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Hand-held ratioing radiometer data for 66 selected mineral samples

by

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ILLUSTRATIONS

INTRODUCTION

The data reported here represent the basis for a systematic study of the capability of a hand-held ratioing radiometer to discriminate among minerals (Whitney et al., 1983, in press). The reader should consult that report for a full discussion of the interpretation and usefulness of this data.

THE INSTRUMENT

Briefly, the hand-held ratioing radiometer (HHRR) consists of a radiometer head, weighing less than 2 kg, connected to a battery pack, which also weighs about 2 kg. The radiometer head is held by a pistol-grip handle, and the battery pack is carried with a shoulder strap, in a belt pack, or in a backpack (fig. 1). The radiometer head has two sets of optics, each composed of a quartz window, a chopper, a selectable filter, and a thermoelectrically cooled lead-sulfide detector (fig. 2). A voltage divider produces a ratio of the outputs from the two detectors and continuously displays the ratio on a digital display at the back of the instrument. The device also has output jacks for continuous recording of ratios or channel voltages. The field of view of the HHRR at 1 m is approximately 4 by 20 cm.

The choice of spectral bands (that is the choice of filters to be installed) is determined by the user for the specific spectral features that the user wishes to examine, within atmospheric and instrumental limitations. Although only two bands may be examined at once, the filters are held in two movable wheels that hold five filters each. This configuration allows 25 different ratios to be measured without removing or replacing filters, although the instrument must be calibrated on a reflectance standard each time a new ratio is selected.

The 10 filters used in this study were selected to give general coverage between 0.5 μm and 2.5 μm, and to examine in detail the region around 2.2 μm. As mentioned above, the 2.2 μm region contains several important bands for sulfate, carbonate, and clay minerals. The filters selected for this study (fig. 3) include broad bands (0.08-1.1 μm wide at half height) centered at 0.5, 0.6, 1.05, 1.2, 1.6, and 2.1 μm and narrower bands centered at 2.17, 2.20, 2.22 μm (0.02 μm wide), and 2.35 μm (0.05 μm wide). The ratios listed in Appendix 2 are for these spectral bands.

Although the broad absorption bands arising from electronic processes provide valuable data, this report emphasizes the analysis of the vibrational bands in the 2.0-2.5 μm region. The 0.02 μm wide bands were chosen specifically to resolve some of the fine spectral features in this region.

We should emphasize here that the numerical values obtained with the HHRR do not identify minerals in an absolute sense, although the mineral composition of a simple assemblage may be tentatively identified from ratio values in some cases. A specific numerical value for a particular ratio cannot be uniquely attributed to a given mineral because the ratio value depends not only on the filters selected by the user, but also on other components of the instrument that may vary from instrument to instrument or from day to day. In addition, a number of environmental factors may cause the ratio value to vary somewhat, as will be discussed in the following section.

Figure 1

Figure 1.--The hand-held ratioing radiometer in use. Batteries are carried in shoulder pack.

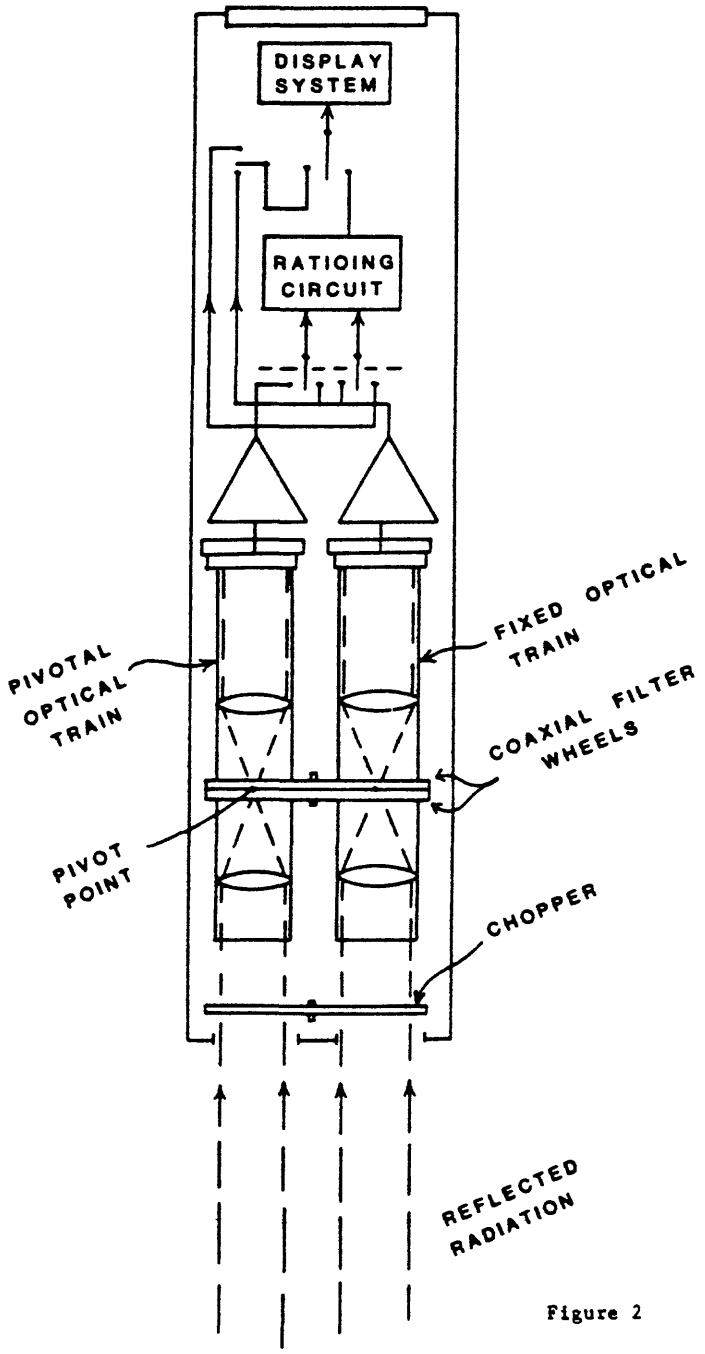

Figure 2.--Simplified diagram of the major components of the hand-held ratioing radiometer showing dual optical train.

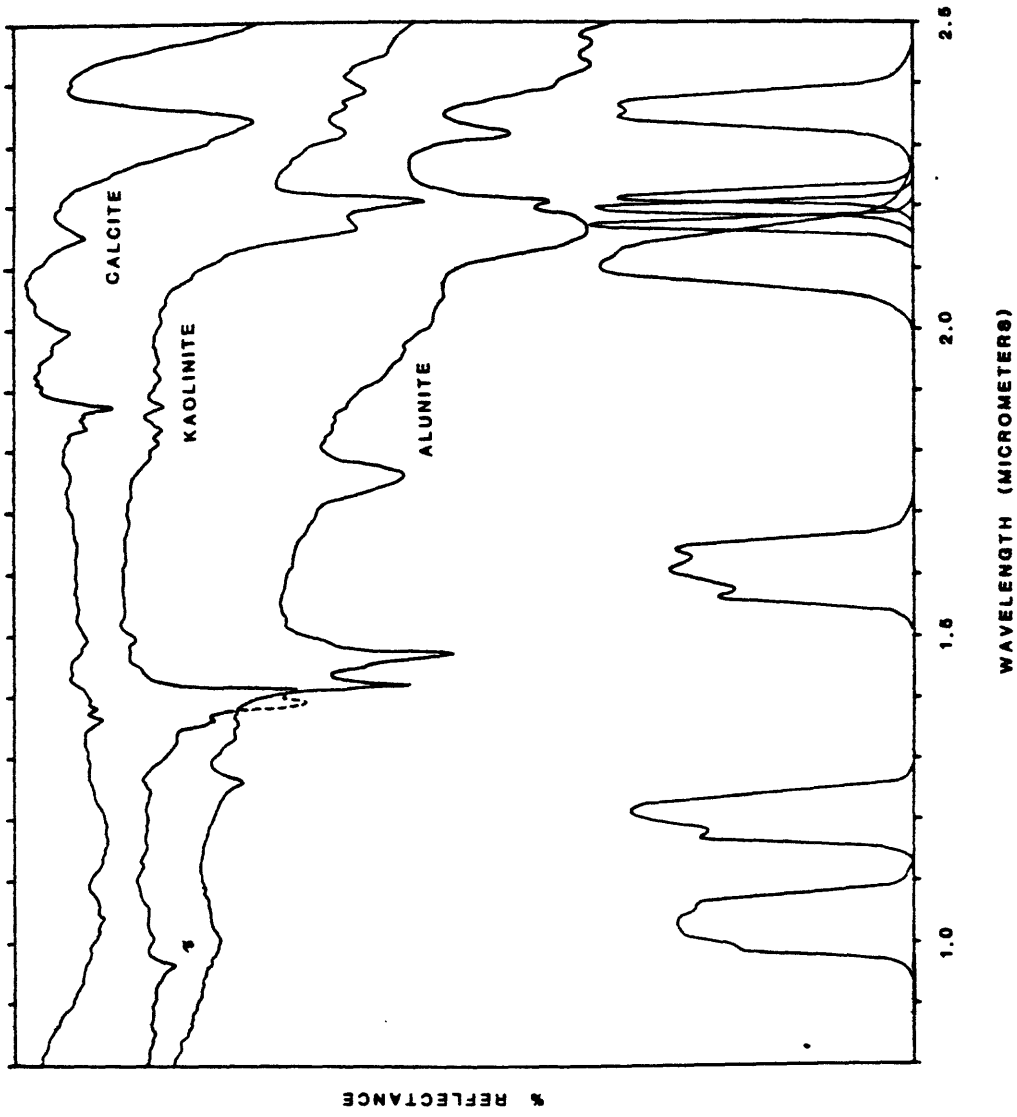

Figure 3

Figure 3.--Transmission spectra of the bandpass filters used in these experiments (bottom) compared to the spectra of alunite, keolinite, and calcite (top).

The most important capability of the HHRR is discrimination, not identification, of minerals or assemblages.

EXPERIMENTAL PROCEDURES

Sample acquisition and preparation

The 66 minerals used for these tests were acquired from Ward's Natural Science Establishment, from the Source Clay Mineral Repository, and from individuals (Appendix 1). We examined each sample to determine its actual mineral composition, because a small amount of certain mineral contaminants may produce a profound spectral change. Microscopic and X-ray diffraction analysis of the samples revealed that many of the samples contained significant amounts of impurities or had been mislabeled by the vendor. The samples were classified as to purity for the statistical analyses.

One kilogram of each sample was pulverized in a disc grinder, if necessary, and the less than 0.4 mm fraction was separated for analysis. The powdered samples were stored in numbered shallow boxes with tight-fitting lids (2.5 cm X 22.9 cm X 30.5 cm). These boxes provided convenient storage and facilitated the HHRR measurements because the samples could be viewed while in the box by removing the lid.

Data Collection

We recorded 25 ratios for each sample, working outside during mid-day when the sun was highest, and collected data only on cloud-free days. The radiometer was held 1 m from the sample and standard in every instance. The procedure for obtaining a ratio is as follows: (1) the filter wheels on the HHRR are adjusted so that the filters for the spectral bands of interest are in the optic paths, (2) a panel of spectrally featureless ceramic wool (Fiberfrax) is placed next to the samples to be analyzed, the HHRR is pointed at the Fiberfrax, and one channel is adjusted so that the reflectance value falls well within the linear range of the HHRR electronics, (3) the second channel is then adjusted so that the ratio value for the Fiberfrax is 1.00, and (4) the HHRR is pointed at the samples, and the ratio value for each sample is recorded. Twenty-five ratios were measured for each sample (Appendix 2). The remaining 20 ratios (for filters on the same wheel) could be calculated from the measured ratios.

REFERENCE

Whitney, G., Abrams, M.J., and Goetz, A.F.H., 1983, Mineral discrimination using a hand-held ratioing radiometer. Economic Geology 78 (in press).

APPENDIX I

Sample Number	Nominal Mineralogy	Actual Mineralogy	Vendor*
1	Kaolinite	Kaolinite (ordered)	SCMR
2	Kaolinite	Kaolinite (disordered)	SCMR
3	Hectorite	Calcite, hectorite	SCMR
4	Montmorillonite	Montmorillonite	SCMR
5	Montmorillonite	Montmorillonite	SCMR
6	Mixed-layer mica/smectite	Mixed-layer mica/smectite	SCMR
7	Kaolinite	Kaolinite, quartz	Private source
8	Alunite	Alunite, quartz, kaolinite	Private source
9	Calcite	Calcite	Ward's
10	Kaolinite	Kaolinite, quartz	Private source
11	Chalk (calcite)	Calcite	Private source
12	Alunite	Alunite	Ward's
13	Kaolinite	Montmorillonite, feldspar	Ward's
14	Lepidolite	Lepidolite, feldspar	Ward's
15	Muscovite	Muscovite, feldspar	Ward's
16	Pyrophyllite	Quartz, calcite, pyrophyllite muscovite	Ward's
17	Anhydrite	Anhydrite, gypsum	Ward's
18	Anhydrite	Anhydrite, gypsum	Ward's
19	Sepiolite	Sepiolite	Ward's
20	Gypsum	Gypsum	Ward's
21	Talc	Talc, amphibole	Ward's
22	Dolomite	Dolomite, quartz	Ward's
23	Chalk (calcite)	Calcite	Ward's
24	Kaolinite	Kaolinite, quartz	Private source
25	Calcite (travertine)	Calcite	Ward's
26	Gypsum	Gypsum	Ward's
27	Dolomite	Dolomite, quartz	Ward's
28	Lepidolite	Lepidolite	Ward's
29	Talc	Talc, serpentine	Ward's
30	Tremolite	Talc, anthophyllite, quartz	Ward's

31	Epidote	Amphibole, calcite, epidote	Ward's
32	Epidote	Feldspar, quartz, epidote	Ward's
33	Serpentine	Serpentine	Ward's
34	Serpentine	Serpentine	Ward's
35	Vermiculite	Amphibole, vermiculite	Ward's
36	Nontronite	Nontronite	Ward's
37	Montmorillonite	Montmorillonite	SCMR
38	Glauconite	Quartz, kaolinite, feldspar glauconite	Ward's
39	Ferrian smectite	Nontronite, quartz	SCMR
40	Diopside	Diopside, mica, talc	Ward's
41	Hedenbergite	Hornblende, quartz, mica	Ward's
42	Ripidolite	Ripidolite (chlorite)	Ward's
43	Illite	Illite, quartz, kaolinite	SCMR
44	Cummingtonite	Cummingtonite, chlorite, mica, feldspar	Ward's
45	Chlorite	Chlorite, mica, chloritoid	Ward's
46	Glaucophane	Glaucophane, chlorite	Ward's
47	Celadonite	Feldspar, pyroxene, celadonnite	Ward's
48	Chlorite	Chlorite	Ward's
49	Aphrosiderite	Aphrosiderite (chlorite), mica	Ward's
50	Illite	Quartz, illite, calcite, kaolinite	Ward's
51	Thuringite	Thuringite (chlorite)	Ward's
52	Vermiculite	Vermiculite, smectite, serpentine (?)	Ward's
53	Glauconite	Glauconite	Ward's
54	Enstatite	Enstatite, serpentine	Ward's
55	Gypsum	Gypsum	Ward's
56	Anthophyllite	Anthophyllite, serpentine	Ward's
57	Prochlorite	Prochlorite (chlorite)	Ward's
58	Pyrophyllite	Pyrophyllite, kaolinite	Ward's
59	Illite	Quartz, illite, kaolinite	Ward's
60	Attapulgite	Attapulgite, quartz	Ward's
61	Montmorillonite	Montmorillonite, quartz	Ward's
62	Illite	Illite	Private source
63	Rhyolite	Feldspar, quartz	Ward's
64	Basalt	Feldspar, pyroxene	Ward's
65	Quartz	Quartz	Ward's
66	Calcite	Calcite	Ward's

*SCMR = Source Clay Mineral Respository
Wards = Ward's Natural Science Establishment

APPENDIX 2. Measured ratio values

		2.1/2.20	2.1/2.22	2.1/2.35	2.1/1.05	2.1/0.6
1.	Kaolinite	1.42	1.32	1.36	0.72	0.91
2.	Kaolinite	1.46	1.37	1.39	0.75	0.90
3.	Hectorite	1.02	1.07	1.19	0.92	1.04
4.	Montmorillonite	1.14	1.30	1.36	0.75	0.84
5.	Montmorillonite	1.19	1.29	1.31	0.75	0.80
6.	M.L. Mica/Mont.	1.15	0.96	0.89	0.35	0.43
7.	Kaolinite	1.33	1.25	1.28	1.10	2.22
8.	Alunite	1.14	1.04	1.02	0.81	1.06
9.	Calcite	1.02	1.13	1.30	1.00	1.08
10.	Kaolinite	1.36	1.29	1.32	0.71	0.84
11.	Chalk	1.02	1.16	1.13	1.00	1.28
12.	Alunite	1.21	0.95	0.94	0.40	0.47
13.	Montmorillonite	1.21	1.28	1.16	1.03	1.10
14.	Lepidolite	1.86	1.37	1.49	0.99	1.31
15.	Muscovite	1.23	1.21	1.15	0.96	1.06
16.	Pyrophyllite	1.18	1.13	1.13	0.94	0.96
17.	Anhydrite	1.02	1.10	1.08	0.95	1.12
18.	Anhydrite	1.03	1.11	1.08	0.96	1.10
19.	Sepiolite	1.06	1.14	1.42	0.80	1.03
20.	Gypsum	1.17	1.25	1.20	0.61	0.68
21.	Talc	1.00	1.14	1.35	0.89	0.96
22.	Dolomite	1.03	1.17	1.16	0.98	1.04
23.	Chalk	1.02	1.04	1.14	1.00	1.26
24.	Kaolinite	1.35	1.30	1.31	0.85	1.03
25.	Calcite	1.02	1.08	1.20	0.95	1.12
26.	Gypsum	1.19	1.23	1.23	0.58	0.64
27.	Dolomite	1.03	1.04	1.09	1.04	1.82
28.	Lepidolite	2.35	1.57	1.86	0.89	0.88
29.	Talc	1.03	1.03	1.32	1.28	1.30
30.	Tremolite	1.03	1.09	1.14	0.95	1.02
31.	Epidote	1.03	1.08	1.55	1.42	2.15
32.	Epidote	1.04	1.11	1.29	1.12	1.50
33.	Serpentine	0.93	1.02	1.88	0.82	0.89
34.	Serpentine	1.03	1.10	1.28	0.83	0.81
35.	Vermiculite	0.99	1.06	1.28	0.85	0.94
36.	Nontronite	1.09	1.10	1.27	1.09	1.43
37.	Montmorillonite	1.36	1.63	2.07	0.54	0.62
38.	Glauconite	1.02	1.07	1.14	1.90	2.80
39.	Nontronite	1.27	1.28	1.62	0.96	1.62
40.	Diopside	1.07	1.07	1.13	1.63	1.47

41.	Hedenbergite	1.03	1.09	1.16	1.97	2.45
42.	Ripidolite	1.02	1.10	1.33	2.80	2.77
43.	Illite	1.15	1.25	1.21	1.83	1.42
44.	Cummingtonite	1.03	1.08	1.08	1.35	1.07
45.	Chlorite	1.00	1.03	1.09	3.72	4.05
46.	Glaucophane	1.08	1.13	1.41	2.05	2.87
47.	Celadonite	1.02	1.02	0.97	1.20	1.24
48.	Chlorite	1.09	1.26	1.81	2.12	2.09
49.	Aphrosiderite	1.01	1.06	1.08	3.93	4.22
50.	Illite	1.06	1.13	1.09	1.27	1.71
51.	Thuringite	1.05	1.14	1.31	2.74	3.03
52.	Vermiculite	1.01	1.07	1.38	1.73	1.98
53.	Glauconite	1.02	1.07	1.09	3.52	2.29
54.	Enstatite	0.99	1.00	0.96	1.84	1.18
55.	Gypsum	1.23	1.30	1.22	0.55	0.56
56.	Anthophyllite	1.07	1.16	1.24	1.02	0.82
57.	Prochlorite	1.05	1.18	1.58	2.45	2.46
58.	Pyrophyllite	1.12	1.15	1.29	0.85	0.93
59.	Illite	1.11	1.16	1.12	1.39	1.30
60.	Attapulgite	1.12	1.27	1.33	0.92	1.02
61.	Montmorillonite	1.29	1.28	1.29	0.96	1.08
62.	Illite	1.16	1.23	1.15	1.34	2.00
63.	Rhyolite	1.08	1.09	1.11	1.20	2.24
64.	Basalt	1.10	1.09	1.01	0.92	0.79
65.	Quartz	1.03	1.03	1.06	1.05	1.24
66.	Calcite	1.02	1.08	1.24	0.98	1.04

		2.17/2.20	2.17/2.22	2.17/2.35	2.17/1.05	2.17/0.6
1.	Kaolinite	1.10	0.95	1.06	0.57	0.72
2.	Kaolinite	1.15	0.95	1.06	0.60	0.73
3.	Hectorite	1.10	1.07	1.22	0.93	0.97
4.	Montmorillonite	1.20	1.26	1.39	0.75	0.96
5.	Montmorillonite	1.24	1.22	1.35	0.73	0.83
6.	M.L. Mica/Mont.	1.06	0.80	0.83	0.31	0.34
7.	Kaolinite	1.12	0.98	1.09	0.90	1.88
8.	Alunite	1.02	0.86	0.88	0.69	0.89
9.	Calcite	1.12	1.02	1.28	0.97	1.08
10.	Kaolinite	1.15	0.97	1.07	0.57	0.64
11.	Chalk	1.10	1.03	1.13	0.99	1.40
12.	Alunite	0.92	0.69	0.73	0.31	0.39
13.	Montmorillonite	1.17	1.06	1.11	0.97	1.13
14.	Lepidolite	1.51	1.02	1.23	0.78	1.16
15.	Muscovite	1.22	1.06	1.11	0.89	1.03

16.	Pyrophyllite	1.13	0.95	1.06	0.86	0.95
17.	Anhydrite	1.13	1.00	1.07	0.94	1.20
18.	Anhydrite	1.12	1.03	1.08	0.95	1.14
19.	Sepiolite	1.10	1.06	1.46	0.80	1.01
20.	Gypsum	1.06	1.06	1.09	0.56	0.64
21.	Talc	1.07	1.03	1.36	0.87	1.01
22.	Dolomite	1.07	1.04	1.19	0.99	1.08
23.	Chalk	1.04	1.02	1.16	1.00	1.28
24.	Kaolinite	1.14	1.00	1.08	0.69	0.81
25.	Calcite	1.06	1.01	1.22	0.94	1.19
26.	Gypsum	1.08	1.05	1.11	0.52	0.58
27.	Dolomite	1.03	1.03	1.10	1.03	1.70
28.	Lepidolite	1.75	1.04	1.35	0.63	0.66
29.	Talc	1.08	1.03	1.36	1.28	1.20
30.	Tremolite	1.03	1.01	1.18	0.95	1.10
31.	Epidote	1.05	1.05	1.63	1.41	2.26
32.	Epidote	1.10	1.03	1.33	1.12	1.33
33.	Serpentine	1.05	1.09	2.09	0.89	1.06
34.	Serpentine	1.08	1.03	1.32	0.84	0.93
35.	Vermiculite	1.05	1.04	1.36	0.89	1.11
36.	Nontronite	1.06	1.03	1.30	1.08	1.42
37.	Montmorillonite	1.31	1.42	2.05	0.54	0.78
38.	Glauconite	1.08	1.06	1.17	1.91	2.20
39.	Nontronite	1.16	1.17	1.66	0.93	1.81
40.	Diopside	1.09	1.01	1.14	1.59	1.66
41.	Hedenbergite	1.08	1.00	1.18	1.97	2.55
42.	Ripidolite	1.09	1.06	1.38	2.78	2.86
43.	Illite	1.17	1.14	1.20	1.75	1.62
44.	Cummingtonite	1.12	1.01	1.13	1.38	1.10
45.	Chlorite	1.08	1.01	1.16	3.86	1.73
46.	Glaucophane	1.11	1.08	1.45	1.99	2.63
47.	Celadonite	1.05	0.97	1.00	1.23	0.99
48.	Chlorite	1.13	1.18	1.89	2.12	2.46
49.	Aphrosiderite	1.04	1.02	1.10	4.04	2.14
50.	Illite	1.11	1.03	1.09	1.25	1.84
51.	Thuringite	1.08	1.07	1.32	2.76	2.95
52.	Vermiculite	1.08	1.02	1.45	1.76	1.99
53.	Glauconite	1.1	1.00	1.14	3.50	2.37
54.	Enstatite	1.07	0.99	1.02	1.89	1.33
55.	Gypsum	1.11	1.04	1.10	0.48	0.56

56.	Anthophyllite	1.06	1.07	1.24	0.98	0.88
57.	Prochlorite	1.09	1.12	1.58	2.44	2.40
58.	Pyrophyllite	0.84	0.80	0.96	0.61	0.72
59.	Illite	1.08	1.08	1.11	1.30	1.46
60.	Attapulgite	1.14	1.19	1.37	0.89	1.14
61.	Montmorillonite	1.15	1.14	1.24	0.88	1.01
62.	Illite	1.10	1.16	1.20	1.29	2.35
63.	Rhyolite	1.06	1.05	1.12	1.16	2.69
64.	Basalt	1.09	1.11	1.06	0.94	0.88
65.	Quartz	1.09	1.01	1.06	1.10	1.25
66.	Calcite	1.08	1.02	1.22	0.97	1.02

		1.6/2.20	1.6/2.22	1.6/2.35	1.6/1.05	1.6/0.6
1.	Kaolinite	2.06	1.73	1.91	0.98	1.14
2.	Kaolinite	2.15	1.79	1.98	1.00	1.20
3.	Hectorite	1.2	1.12	1.33	0.97	1.07
4.	Montmorillonite	1.45	1.69	1.92	0.93	1.15
5.	Montmorillonite	1.49	1.55	1.70	0.87	0.92
6.	M.L. Mica/Mont.	2.37	1.92	2.04	0.78	0.79
7.	Kaolinite	1.46	1.37	1.56	1.24	2.53
8.	Alunite	1.40	1.26	1.26	0.97	1.18
9.	Calcite	1.00	1.00	1.33	0.97	0.87
10.	Kaolinite	1.90	1.66	1.88	0.94	0.99
11.	Chalk	1.10	1.07	1.23	1.06	1.21
12.	Alunite	2.38	1.94	1.85	0.84	0.93
13.	Montmorillonite	1.3	1.21	1.27	1.04	1.15
14.	Lepidolite	1.86	1.37	1.71	1.08	1.37
15.	Muscovite	1.25	1.16	1.27	1.00	1.03
16.	Pyrophyllite	1.20	1.15	1.28	0.98	1.01
17.	Anhydrite	1.07	1.12	1.17	0.98	1.10
18.	Anhydrite	1.07	1.06	1.14	0.97	1.03
19.	Sepiolite	1.22	1.31	1.74	0.95	1.19
20.	Gypsum	1.72	1.75	1.80	0.82	0.85
21.	Talc	1.15	1.20	1.62	0.99	1.03
22.	Dolomite	1.10	1.11	1.22	1.02	1.01
23.	Chalk	1.04	1.08	1.21	1.02	1.20
24.	Kaolinite	1.63	1.56	1.72	1.02	1.18
25.	Calcite	1.07	1.07	1.28	0.97	1.08

26.	Gypsum	1.70	1.75	1.85	0.82	0.82
27.	Dolomite	1.01	1.02	1.12	1.01	1.62
28.	Lepidolite	3.00	1.96	2.61	1.14	1.14
29.	Talc	1.06	1.07	1.44	1.27	1.22
30.	Tremolite	1.05	1.05	1.25	0.97	0.98
31.	Epidote	0.94	0.99	1.53	1.35	1.82
32.	Epidote	0.99	1.02	1.36	1.08	1.30
33.	Serpentine	1.27	1.37	2.86	1.06	1.13
34.	Serpentine	1.12	1.16	1.50	0.97	0.91
35.	Vermiculite	1.12	1.15	1.53	0.96	1.07
36.	Nontronite	1.30	1.29	1.69	1.29	1.57
37.	Montmorillonite	2.22	2.92	3.88	0.85	1.13
38.	Glauconite	0.85	0.87	0.98	1.60	2.42
39.	Nontronite	1.78	2.05	2.64	1.34	2.65
40.	Diopside	1.11	1.14	1.24	1.64	1.62
41.	Hedenbergite	0.90	0.85	1.04	1.76	2.17
42.	Ripidolite	0.70	0.72	0.96	2.10	2.08
43.	Illite	0.89	0.96	1.00	1.47	1.26
44.	Cummingtonite	1.14	1.06	1.27	1.41	1.14
45.	Chlorite	0.55	0.58	0.67	2.40	2.63
46.	Glaucophane	0.98	0.98	1.40	1.83	2.47
47.	Celadonite	0.98	0.98	1.01	1.22	1.27
48.	Chlorite	0.88	0.99	1.52	1.79	1.83
49.	Aphrosiderite	0.58	0.58	0.64	2.57	2.57
50.	Illite	1.07	1.06	1.05	1.31	1.70
51.	Thuringite	0.75	0.82	0.99	2.11	2.26
52.	Vermiculite	0.90	0.93	1.33	1.51	1.78
53.	Glauconite	0.54	0.57	0.63	2.10	1.32
54.	Enstatite	0.88	0.93	0.95	1.66	1.11
55.	Gypsum	1.78	1.86	1.87	0.80	0.80
56.	Anthophyllite	1.23	1.30	1.51	1.20	1.03
57.	Prochlorite	0.82	0.89	1.22	1.87	1.74
58.	Pyrophyllite	1.35	1.27	1.64	1.03	1.12
59.	Illite	1.03	1.00	1.01	1.31	1.33
60.	Attapulgite	1.20	1.35	1.64	1.00	1.10
61.	Montmorillonite	1.40	1.36	1.41	1.05	1.10
62.	Illite	1.10	1.20	1.19	1.27	2.07
63.	Rhyolite	1.09	1.12	1.17	1.24	2.36
64.	Basalt	1.19	1.24	1.28	1.05	0.84
65.	Quartz	1.02	1.03	1.05	1.02	1.22
66.	Calcite	1.06	1.04	1.29	1.00	1.00

		1.2/2.20	1.2/2.22	1.2/2.35	1.2/1.05	1.2/0.6
1.	Kaolinite	1.94	1.70	1.85	1.02	1.16
2.	Kaolinite	1.92	1.73	1.83	1.03	1.17
3.	Hectorite	1.11	1.24	1.27	1.03	1.08
4.	Montmorillonite	1.54	1.86	1.85	1.03	1.16
5.	Montmorillonite	1.62	1.82	1.73	1.04	1.04
6.	M.L. Mica/Mont.	3.23	2.60	2.47	1.01	1.01
7.	Kaolinite	1.40	1.39	1.33	1.12	2.06
8.	Alunite	1.46	1.38	1.27	1.02	1.20
9.	Calcite	1.04	1.13	1.29	1.04	1.00
10.	Kaolinite	1.93	1.87	1.84	1.03	1.03
11.	Chalk	1.06	1.18	1.15	1.08	1.20
12.	Alunite	2.92	2.52	2.28	1.06	1.12
13.	Montmorillonite	1.22	1.39	1.17	1.03	1.11
14.	Lepidolite	2.03	1.56	1.64	1.09	1.35
15.	Muscovite	1.28	1.26	1.19	0.96	1.02
16.	Pyrophyllite	1.27	1.16	1.17	0.95	1.02
17.	Anhydrite	1.07	1.10	1.09	0.94	1.13
18.	Anhydrite	1.08	1.16	1.06	0.95	1.05
19.	Sepiolite	1.36	1.39	1.80	0.97	1.27
20.	Gypsum	1.80	1.90	1.80	0.92	0.95
21.	Talc	1.16	1.23	1.52	0.97	1.04
22.	Dolomite	1.06	1.11	1.16	1.00	0.98
23.	Chalk	1.06	1.11	1.15	1.00	1.21
24.	Kaolinite	1.66	1.39	1.53	0.99	1.14
25.	Calcite	1.07	1.12	1.19	0.99	1.08
26.	Gypsum	1.97	1.99	1.97	0.83	0.92
27.	Dolomite	1.01	1.06	1.03	0.98	1.63
28.	Lepidolite	2.61	1.68	1.99	0.94	0.95
29.	Talc	0.94	0.99	1.13	1.10	1.03
30.	Tremolite	1.08	1.10	1.17	0.96	1.01
31.	Epidote	0.88	0.89	1.18	1.18	1.54
32.	Epidote	1.00	1.02	1.25	1.04	1.32
33.	Serpentine	1.17	1.30	2.48	1.02	1.05
34.	Serpentine	1.15	1.17	1.44	0.96	0.91
35.	Vermiculite	1.17	1.20	1.42	0.98	1.10
36.	Nontronite	1.26	1.23	1.16	1.19	1.51
37.	Montmorillonite	2.58	3.55	3.93	1.00	1.26
38.	Glauconite	0.61	0.67	0.66	1.08	1.58
39.	Nontronite	1.62	1.81	2.30	1.21	2.38
40.	Diopside	0.80	0.87	0.84	1.20	1.18

41.	Hedenbergite	0.61	0.63	0.67	1.08	1.36
42.	Ripidolite	0.40	0.47	0.51	1.03	1.06
43.	Illite	0.65	0.71	0.67	1.00	0.83
44.	Cummingtonite	0.98	1.03	1.02	1.13	1.01
45.	Chlorite	0.30	0.30	0.33	1.11	1.20
46.	Glaucophane	0.63	0.72	0.90	1.24	1.62
47.	Celadonite	0.94	0.98	0.91	1.07	1.16
48.	Chlorite	0.50	0.63	0.83	1.09	1.08
49.	Aphrosiderite	0.29	0.30	0.31	1.00	1.15
50.	Illite	0.92	0.91	0.92	1.04	1.38
51.	Thuringite	0.42	0.45	0.53	1.09	1.18
52.	Vermiculite	0.64	0.65	0.89	1.03	1.24
53.	Glauconite	0.31	0.31	0.33	1.00	0.65
54.	Enstatite	0.72	0.73	0.69	1.17	0.85
55.	Gypsum	2.05	2.03	2.11	0.88	0.91
56.	Anthophyllite	1.15	1.23	1.31	1.06	0.95
57.	Prochlorite	0.48	0.53	0.72	1.05	1.05
58.	Pyrophyllite	1.33	1.34	1.57	1.01	1.13
59.	Illite	0.80	0.86	0.87	0.98	1.00
60.	Attapulgite	1.24	1.33	1.51	0.98	1.10
61.	Montmorillonite	1.36	1.34	1.36	0.99	1.11
62.	Illite	0.96	1.05	1.00	1.05	1.83
63.	Rhyolite	1.07	1.09	1.07	1.13	2.31
64.	Basalt	1.24	1.24	1.27	0.91	0.88
65.	Quartz	1.00	1.04	1.00	1.07	1.25
66.	Calcite	1.05	1.09	1.24	1.05	1.05

		0.5/2.20	0.5/2.22	0.5/2.35	0.5/1.05	0.5/0.6
1.	Kaolinite	1.46	1.32	1.42	0.81	1.00
2.	Kaolinite	1.37	1.25	1.34	0.82	0.93
3.	Hectorite	0.89	1.04	1.04	0.88	1.04
4.	Montmorillonite	1.16	1.36	1.38	0.81	1.00
5.	Montmorillonite	1.37	1.52	1.53	0.94	1.05
6.	M.L. Mica/Mont.	2.89	2.31	2.31	0.97	1.06
7.	Kaolinite	0.54	0.49	0.49	0.76	0.85
8.	Alunite	1.00	0.94	0.88	0.77	0.94
9.	Calcite	0.96	1.04	1.18	0.99	1.06
10.	Kaolinite	1.77	1.56	1.81	0.97	1.05
11.	Chalk	0.76	0.81	0.87	0.81	1.02
12.	Alunite	2.26	1.80	1.76	0.80	0.95
13.	Montmorillonite	1.01	1.03	1.97	0.90	0.96
14.	Lepidolite	1.33	1.05	1.09	0.77	1.06
15.	Muscovite	1.14	1.11	1.03	0.95	1.01

16.	Pyrophyllite	1.18	1.09	1.17	1.00	1.08
17.	Anhydrite	0.94	1.01	0.90	0.89	1.08
18.	Anhydrite	1.00	1.07	1.02	0.96	1.07
19.	Sepiolite	0.91	0.98	1.27	0.74	0.98
20.	Gypsum	1.77	1.96	1.94	0.98	1.08
21.	Talc	1.06	1.17	1.49	0.96	1.00
22.	Dolomite	0.99	1.12	1.04	1.00	1.03
23.	Chalk	0.78	0.84	0.85	0.83	0.98
24.	Kaolinite	1.25	1.28	1.23	0.85	1.01
25.	Calcite	0.92	0.98	0.96	0.87	0.99
26.	Gypsum	1.92	2.09	2.09	1.01	1.07
27.	Dolomite	0.37	0.41	0.40	0.40	0.67
28.	Lepidolite	2.35	1.63	1.90	0.94	0.97
29.	Talc	0.80	0.89	0.97	1.07	1.01
30.	Tremolite	1.02	1.07	1.09	0.98	1.07
31.	Epidote	0.44	0.49	0.60	0.65	0.94
32.	Epidote	0.60	0.63	0.73	0.64	0.85
33.	Serpentine	1.00	1.21	2.02	0.94	1.02
34.	Serpentine	1.22	1.29	1.45	1.12	1.08
35.	Vermiculite	0.96	1.03	1.15	0.86	1.01
36.	Nontronite	0.57	0.59	0.67	0.62	0.75
37.	Montmorillonite	1.51	2.15	2.30	0.69	0.88
38.	Glauconite	0.23	0.28	0.25	0.49	0.51
39.	Nontronite	0.50	0.56	0.71	0.44	0.83
40.	Diopside	0.66	0.66	0.69	1.05	1.01
41.	Hedenbergite	0.42	0.43	0.43	0.86	1.06
42.	Ripidolite	0.35	0.39	0.48	1.13	1.15
43.	Illite	0.68	0.79	0.70	1.18	0.96
44.	Cummingtonite	0.92	0.75	0.98	1.22	0.98
45.	Chlorite	0.24	0.26	0.25	1.07	1.12
46.	Glaucophane	0.38	0.42	0.49	0.76	1.04
47.	Celadonite	0.69	0.73	0.66	0.91	0.90
48.	Chlorite	0.50	0.57	0.87	1.06	1.09
49.	Aphrosiderite	0.24	0.27	0.24	1.08	1.12
50.	Illite	0.56	0.60	0.55	0.73	0.94
51.	Thuringite	0.30	0.34	0.37	0.91	0.93
52.	Vermiculite	0.40	0.43	0.55	0.74	0.86
53.	Glauconite	0.47	0.47	0.48	1.87	1.19
54.	Enstatite	0.76	0.76	0.66	1.52	1.00
55.	Gypsum	2.02	2.12	2.09	1.01	1.03

56.	Anthophyllite	1.16	1.23	1.30	1.16	1.10
57.	Prochlorite	0.49	0.56	0.72	0.79	1.19
58.	Pyrophyllite	0.97	1.02	1.04	1.21	0.96
59.	Illite	0.77	0.83	0.77	1.06	1.12
60.	Attapulgite	0.99	1.09	1.66	0.88	1.04
61.	Montmorillonite	1.19	1.21	1.22	0.92	0.98
62.	Illite	0.48	0.50	0.50	0.57	0.91
63.	Rhyolite	0.36	0.37	0.38	0.41	0.80
64.	Basalt	1.49	1.52	1.52	1.28	1.06
65.	Quartz	0.72	0.80	0.73	0.76	1.00
66.	Calcite	0.97	1.04	1.24	0.95	1.09