns undeveloped sections, put into new plastic bags to prevent any contamination, and given a number. Samples were collected based on size (must fit in a medium sandwich bag). A variety of speleothems from a wide area were collected through the cave in an attempt to prevent any collection bias from occurring.

Sample Preparation

All collected speleothems were cut on a brick saw, then sanded using distilled water to remove saw marks so as to not introduce any contamination from the blade. All samples were then scrubbed with distilled water and a new plastic brush to remove any residue from the cutting process and any soil material.

Testing

Samples were tested multiple times in different areas of color using a Vanta Olympus Max pXRF device, then all samples were tested under 365nm and 310nm UV light.

Photography

While testing with the pXRF was happening, photographs of all samples were taken with a Nikon D40 DSLR (2008) with a PHOTOOLEX Camera Flash Speedlite FK300, GN33. Included in all photographs is a Calibrite ColorChecker Passport 2 to allow for color correction of all photos.

After all photos were taken, they were transferred to a laptop and color corrected to be a neutral light and as close to CIR 100 as possible in Darktable, after which the locations of the pXRF tests were marked with photo editing software (Krita).

Results and Discussion.

There are limitations to the pXRF method of sampling. This device cannot detect Hydrogen, Helium, Lithium, Beryllium, Boron, Carbon, Nitrogen, Oxygen, Fluorine, Neon, Sodium, or Technetium, this is not a major concern, as the most likely

chromophores are not H, He, Li, Be, B, C, N, O, F, Ne, Na, or Tc (Lemière, 2018). Magnesium is sometimes detectable; however, it is not consistent with the pXRF device used. Of the 139 measurements taken, only 37 registered on the pXRF as having magnesium.

While the limitations of the pXRF device may make it unsuitable for detecting Fulvic and Humic substances, Fulvic acid is known to fluoresce in speleothems (Beynen et al., 2001). Because of this, 365/310nm UV light can be used to detect the presence of Fulvic acid. All speleothems glowed a green-blue color none showed yellow, implying lower concentrations of humic acid (White et al., 2019)

The data show a correlation between iron content over ~3,500 PPM and an orange-to-red color in speleothems; however, similar color can be found in speleothems with less than 1,000 PPM iron content. While iron may be related to these colors, it is likely not the only contributing chromophore.

The majority of the samples that have a measured magnesium content show sections of darkened or gray color, while the remaining samples show no variation from other measurements taken on the same speleothems, such as samples G12, RW12, RW3, RW6, and RW7. The limited sample size of speleothems with magnesium makes it impossible to draw any conclusion, but it hints at a trend of magnesium darkening existing colors.

Conclusion.

The color photography of speleothems is made more accurate when a color card of some kind is added. The camera and light source used should be listed to allow for color correction of any photos used, even if they are compressed or rendered improperly as a result of corruption or compressed data transfer. As long as the color card is present in any photographs used, color can be made consistent between all photos and color accuracy can be assured.

From the data gathered in this study, there is a trend with the presence of iron in concentrations above ~3,500 PPM and orange-to-red colors in speleothems; however, there are some outliers to this with orange or red samples that have less than 1,000 PPM iron content. Magnesium, while not always detected, appears to cause a darkening of other chromophores; however, the sample size for magnesium is small enough that it is not conclusive. While metal may influence coloration in speleothems, it is likely not the main component.

Future Work:

The planned future tests for the samples of this study are to first use optical microscopy to look at crystal size in relation to color, as seen in fried egg stalagmites (Beck, 1978). If the crystals are too small or similar in size to be noted with a reflected light microscope, then thin sections will be made and a petrographic microscope used. Other testing methods, should microscopy not yield any correlations, will be IR testing looking for organic compounds, then XRD to get a more accurate measurement of magnesium, and mass spectrometry last, as they require destruction of samples.

Along with the testing of the speleothems from this study, more data points will be collected from Worley's Cave and Appalachian Caverns to undergo the same testing, thereby increasing sample size for more accurate results.

Table 1.

Sample Name	Mg	Al	P	S	Ti	V	Cr	Mn	Fe	Sr	Ag
G1-AC	0	2055	0	0	1045	125	0	0	438	78	145
G1-AC-T2	0	1206	0	0	331	0	53	0	100	89	142
G1-AC-T3	0	0	0	0	322	50	0	168	59	110	246
G1-AC-T4	0	0	0	3475	477	123	0	146	3645	121	131
G2-AC	14378	3778	0	0	432	88	0	87	125	103	189
G2-AC-T2	0	2373	0	0	1975	0	0	59	3515	57	170
G3-AC	0	1654	0	0	0	0	0	0	2470	109	112
G3-AC-T2	0	5242	1218	0	737	0	237	159	4392	92	148
G4-AC	0	0	307	620	0	65	0	0	72	243	114
G4-AC-T2	0	3808	0	0	0	0	0	0	88	223	172
G4-AC-T3	0	2036	0	0	0	54	95	0	114	163	161
G4-AC-T4	0	0	0	0	545	0	0	156	164	227	148
G5-AC	0	0	0	501	0	0	0	0	87	112	169
G5-AC-T2	0	0	0	0	544	132	117	0	170	100	200
G5-AC-T3	0	0	0	0	0	0	0	199	566	94	158
G5-AC-T4	0	0	634	1292	663	0	0	0	491	124	109
G6-GS	0	2821	0	0	519	147	0	160	869	63	188
G6-GS-T2	0	994	0	0	357	81	0	0	396	46	159
G7-GS-Only	0	11294	588	117	2174	0	150	292	4638	115	212
G8-GS	0	0	0	0	682	0	0	51	142	54	208
G8-GS-T2	0	1261	0	0	0	0	0	0	511	74	189
G8-GS-T3	0	0	0	0	0	0	0	53	183	67	158
G8-GS-T4	0	0	0	420	570	60	0	101	423	75	251
G8-GS-T5	21788	2696	0	0	579	47	65	138	226	77	173
G9-BR	0	1988	0	179	773	0	207	60	63	231	95
G9-BR-T2	0	1196	0	0	0	0	155	0	245	161	198
G9-BR-T3	0	0	0	0	831	106	95	0	28	164	225
G10-BR	0	1783	0	0	609	0	0	0	182	118	167
G10-BR-T2	0	0	0	0	403	90	0	74	244	129	238
G10-BR-T3	24104	0	0	0	0	0	85	0	133	90	170
G10-BR-T4	19204	0	0	0	0	79	0	0	92	70	89
G10-BR-T5	0	0	0	0	0	0	0	0	140	75	128
G11-BR	31377	7719	340	344	1994	55	487	1242	11502	238	133
G11-BR-T2	0	1936	0	0	606	0	158	0	4143	83	177
G11-BR-T3	0	0	0	0	423	0	0	126	374	103	184
G11-BR-T4	0	0	0	0	0	124	0	0	61	49	165
G11-BR-T5	0	0	0	965	947	0	0	168	354	165	204
G12-BR	0	0	0	904	0	134	0	68	46	74	128
G12-BR-T2	11353	3255	0	0	0	0	190	0	77	63	170
G13-BR	0	6358	13014	656	0	0	456	432	9789	403	149
G13-BR-T2	0	0	6283	594	1560	98	432	161	8423	345	115
G14-BR	18437	3859	284	0	551	0	0	0	2792	69	137
G14-BR-T2	31156	2537	633	402	0	58	0	89	1041	61	218
G14-BR-T3	0	0	0	0	510	0	143	43	1478	73	170
G14-BR-T4	14076	1097	1734	0	721	67	0	0	702	46	140
G14-BR-T5	19912	0	339	0	0	70	0	85	565	68	260
G15-BR	0	3289	165	0	332	0	168	0	362	86	126
G15-BR-T2	12046	0	0	116	1442	0	0	0	169	186	166
G15-BR-T3	0	1274	462	0	1008	0	226	0	253	49	187
G16-BR	0	0	251	0	443	113	0	0	1282	29	144
G16-BR-T2	0	14447	804	0	1851	145	0	146	11996	69	187
G16-BR-T3	0	0	1805	0	0	346	13355	0	29276	188	194
RW1-t1	0	2179	0	0	671	98	0	52	1207	91	148
RW1-t2	0	5203	180	0	505	0	100	0	732	78	143
RW1-t3	26916	1956	0	0	819	48	0	55	4070	65	151
RW1-t4	0	0	0	0	835	0	95	49	1162	69	100
RW2-t1	19858	0	0	0	0	0	0	0	432	46	133
RW2-t2	0	1872	0	0	0	0	0	676	1277	59	104
RW2-t3	0	0	0	0	646	154	91	0	647	72	152
RW2-t4	0	0	0	0	889	59	115	0	539	54	152
RW3-t1	13653	0	0	0	843	67	0	176	732	104	216
RW3-t2	17000	2136	0	0	655	0	0	403	2222	118	144
RW3-t3	0	7490	253	0	876	0	0	922	3479	123	141
RW4-t1	0	5777	0	0	422	188	0	118	866	58	145
RW4-t2	0	1445	0	0	447	0	93	94	670	77	196
RW5-t1	0	0	0	0	0	55	0	49	411	82	95
RW6-t1	0	0	0	0	1006	0	0	43	478	106	120
RW6-t2	10657	6010	0	0	1376	49	101	0	1551	176	204
RW7-t1	0	7114	0	0	1200	140	0	376	11662	71	82
RW7-t2	18363	11533	0	0	4053	0	103	267	13245	112	120
RW8-t1	0	0	0	0	583	0	326	0	125	40	30
RW9-t1	0	16460	0	0	2138	67	0	196	6163	139	107
RW9-t2	0	9855	189	0	1342	120	86	100	5533	144	117

RW10-t1	0	27148	416	549	2235	0	140	406	9328	180	131
RW10-t2	0	19983	896	99	2023	85	64	278	4395	158	98
RW11-t1	0	0	0	0	2024	0	395	152	3474	49	54
RW11-t2	0	0	2175	0	0	0	0	0	667	42	25
RW11-t3	0	0	0	0	0	0	102	0	0	37	59
RW11-t4	10139	0	1024	0	1092	77	133	133	2066	56	108
RW12-t1/R	0	5387	1595	0	436	0	0	375	6021	269	89
RW12-t2	0	2935	1899	0	1132	85	0	349	8610	30	84
RW12-t3	38843	5597	1099	0	2896	76	0	2711	10950	52	0
RC1-t1	0	0	0	0	0	0	232	879	1906	16	66
RC1-t2	0	3565	256	0	867	127	232	148	3982	23	67
RC1-t3	14561	5276	230	0	688	99	63	808	4479	27	106
RC1-t4	0	0	382	0	1812	0	0	330	2507	52	94
RC1-t5	0	0	0	0	591	205	0	448	2514	13	0
RC2-t1	0	3697	0	0	1107	0	0	308	2642	48	125
RC3-t1	0	7898	0	0	616	90	107	69	2045	67	157
RC3-t2	0	0	0	0	816	61	0	0	231	84	131
RC4-t1	0	0	0	0	286	56	0	66	0	65	115
RC4-t2	21231	0	0	0	874	0	0	0	257	72	200
RC4-t3	0	1564	0	0	925	0	178	302	3599	62	123
RC4-t4	0	7438	286	245	2633	0	82	474	8543	64	151
RC5-t1	0	0	426	0	0	0	0	85	715	105	37
RC5-t2	0	0	405	0	0	0	0	106	513	118	66
RC5-t3	0	0	534	0	346	79	0	424	1370	88	94
RC6-t1	0	3642	0	0	0	154	0	86	70	254	206
RC6-t2	9701	0	0	0	0	0	0	0	107	247	170
RC6-t3	0	1382	0	0	680	0	82	0	88	260	198
RC6-t4	0	0	0	0	1107	0	0	0	266	246	121
RC6-t5	19173	0	0	0	0	69	0	99	244	208	190
RC7-t1	14821	16136	10846	0	1269	0	107	91	5710	121	186
RC7-t2	10275	0	0	86	390	52	143	0	378	229	246
RC7-t3	0	1075	0	0	1054	195	0	156	671	139	140
RC7-t4	0	0	0	0	0	0	0	60	200	193	209
RC7-t5	0	0	0	0	529	62	0	0	188	205	215
RC7-t6	0	0	0	0	0	0	0	0	323	99	81
RC7-t7	0	0	313	198	448	109	0	71	601	251	112
RC7-t8	9696	0	0	0	311	0	58	153	115	199	131
RC8-t1	17720	5635	833	0	898	94	0	213	4042	48	168
RC8-t2	32435	0	0	0	511	0	508	209	952	286	176
RC8-t3	14157	6754	511	0	1437	0	0	168	6111	134	150
RC8-t4	13143	0	0	0	237	157	110	0	224	226	223
RC9-t1	0	0	0	0	0	168	0	84	83	197	115
RC9-t2	0	0	0	0	1081	108	220	56	0	154	188
RC9-t3	8712	1121	0	701	0	58	189	57	49	177	111
RC10-t1	0	0	0	1051	751	87	0	0	76	218	168
RC10-t2	0	0	0	0	1338	0	0	64	91	198	207
RC10-t3	0	0	0	0	757	54	127	0	398	113	189
RC10-t4	0	0	0	0	0	51	283	0	59	202	147
RC10-t5	12364	0	0	0	753	0	53	0	86	190	152
RC11-t1	0	0	612	178	0	0	336	0	1507	63	88
RC11-t2	0	0	0	0	0	151	89	0	235	35	192
RC12-t1	9104	0	0	0	323	64	77	0	123	34	139
RC12-t2	0	0	0	0	486	0	0	0	341	37	197
RC12-t3	0	0	0	0	534	0	0	41	118	42	139
RC12-t4	0	6363	143	0	0	93	81	85	1781	48	184
RC12-t5	27998	0	0	0	1451	0	0	138	317	43	144
RC12-SmallSideCut	11173	0	0	0	0	132	102	0	105	34	154
RC13-t1	11986	0	0	0	0	0	0	0	383	58	174
RC13-t2	23236	25597	841	0	4832	0	119	508	15233	60	148
RC14-t1	0	10505	246	0	1317	44	323	170	5086	63	88
RC14-t2	0	9037	470	0	3448	0	147	239	7322	68	80
RC14-t3	0	3745	332	0	1876	0	1047	170	6200	39	57
LoftSoil-t1	0	31710	1327	1344	1953	126	290	1038	15837	179	127
LoftSoil-t2	0	35173	1372	1036	2843	0	178	658	19196	194	64
LoftSoil-t3	0	19709	487	804	1059	54	0	419	15672	65	0
LoftSoil-t4	0	30325	635	377	3282	218	0	604	21032	69	54
AVERAGES	4710.4029	3376.8561	432.18705	124.1223	767.02158	49.2230216	175.402878	162.064748	2729.01439	112.856115	143.338129

Table 2.

Sample Name	Mg	Al	Si	P	S	Cl	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd	Sn	Sb	W	Hg	Pb	Bi	Th	U
RW3-r2	0	3855	55416	183	0	0	248236	1342	120	86	100	5533	0	0	0	25	0	0	3	144	6	116	16	0	117	38	0	0	25	0	0	29	0	0
RW3-r1	0	19460	58310	0	0	0	276125	2138	67	0	136	8163	0	0	0	17	0	4	9	133	0	29	15	0	107	0	0	0	0	8	0	0	0	10
RW8-r1	0	0	429	0	0	0	245547	583	0	326	0	125	0	0	0	0	5	0	0	40	0	117	0	0	30	0	0	0	0	18	0	0	26	0
RW7-r2	18363	11533	188472	0	0	0	407771	4053	0	103	267	13245	0	0	17	40	0	0	25	112	17	171	6	0	120	0	0	0	0	0	9	0	0	0
RW7-r1	0	7114	39088	0	0	0	153591	1200	140	0	376	11682	0	0	0	28	0	2	15	71	3	74	0	0	82	0	0	0	0	0	5	44	0	0
RW6-r2	10657	6010	23425	0	0	0	377794	1376	49	101	0	1551	0	0	26	12	0	4	4	176	0	10	9	9	204	0	0	0	0	11	10	22	0	0
RW6-r1	0	0	3912	0	0	0	334012	1006	0	0	43	478	0	0	18	12	0	0	5	106	3	9	0	21	120	0	0	0	0	0	11	0	18	0
RW5-r1	0	0	7697	0	0	0	335523	0	55	0	49	411	0	0	0	28	10	0	4	82	4	0	13	0	95	0	0	0	0	0	0	0	51	0
RW4-r2	0	1445	6335	0	0	0	345663	447	0	33	34	670	0	0	0	8	0	0	0	77	0	7	0	0	196	55	0	0	0	17	0	0	54	0	10
RW4-r1	0	5777	11474	0	0	0	335385	422	188	0	118	866	0	0	0	8	0	0	0	58	6	8	0	0	145	39	82	0	0	10	8	0	0	0
RW3-r3	0	7490	28967	253	0	0	342478	876	0	0	922	3479	0	0	20	19	9	0	2	123	8	17	5	11	141	0	0	61	22	0	5	0	48	0
RW3-r2	17000	2136	13058	0	0	0	324986	855	0	0	403	2222	0	0	0	5	0	0	0	118	0	6	0	0	144	0	53	34	88	0	0	0	0	0
RW3-r1	13653	0	11822	0	0	0	346236	843	67	0	176	732	0	0	16	19	0	2	8	104	0	0	0	21	216	140	0	0	0	0	13	0	28	20
RW2-r4	0	0	309	0	0	0	338250	689	59	115	0	539	0	0	0	0	19	6	5	54	7	12	0	0	152	0	0	0	0	0	0	0	50	0
RW2-r3	0	0	0	0	0	0	336127	646	154	51	0	647	0	0	21	21	8	0	0	72	0	0	3	0	152	0	0	0	0	0	0	0	0	11
RW2-r2	0	1872	1325	0	0	0	329711	0	0	0	676	1277	0	0	16	0	0	0	0	59	3	0	0	0	104	48	0	0	0	0	0	0	31	0
RW2-r1	19656	0	233	0	0	0	329467	0	0	0	0	432	0	0	0	0	0	0	0	46	0	14	0	0	133	72	0	96	0	13	9	0	0	0
RW1-r4	0	0	2152	0	0	0	285332	835	0	0	95	49	1162	0	0	14	0	0	0	6	69	0	10	0	5	100	36	0	46	50	19	8	21	0
RW1-r3	26916	1356	5876	0	0	0	290393	819	48	0	55	4070	0	0	14	0	0	0	0	3	65	5	0	0	0	151	77	104	0	0	0	0	51	0
RW1-r2	0	5203	2128	180	0	0	357622	505	0	100	0	732	0	0	0	12	0	0	0	76	3	0	7	0	143	30	0	0	0	0	12	0	32	0
RW1-r1	0	2179	1954	0	0	0	362330	1951	98	0	52	1207	0	0	0	25	4	0	5	91	7	5	4	8	148	44	94	57	0	0	9	0	14	6
RW12-r3	38843	5597	30793	1099	0	0	129151	2896	76	0	2711	10950	0	0	33	99	11	0	37	52	0	149	0	10	0	0	0	0	123	0	0	0	0	0
RW12-r2	0	2935	42716	1899	0	0	133279	1132	85	0	349	8610	0	0	0	60	4	0	21	30	8	238	0	15	84	0	102	139	0	0	15	0	0	0
RW12-r1R	0	5387	29865	1595	0	0	283723	436	0	0	375	6021	0	0	0	17	19	0	12	263	10	6	0	0	89	0	56	0	0	18	0	0	40	0
RW11-r4	10139	0	6962	1024	0	0	241747	1082	77	133	133	2066	0	0	0	16	3	4	8	56	0	25	0	9	108	57	74	133	0	0	0	19	17
RW11-r3	0	0	369	0	0	0	216601	0	0	102	0	0	0	0	0	8	8	0	0	37	0	0	0	0	59	41	0	0	13	0	0	0	42	0
RW11-r2	0	0	2665	2175	0	0	220232	0	0	0	0	667	0	0	0	7	0	0	4	42	0	0	6	9	25	0	0	0	0	0	0	19	0	0
RW11-r1	0	0	2238	0	0	0	218613	2024	0	395	152	3474	0	0	17	33	4	0	0	49	0	24	10	0	54	36	142	68	0	0	8	42	0	0
RW10-r2	0	13983	58177	896	99	0	315695	2023	85	64	278	4395	0	0	26	0	6	2	10	158	7	17	0	6	98	0	0	42	0	0	28	0	0	0
RW10-r1	0	27148	72252	416	549	0	280493	2235	0	140	406	5328	0	0	0	36	10	0	13	180	0	20	13	0	131	58	0	63	0	0	0	0	0	0
RC9-r3	8712	1121	0	0	701	0	398834	0	58	189	57	49	0	0	0	23	6	4	0	177	0	0	0	0	111	0	0	0	0	0	0	0	0	0
RC9-r2	0	0	607	0	0	0	301442	1081	108	220	56	0	0	0	17	12	0	0	4	154	0	0	0	0	188	98	0	92	0	0	0	0	0	0
RC9-r1	0	0	715	0	0	0	322011	0	168	0	84	83	0	0	0	10	0	0	0	197	7	0	0	0	115	0	0	37	26	0	0	0	0	7
RC8-r4	13143	0	769	0	0	0	375669	237	157	110	84	224	0	0	0	28	0	0	12	226	0	0	0	6	223	0	0	0	0	0	14	0	34	0
RC8-r3	14157	6754	35574	511	0	0	258652	1437	0	0	168	6111	0	0	0	36	0	0	14	134	12	40	7	0	150	73	0	0	39	0	16	0	0	0
RC8-r2	32435	0	536	0	0	0	303347	511	0	508	209	952	0	0	0	8	0	6	0	286	10	11	13	0	176	0	85	0	0	0	0	0	0	0
RC8-r1	17720	5635	22736	833	0	0	308164	838	94	0	213	4042	0	0	0	0	11	7	12	48	0	17	7	0	168	149	51	0	19	0	0	0	0	0
RC7-r8	9636	0	737	0	0	0	373975	311	0	58	153	115	0	0	27	0	4	0	0	193	8	4	0	0	131	0	0	0	0	30	14	0	0	0
RC7-r7	0	0	3246	313	198	0	363415	448	109	0	71	601	0	0	31	0	0	0	0	251	8	11	9	0	112	44	0	0	43	0	10	0	21	5
RC7-r6	0	0	1676	0	0	0	306383	0	0	0	0	323	0	0	0	0	0	6	18	99	0	0	0	0	81	0	134	0	0	40	11	0	24	0
RC7-r5	0	0	204	0	0	0	368117	528	62	0	0	188	0	0	0	0	6	2	0	205	12	6	0	0	215	25	70	0	30	0	0	0	25	18
RC7-r4	0	0	0	0	0	0	366256	0	0	0	60	200	0	0	0	9	0	0	0	193	0	12	0	15	209	0	0	0	0	0	7	38	0	0
RC7-r3	0	1075	3047	0	0	0	390044	1054	195	0	156	671	0	0	21	20	0	7	3	139	8	5	0	13	140	0	0	0	20	0	8	0	0	0
RC7-r2	10275	0	995	0	86	0	361387	390	52	143	0	378	0	0	21	0	4	0	0	229	7	0	8	11	246	82	117	141	60	18	0	0	18	0
RC7-r1	14821	16136	45892	10846	0	0	278724	1269	0	107	91	5710	0	0	11	20	0	4	17	121	6	11	0	6	186	80	30	55	32	9	26	0	14	0
RC6-r5	19173	0	1945	0	0	0	361172	0	69	0	99	244	0	0	19	16	7	6	0	208	9	0	0	0	190	73	84	69	0	0	0	0	0	0
RC6-r4	0	0	223	0	0	0	353522	1107	0	0	0	266	0	0	21	8	5	0	0	246	0	0	0	0	121	0	0	0	0	0	6	0	15	13
RC6-r3	0	1382	0	0	0	0	353503	680	0	82	0	88	0	0	0	0	0	3	0	260	0	11	0	6	138	107	0	0	23	0	0	0	19	0
RC6-r2	3701	0	0	0	0	0	351539	0	0	0	0	107	0	0	30	24	7	2	6	247	0	0	0	9	170	96	80	0	0	8	0	0	0	0
RC6-r1	0	9942	377	0	0	0	364851	0	154	0	66	701	0	0	0	0	0	0	6	254	0	5	9	5	206	146	0	70	0	16	0	0	0	0

RC5-r3	0	0	4528	534	0	0	216371	346	79	0	424	1370	0	0	0	48	21	9	0	88	0	13	0	3	94	0	103	0	0	0	0	74	0	13
RC5-r2	0	0	3079	405	0	0	265242	0	0	0	106	513	0	0	0	7	0	4	0	118	0	13	10	8	66	78	0	0	54	10	11	22	0	0
RC5-r1	0	0	2236	426	0	0	235448	0	0	0	85	715	0	0	0	19	4	0	4	105	0	0	0	0	37	0	0	0	0	0	0	0	0	0
RC4-r4	0	7438	33383	286	245	0	190851	2633	0	82	474	8543	0	0	14	13	5	5	0	15	64	10	139	6	7	151	0	0	42	25	0	0	18	0
RC4-r3	0	1564	7428	0	0	0	336200	325	0	178	302	3539	0	0	16	12	0	3	4	62	20	0	0	8	123	0	76	0	36	0	5	0	20	0
RC4-r2	21231	0	0	0	0	0	363506	874	0	0	0	257	0	0	24	17	5	0	3	72	10	0	9	0	200	80	0	0	0	0	0	14	15	
RC4-r1	0	0	0	0	0	0	364256	286	56	0	66	0	0	0	21	12	4	0	0	65	0	12	4	0	116	31	66	0	27	15	0	51	0	0
RC3-r2	0	0	1253	0	0	0	355750	616	61	0	0	231	0	0	0	0	0	2	0	84	5	10	5	8	131	35	57	43	0	0	0	0	18	0
RC3-r1	0	7898	17890	0	0	0	323739	616	90	107	69	2045	0	0	17	15	4	0	0	67	8	15	0	0	157	0	0	0	0	23	0	0	0	11
RC2-r1	0	3697	23322	0	0	0	248907	1107	0	0	308	2642	0	0	0	15	8	0	0	48	0	447	0	11	125	62	63	68	44	0	0	24	0	0
RC1-r5	0	0	24158	0	0	0	155717	531	205	0	448	2514	0	0	0	0	0	0	11	13	0	248	0	6	0	0	0	0	64	0	0	23	0	0
RC1-r4	0	0	13767	382	0	0	226589	1812	0	0	330	2507	0	0	41	0	0	0	0	52	5	831	0	0	94	0	101	0	0	18	0	0	0	0
RC1-r3	14561	5276	88787	230	0	0	121542	686	59	63	808	4479	0	0	0	0	3	0	3	27	0	10	0	0	106	88	0	0	0	0	0	23	0	0
RC1-r2	0	3565	59871	256	0	0	122594	867	127	232	148	3382	0	0	0	14	0	0	0	23	0	105	0	0	67	0	0	93	0	0	8	35	0	0
RC1-r1	0	0	3718	0	0	0	176049	0	0	232	873	1906	0	0	16	0	4	0	0	16	0	43	0	0	66	33	0	0	0	0	0	28	0	0
RC14-r3	0	3745	19202	332	0	0	238253	1876	0	1047	170	6200	0	0	0	19	0	3	3	39	11	201	0	14	57	0	0	112	0	0	0	0	0	14
RC14-r2	0	9037	23466	470	0	0	231693	3448	0	147	239	7322	0	0	0	21	0	5	9	68	5	36	0	0	80	0	0	0	0	0	10	0	14	10
RC14-r1	0	10505	32646	246	0	0	267213	1317	44	323	170	5086	0	0	0	21	9	0	10	63	5	100	0	0	88	113	119	0	0	8	5	24	0	0
RC13-r2	23236	25597	136975	841	0	0	188273	4832	0	119	508	15233	0	0	15	44	0	0	24	60	7	159	16	3	148	51	110	34	0	8	24	0	27	0
RC13-r1	11386	0	3852	0	0	0	368072	0	0	0	0	383	0	0	0	0	0	0	0	58	14	10	11	16	174	35	73	45	42	0	17	0	24	0
RC12-r5	27398	0	2323	0	0	0	369273	1451	0	0	138	317	0	0	15	0	0	4	4	43	12	0	0	8	144	0	153	125	0	0	7	64	0	0
RC12-r4	0	6363	10305	143	0	0	310367	0	53	81	85	1781	0	0	0	0	0	3	0	48	24	6	0	0	184	0	51	0	44	0	17	55	0	13
RC12-r3	0	0	0	0	0	0	366103	534	0	0	41	118	0	0	0	0	0	0	0	42	0	5	0	0	139	0	111	0	0	0	0	0	10	
RC12-r2	0	734	0	0	0	0	355747	486	0	0	0	341	0	0	29	11	0	4	0	37	7	0	0	0	197	0	0	0	34	0	9	0	0	0
RC12-r1	9104	0	0	0	0	0	343674	323	64	77	0	123	0	0	10	0	0	3	0	34	0	0	0	0	139	0	0	0	0	22	15	0	0	5
RC12-SmallSideCo	11173	0	448	0	0	0	367337	0	132	102	0	105	0	0	32	0	3	7	0	34	4	5	0	6	154	0	53	42	0	0	0	0	0	6
RC11-r2	0	0	269	0	0	0	372857	0	151	69	0	235	0	0	0	9	0	0	0	35	4	15	13	11	192	81	86	0	39	0	0	0	0	3
RC11-r1	0	0	5323	612	178	0	236424	0	0	336	0	1507	0	0	0	0	0	8	5	63	16	0	0	0	88	0	0	0	0	26	21	0	50	0
RC10-r5	12364	0	0	0	0	0	372051	753	0	53	0	86	0	0	16	0	6	0	6	190	5	0	0	6	152	0	54	0	36	0	0	25	0	5
RC10-r4	0	0	0	0	0	0	351292	0	51	283	0	59	0	0	30	0	4	0	0	202	0	0	11	0	147	47	0	0	0	0	0	53	5	0
RC10-r3	0	0	1103	0	0	0	320990	757	54	127	0	398	0	0	20	25	0	4	0	113	6	12	6	5	189	28	61	158	0	17	0	52	0	0
RC10-r2	0	0	0	0	0	0	366136	1338	0	0	64	91	0	0	24	0	0	3	0	138	0	0	0	0	207	0	0	0	27	11	12	32	0	0
RC10-r1	0	0	0	0	1051	0	365440	751	87	0	0	78	0	0	0	0	9	5	3	216	0	5	0	0	168	90	78	0	22	0	0	0	0	0
LokSail-r4	0	30325	128500	635	377	0	328282	218	0	604	21032	0	0	0	14	95	13	4	80	69	23	229	3	7	54	31	0	36	604	7	0	0	10	
LokSail-r3	0	19709	64039	487	804	0	147655	1059	54	0	419	15672	0	0	13	56	9	0	46	65	22	109	6	11	0	0	164	0	0	0	0	10	0	0
LokSail-r2	0	35173	123414	1372	1036	0	124017	2843	0	178	658	19136	0	0	0	83	23	0	34	194	15	75	5	0	64	80	0	0	0	0	0	12	0	0
LokSail-r1	0	31710	115749	1327	1344	0	132746	1953	126	240	1038	15837	0	0	0	79	8	6	38	179	0	82	8	7	127	0	0	0	0	0	0	19	10	
G9-BR-T3	0	0	0	0	0	0	375377	831	106	95	0	28	0	0	0	0	0	5	0	164	4	17	0	7	225	117	52	0	18	0	0	0	0	5
G9-BR-T2	0	1196	598	0	0	0	356272	0	0	155	0	245	0	0	20	9	4	0	0	161	15	7	0	0	198	63	75	84	0	8	0	0	0	0
G9-BR	0	1988	0	0	178	0	368372	773	0	207	60	63	0	0	10	0	0	0	5	231	0	8	0	0	95	0	61	46	0	23	0	0	19	0
G8-GS-T5	21788	2836	1243	0	0	0	372285	579	47	65	138	226	0	0	0	0	0	5	0	77	4	0	4	3	173	92	0	0	97	0	13	0	36	0
G8-GS-T4	0	0	508	0	420	0	390653	570	60	0	101	423	0	0	0	0	12	9	4	75	0	12	0	8	251	35	0	118	32	0	0	0	40	0
G8-GS-T3	0	0	832	0	0	0	364724	0	0	0	0	53	183	0	0	0	0	14	3	0	0	0	67	0	8	3	0	158	0	0	0	0	18	0
G8-GS-T2	0	1261	2660	0	0	0	372857	0	0	0	0	0	511	0	0	0	0	0	0	0	5	74	5	7	8	0	189	0	0	38	0	27	0	36
G8-GS	0	0	821	0	0	0	328377	682	0	0	0	51	142	0	0	13	0	5	0	8	54	4	0	0	208	31	0	0	0	0	0	0	0	8
G7-GS-Only	0	11294	28678	588	117	0	351723	2174	0	150	292	4638	0	0	0	23	42	17	10	7	15	3	24	0	0	212	54	0	48	37	0	0	0	0
G6-GS-T2	0	594	3622	0	0	0	352383	1857	81	0	0	336	0	0	0	13	0	0	2	46	6	12	4	0	0	153	0	128	53	0	3	0	0	5
G6-GS	0	2821	3215	0	0	0	360673	519	147	0	160	869	0	0	13	23	0	3	0	63	0	0	9	14	188	0	87	61	0	19	0	0	33	0
G5-AC-T4	0	0	6771	634	1292	0	357594	663	0	0	0	491	0	0	0	20	0	0	0	124	5	20	8	12	109	42	54	0	0	12	0	27	0	0
G5-AC-T3	0	0	5378	0	0	0	361571	0	0	0	0	139	566	0	27	10	0	8	0	94	0	10	0	0	158	0	0	0	0	0	0	67	0	0
G5-AC-T2	0	0	1389	0	0	1564	382660	544	132	117	0	170	0	0	32	13	3	0	2	100	3	0	11	0	200	33	0	0	0	10	0	0	0	3

G5-AC	0	0	1083	0	501	0	367230	0	0	0	0	87	0	0	21	5	0	3	0	112	8	0	0	0	169	0	0	0	0	0	0	0	0	12
G4-AC-T4	0	0	314	0	0	0	369484	545	0	0	156	164	0	0	13	0	0	7	0	227	0	19	3	0	148	0	96	94	0	0	0	0	14	16
G4-AC-T3	0	2036	2300	0	0	0	318361	0	54	95	0	114	0	0	35	8	0	3	0	163	0	0	0	0	151	0	0	43	0	0	0	0	15	0
G4-AC-T2	0	3808	2155	0

Photographs.
G1-G16.














Hefty
TRUSTED SEAL
G8-G5


G10-BR


Hefty
TRUSTED SEAL
G12 BR


CLOSED
Hefty
TRUSTED SEAL
G7-G5


Hefty
TRUSTED SEAL
G9-BR


Hefty
TRUSTED SEAL
G11-BR


G13-BR
Hefty
TRUSTED SEAL
CLOSED


G14-BR
Hefty
TRUSTED SEAL


G15-BR
Hefty
TRUSTED SEAL


G16-BR
Hefty
TRUSTED SEAL

RC1-RC14.


RC1 RC1
Hefty
TRUSTED SEAL


RC1 RC1
Hefty
TRUSTED SEAL


RC2


RC3


RC4


RC5


RC6




Hefty
TRUSTED SEAL
CLOSED
Rc7


Hefty
TRUSTED SEAL
CLOSED
Rc8


Hefty
TRUSTED SEAL
CLOSED
Rc9


Hefty
Rc10


Hefty
TRUSTED SEAL
CLOSED
Rc11


Hefty
Rc12









RW1-RW12.1






Hefty
TRUSTED SEAL
CLOSED
RW7


Hefty
TRUSTED SEAL
CLOSED
RW5


Hefty
TRUSTED SEAL
RW3


Hefty
TRUSTED SEAL
CLOSED
RW8


Hefty
TRUSTED SEAL
CLOSED
RW6


Hefty
TRUSTED SEAL
CLOSED
RW4



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