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In Situ Rock Reflectance

Apparently no practical numerical basis exists for selecting any particular spectral band as best for rock discrimination.

Abstract: *The purposes of this paper are to summarize, generalize, and give a statistical model of sedimentary rock reflectance data measured* in situ. *The data consist of more than 8600 measurements along the Front Range of Colorado. The typical spectral reflectance curve for a geologic formation shows a gradual increase of spectral reflectance with increasing wavelength. Extrapolation of measured values from one area to another is valid; however, the geologic exposure may change and must be considered for best filter selection. Statistically, band reflectance measurements can be considered to be from a normally distributed population with a minimum standard deviation of 0.042. From a statistical consideration of the observed differences in contrast-ratio and the number of reflectance measurements per band per formation necessary to discriminate these differences, it is concluded that "best" spectral bands cannot be selected with sufficient confidence in a practical manner with current techniques and equipment.*

Introduction

In the course of our research at the Colorado School of Mines in evaluating the capabilities of multiband photography to discriminate rocks, over 8600 *in situ* measurements of band reflectance of several sedimentary rocks were acquired. "Band reflectance" refers to the average spectral reflectance within a wavelength band, the width of which is defined by the transmission characteristics of the filter under consideration. Therefore, if an object reflects 20 percent of the incident radiation in a wavelength interval, the band reflectance of the object in the wavelength interval is 0.20.

The purposes of this paper are (1) to summarize these measurements, (2) to note generalizations that are of interest to remote-sensing researchers working with the visible and photographic infrared parts of the spectrum (400 to 950 nanometers), and (3) to give generalized parameters for a statistical model of rock reflectance. Then, using the data presented, the sample size requirements to use these types of data are considered. Specifically, data on the amplitude variation of the mean band reflectances between formations and the natural variability of band reflectance within a formation are discussed.

The formations considered in this research are the sedimentary rocks exposed along the Front Range of Colorado, with 50 percent of the measurements made near Phantom Canyon, 10 miles east of Canon City, Colorado. These sedimentary rocks consist of sandstones, shales, and carbonates; thus, the most common types of sedimentary rocks are represented. The formations studied have not been selected in a manner that would allow statistical inferences to be made about all rocks or even all sedimentary rocks. However, there is no geologic reason to suspect that the rocks and formations considered have unique reflectance properties with re-

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spect to other sedimentary rocks. Therefore, the conclusions drawn apply in detail only to the formations considered; however, generalizations of conclusions are probably valid for most sedimentary rocks.

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Measurement Technique

The measurement procedure consists of using a simple filter wheel photometer (referred to as FWP), modified from an instrument used by Egbert and Ulaby (1972). An extensive discussion of this FWP and the measuring technique is given in Raines and Lee (1974). The FWP consists of a photometer and a filter wheel with 13 filters. These 13 filters are those Wratten filters, sandwiched with an infrared blocking filter, that can be used for aerial photography and are stable. The passbands of the 13 filters are shown in Figure 1.

Matte-surface neutral gray cards of known band reflectance are used as standards for calibration of the system. The measurement procedure in the field consists of (1) measurement of standards, (2) measurement of the unknown target(s), and (3) re-measurement of the standards. Data reduction then consists of (1) averaging the two sets of standards measurements and (2) linear interpolation between the standards to reduce the unknown target measurements to band reflectance. The accuracy of this procedure is 20 percent of average band reflectance, and precision is approximately 3 to 5 percent of the average band reflectance. Correlation of *in situ* mean band reflectances with densities measured on aerial multiband photography gives a correlation coefficient ranging from 0.70 to 0.96.

Rock Reflectance Properties

Typical band reflectance measurements made at Phantom Canyon, about 10 miles east of Canon City, are presented in Figure 2. Figure 2 shows the mean band reflectance for each formation and an 80 percent confidence interval about the mean for a sample size of generally 12 measurements per band per formation. As has been suggested before, spectral reflectance in this part of the spectrum (400 to 950 nanometers) offers little opportunity for unique identification by use of the spectral character.

The standard deviation is an estimate of the total variation within the reflectance data, and a summary of all the standard deviations observed is shown in Figure 3. Total variation includes variation due to random error, measurement procedure, and natural target variability. As stated above concerning measurement technique, the variation due to random error and measurement procedure is 3 to 5 percent of the mean band reflectance; thus the observed variation is primarily due to natural variability.

The grand mean of all the standard deviations is 0.042 percent band reflectance, and analysis of the range shows that 85 percent of the observed standard deviations are less than or equal to 0.07. The grand median of the standard deviations is 0.038. The significance of these standard deviations is best assessed by realizing that the grand mean band reflectance, using all the data, is approxi-

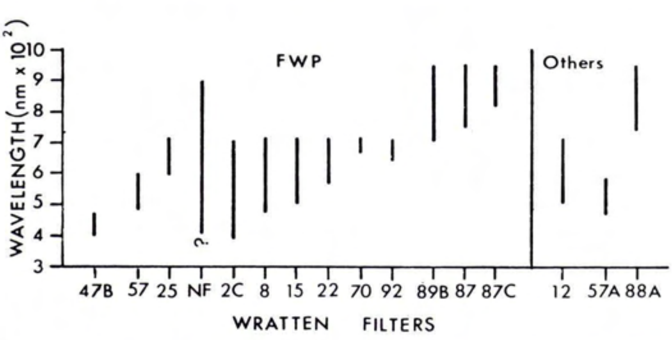

FIG. 1. Passbands of filters. All of the filters are Wratten gelatin filters. All the filters except the 87, 87C, 88A, 89B, and NF are used with an infrared blocking filter (Corning 3961). *NF* means no filter and is therefore not a filter; however, for convenience of terminology the *NF* spectral band will be referred to as a filter. The passband is defined by the wavelength interval with greater than 10 percent transmission. Other filters refer to filters not used with the FWP but referred to in the text.

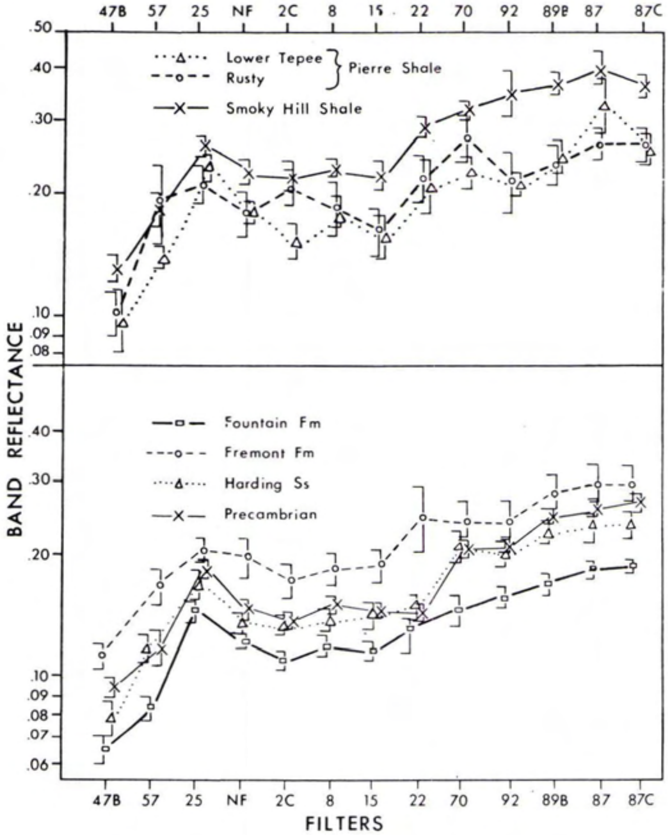

FIG. 2. Mean band reflectance and 80 percent confidence intervals for some of the Phantom Canyon data. Lines connecting the points are to aid visualization only. Formations are listed in stratigraphic order.

mately 0.20; therefore, the grand mean standard deviation (0.042) is about 20 percent of the grand mean of the mean band reflectances. Furthermore, the procedure used in the field was to measure *typical* areas; therefore, the mean standard deviation (0.042) is an under-estimate of the variability. Thus, for a single formation, the data indicate very significant variation of the band reflectance within a formation.

In order to delimit the population standard deviation, Lee selected the Fremont Formation and the Fountain Formation and made, respectively, 62 and 39 band reflectance measurements per band. For measurements of these large samples, Lee specifically looked for variation, thus acquiring an estimate of the maximum standard deviation. The sample standard deviations are shown in Figure 4.

From inspection of Figure 4, the standard deviations increased half the time when variation was sought. From this test it is difficult to conclude what the population standard deviation is; however, the test supports the idea that 0.042 is below the minimum standard deviation, and an average population

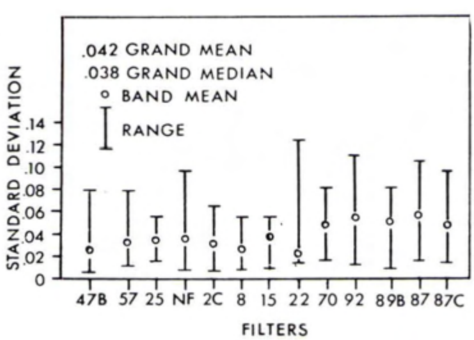

FIG. 3. Sample standard deviations for the Phantom Canyon data. Eighty-five percent of the observed standard deviations are less than 0.07.

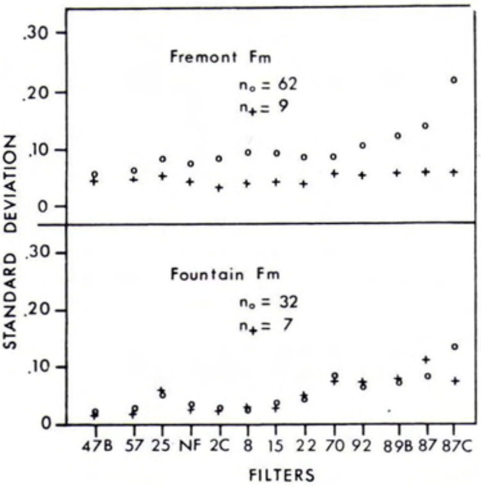

FIG. 4. Sample standard deviations for the Fountain and Fremont formations. Circle *(o)* denotes the large sample where variation was sought; cross (+) denotes a small sample of measurements from *typical* outcrops. In all instances the mean confidence intervals for each band of both formations overlap, so the differences between the means from small samples and large samples is not significant. The sample sizes are denoted by *n* and the appropriate subscript.

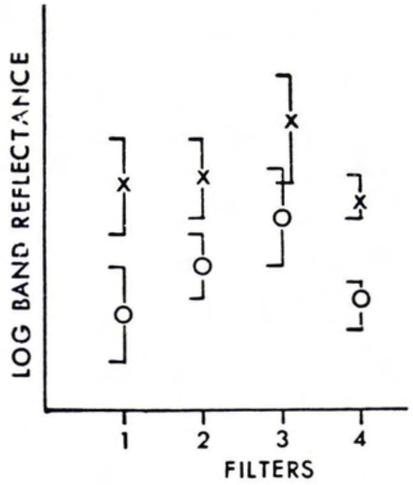

FIG. 5. Use of the 80-percent confidence intervals. The *x*'s denote the means for Formation X, the circles denote the means for Formation *O*, and the brackets denote the confidence intervals. Filter 1 would be considered best because (1) no overlap of the confidence intervals and (2) maximum separation of the means (that is, maximum mean contrast ratio).

standard deviation might be a number around 0.07.

Using the standard deviation, the sample size, and assuming a normal distribution of band reflectance, an 80 percent confidence interval can be calculated. This assumption of a normal distribution (within each band) of the band reflectance data is justified at the 10 percent significance level by numerous chi-square tests of the normal distribution. The results of the chi-square tests were such that for a sample size, generally of 12, the alternate hypothesis that band reflectance is not normally distributed could not be accepted. The 80-percent confidence level was empirically selected as a level that is adequate for a data-sorting tool if comparing logarithmic plots of band reflectance for different formations. For example, in those filter bands where the confidence intervals overlap, the formations are taken to have a contrast ratio of 1., or very close to 1., and are therefore not sufficiently different to be considered to have different band reflectances. See Figure 5 for an example. Contrast ratio, as used here, is the ratio of mean band reflectances, ratioed so as to give a number greater than (or equal to) 1. The validity and statistical significance of this use of confidence intervals is given by Barr (1969) and Jones and Karson (1972).

With regard to variation between formations, Figure 6 and Table 1 are summaries of the contrast ratios determined using mean band reflectances from the Phantom Canyon area. The range of contrast ratios is very narrow, generally between 1.0 and 1.8, with very few greater than 1.8. From examination of these data, the typical difference between contrast ratios for the filter bands considered is about 0.2. Therefore, in most instances, only small differences occur between the filter bands considered.

A statistical test of the variation, performed using analysis of variance (Koch & Link, 1970, p. 141), considers the question of whether the variation of band reflectance between formations is more significant than the variation of band reflectance within formations. Because of the large volume of data, all the data were not tested in this manner; however, members of the Pierre Shale, which are considered some of the subtlest rock discriminations made, were tested. The conclusion of this test was that the variation between members was greater than the variation within members at the 0.05 significance level (95 percent confidence level). The same conclusion is therefore assumed with respect to other formations studied.

One very important aspect observed in all the data obtained to date (shown in Figure 2) is that in not one single instance did a signifi-

TABLE 1. ACTUAL CONTRAST RATIOS OBTAINED FROM THE PHANTOM CANYON DATA. BLANKS DENOTE A CONTRAST RATIO OF 1.0.

		Filters												
	Formations	47B	57	25	NF	2C	8	15	22	70	92	89B	87	87C
Pierre Shale Zones	Transition-D					1.2					1.6			1.3
Pierre Shale Zones	D-C	1.4	1.6		1.6	1.4	1.8		2.0	1.5	2.7	1.3	1.3	1.9
Pierre Shale Zones	C-Upper Tepee		1.5				1.3			1.4				
Pierre Shale Zones	Upper Tepee-Lower Tepee			1.7			1.2		1.6					1.2
Pierre Shale Zones	Lower Tepee-Rusty					1.3								
	Rusty-Smoky Hills Shale	1.3		1.3			1.3	1.4	1.4	1.2	1.7	1.6	1.6	1.4
	Fountain-Fremont	1.7	2.0	1.4	1.6	1.6	1.6	1.6	1.9	1.7	1.5	1.7	1.6	1.6
	Fountain-Harding		1.4			1.2		1.2		1.4	1.2	1.3	1.2	1.3
	Fountain-Precambrian	1.4	1.4	1.3	1.2	1.3	1.3	1.3		1.4	1.4	1.5	1.4	1.4
	Fremont-Harding	1.4	1.4	1.2	1.5	1.3	1.4	1.4	1.7	1.2	1.2	1.3	1.3	1.3
	Harding-Manitou							1.2	1.2		1.2			
	Manitou-Precambrian	1.3		1.2	1.2		1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3

cant crossover in band reflectance occur. By a significant crossover, we mean that occasion where the mean band reflectances do cross over (relative relationship of band reflectances from one band to the next is inverse) and the confidence intervals do not overlap.

Because of the lack of real crossovers, an approach to color additive viewing requires some sort of positive-negative masking (i.e., a ratioing technique) in order to produce large changes in the color coding of a scene. This assumes the purpose of color additive viewing is to produce significant enhancement beyond a true color (or color-IR) type of display.

EXTRAPOLATION TO DISTANT AREAS

A question of major importance is whether these measurements made in a local area (Phantom Canyon Test Site) can be used in other areas where the same formations are exposed at the surface. To answer this question, measurements were made on these same formations at the Gorge Hills Test Site west of Canon City, about 10 miles from the Phantom Canyon Site, and near Kassler, Colorado, 100 miles north of the Canon City sites.

The conclusion of the comparison of the Phantom Canyon data with the Gorge Hills data is that the values are essentially the same. The means of band reflectance for each formation have a linear correlation coefficient of 0.97, and the standard deviations have a linear correlation coefficient of 0.67. Using a hypothesis test for equivalence of means, it was found that a systematic difference of 0.04 to 0.05 band reflectance exists between the Gorge Hills and Phantom Canyon sites, with Gorge Hills values greater than Phantom Canyon. This may be due to (1) slight differences in operator techniques

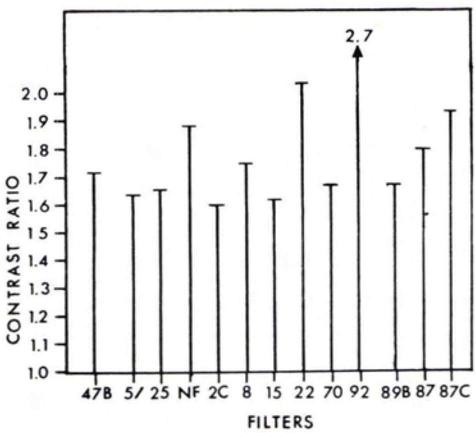

FIG. 6. Range of the contrast ratios observed at the Phantom Canyon Site.

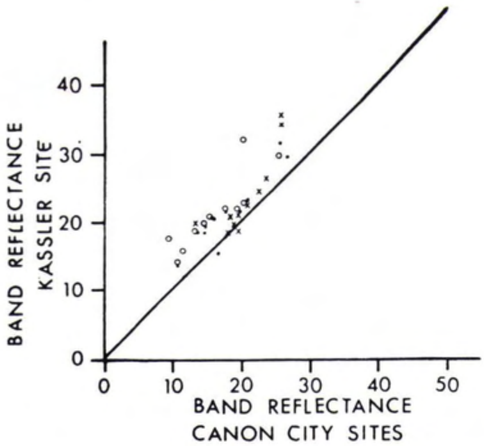

FIG. 7. Comparison between band reflectance measurements from the Kassler Site and the Canon City sites. The formations considered are Dakota Group (upper member) (.), the Fort Hays Limestone (×), and the Fountain Formation (0). The line is the line of perfect agreement. Each symbol stands for a mean band reflectance for both sites.

(Lee measured all Gorge Hill sites and Raines measured all Phantom Canyon sites), (2) possible real differences between sites, or (3) possible errors in data reduction. As this difference is systematic and small, it is not considered significant. The standard deviations do not correlate as well as the means, probably because the Gorge Hills standard deviations have a larger range and tend to be slightly larger. Therefore, the use of a standard deviation of 0.042 (derived above) as a lower bound is justified.

The conclusion of the comparison of the Kassler Test Site with the two Canon City sites (Gorge Hills and Phantom Canyon) is essentially the same. The means of band reflectance for each formation have a linear correlation of about 0.90 and are essentially the same. This is shown in Figure 7, which is a comparison of the Kassler data with the Canon City data. The average difference, where the difference is calculated as a least squares difference, is 0.04 band reflectance. The standard deviations correlate very poorly; however, 0.042 is a good estimate of a lower bound of the average standard deviation.

Therefore, it is possible to make measurements of band reflectance in one area and to use those measurements for the same formations in another area with reasonable accuracy. This assumes. of course, that the formations do not show a great deal of lateral change. However, this does not imply that a group of filters that is best for one area will be best for another. As an example, consider the diagrammatic geologic cross sections shown in Figure 8.

Thus, for selection of best filter, it is necessary to consider the geologic expression and the geologic significance of the contact for the problem to be solved.

STATISTICAL MODEL

It is concluded that a very simple statistical model can be used to characterize band reflectance for a formation. For any particular formation and band, the band reflectance population is normally distributed. There is significant variation of standard deviations between and within formations; however, if a lower bound is sufficient, the average standard deviation of the population will be at

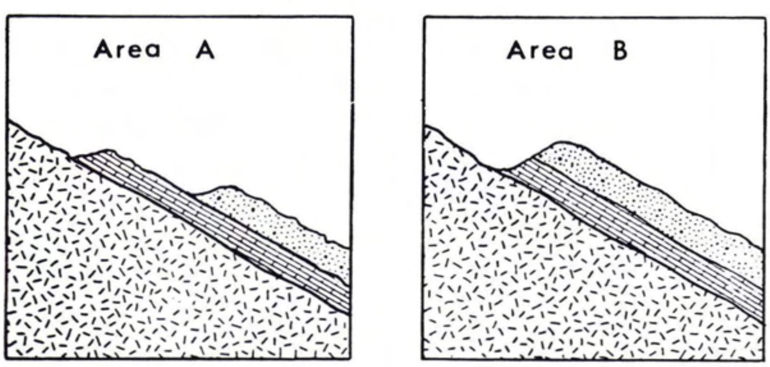

FIG. 8. Effect of geologic expression upon the selection of best filters. In Area *A*, all three formations are important; whereas in Area *B*, the limestone formation may not even be visible on aerial photographs, and the more practical discrimination would be between the sandstone formation and the igneous basement.

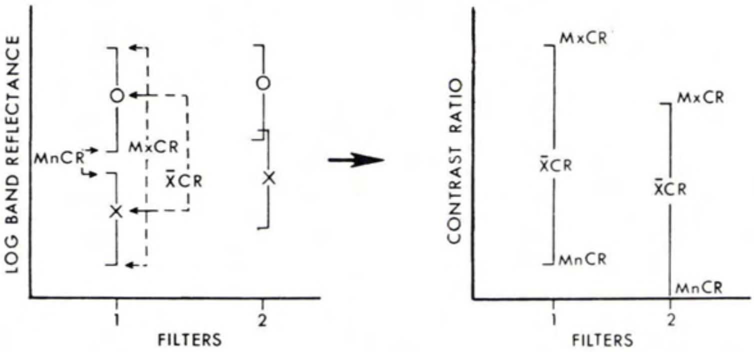

FIG. 9. Definition of the min-max interval for the contrast ratio. The log band reflectance plot is used for comparison of formations *X* and *O* because with this plot the contrast ratio plot with min-max intervals can be visualized. It can be seen that the min-max intervals for Filters 1 and 2 would overlap in the example given. Calculation of the min-max interval would be as follows: for the minimum value of the interval, ratio the antilog of the numbers marked by the *MnCR* arrow; for the maximum value, ratio the antilogs of the numbers marked by the *MxCR* arrows; and for the mean contrast ratio, ratio the antilogs of the numbers marked by the *XCR* arrows. This min-max interval is used like a confidence interval.

least 0.042. The band reflectances also show significant variation between and within most formations; however, for a large number of formations and bands, the grand mean will be approximately 0.20 band reflectance. These conclusions apply directly to those specific bands used in this research; for other bands or narrower bands, the general conclusions would probably be about the same.

IMPLICATIONS OF THE DATA

Once reflectance measurements have been made, these data theoretically can be used for the selection of a *best* spectral band for discriminating the measured formations by tonal contrast on aerial photography. The generally accepted technique for selection of *best* band is to select that band having the maximum contrast ratio for the formations being considered (where the contrast ratio is defined as the ratio of the band reflectance of the two formations being considered, and, by convention, a number greater than or equal to 1.0). The reason for using the contrast ratio is because it is a mathematical relationship that relates the resulting film density to the exposure on the film.

However, in order to select the band with the maximum contrast ratio, it is necessary to be confident that this ratio is larger than the contrast ratios of all other bands. Using the data from the previous sections, this question can be answered in the following manner.

As depicted in Figure 9, a min-max interval on the mean contrast ratio can be derived that is similar to, and derived from, the 80-percent confidence intervals on the band reflectance means of each band for two adjacent formations.

Then, using this min-max interval on the contrast ratio, the equations for the 80-percent confidence interval on the band reflectance mean, and the data summarized in this paper, it is possible to calculate the required number of measurements per band per formation (sample size) to be confident that the contrast ratios are different (nonoverlapping min-max intervals). Because of the lack of established statistical procedures for this type of calculation, the sample sizes derived can only be treated as order-of-magnitude figures. An example of the calculation procedure is given in Table 2 and the results in Table 3.

Thus from Table 3 and the generalizations that the typical standard deviation is greater than 0.042, that an average population standard deviation is about 0.07, and that a typical difference between mean contrast ratios is 0.16; the number of measurements required in order to select the *best* band for the discrimination of two formations is much too large for a practical technique.

As a further test of this conclusion and as a suggested procedure for future research, the following observation is offered. If a confidence level of 95 percent on the band reflectance mean had been used instead of an 80-percent confidence interval, then in almost all applications the confidence intervals

TABLE 2. ACTUAL EXAMPLE OF THE CALCULATION PROCEDURE USED TO DETERMINE THE MINIMUM SAMPLE SIZE.

$\bar{w} \pm \frac{t \cdot s}{\sqrt{n}}$	Student's confidence interval t = Student's T s = sample standard deviation n = sample size $\bar{w}$ = sample mean.
$\frac{0.2600}{0.2025} = 1.25$	Mean contrast ratio in a given band for two adjacent formations with mean band reflectances of 0.2600 and 0.2025 respectively.
$\frac{0.2525}{0.2100} = 1.20$	Minimum contrast ratio ±0.0075 interval on the mean band reflectance and
$\frac{0.2675}{0.1950} = 1.37$	Maximum contrast ratio approximately a ±0.08 interval on the contrast ratio.
$\frac{t \cdot s}{\sqrt{n}} = .0075$	From Student's t confidence interval and assuming $t = 1.3$ and $s = .043$
n = 53.7	Sample size = 54.

on a log band reflectance-filter plot (such as Figure 5) would have overlapped. Thus, the same type of sample size conclusion would have been drawn more easily and rapidly. This observation, of course, is derived in retrospect and applies to these data only.

Further support of the conclusion that a *best* band cannot be practically selected can be derived by an analysis of the relative amplitude variation of band reflectance between formations. Figure 10 was prepared by normalizing the grand mean band reflectance data so that the *NF*-band has a value of 1.00. The circles are the normalized grand mean of all formations and the dashed lines are the normalized 80-percent confidence interval. The circles and confidence intervals are connected between bands for visualization. Then, normalizing the mean data for each formation, it was found that all of the means were not statistically different at the 5 percent significance (95-percent confidence) level from the grand mean. Therefore, the differences between the band reflectance data for most formations have a constant relative difference that is independent of wavelength.

TABLE 3. RELATIONSHIP BETWEEN SAMPLE SIZE (*n*), SAMPLE STANDARD DEVIATION (*s*) THE DIFFERENCES BETWEEN MEAN CONTRAST RATIOS (*D*), AND THE LENGTH OF THE INTERVAL ON THE CONTRAST RATIO (LCR). (These sample sizes are believed justified as order-of-magnitude estimates only.)

s	.020	.038	.042	.070	.100	D	LCR
n	28	100	121	332	676	.10	±.05
	12	45	54	147	300	.16	±.08
	7	25	31	82	169	.22	±.11
	2	7	8	21	42	.44	±.22

If this conclusion is valid, using one known band reflectance the band reflectance for the other 12 bands can be calculated. An empirical solution of this prediction is an equation of the form:

$$B_i = B_m \times P_i$$

where B_i is an unknown band band reflectance $i = 1 \ldots 12$, B_m is the known or measured band reflectance, and P_i is the proportionality factor between B_m and B_i, $i = 1 \ldots 12$. Selecting the *NF*-band as the known band reflectance, because this band averages across the full spectrum, and using the grand mean data from the Phantom Canyon Site to derive P_i, the results in Table 4 were derived. The average error is a root-mean-square error. From inspection of Table 4, it can be seen that the error is generally less than the minimum average standard deviation, 0.04 band reflectance.

DISCUSSION

In the previous section, we have summarized the rock band reflectance properties of more than 8600 measurements from the Canon City and Kassler test sites, shown that

TABLE 4. CALCULATED BAND REFLECTANCE.

Average error for all the Phantom Canyon data is 0.021. Grand average error of all data shown is 0.035. Average error is a root-mean square type error. *P* is the proportionality factor between the measured values and the *NF*-band reflectance. *M* is the measured value and *C* is the calculated value.

Filter	Grand Mean Band Reflectance	P	Precambrian M	Precambrian C	Manitou Fm. M	Manitou Fm. C	Fremont Fm. M	Fremont Fm. C	Fountain Fm. M	Fountain Fm. C	Rusty zone M	Rusty zone C	Lower Tepee zone M	Lower Tepee zone C	C Unit M	C Unit C	Average Row Error
NF	.166		.144		.120		.198		.122		.176		.181		.113		
47B	.099	0.596	.093	.086	.071	.072	.112	.118	.065	.073	.100	.105	.097	.108	.073	.067	.007
57	.147	0.886	.117	.126	.101	.106	.168	.175	.082	.108	.189	.156	.139	.160	.113	.100	.020
25	.192	1.157	.181	.167	.150	.139	.203	.229	.144	.141	.206	.204	.235	.209	.175	.131	.025
2C	.157	0.946	.136	.136	.124	.114	.173	.178	.108	.115	.204	.166	.154	.171	.117	.107	.019
8	.168	1.012	.149	.146	.120	.121	.185	.200	.118	.123	.183	.178	1.80	.183	.112	.114	.007
15	.160	0.964	.145	.139	.120	.116	.189	.191	.116	.118	.160	.170	.157	.174	.145	.109	.017
22	.194	1.169	.143	.168	.125	.140	.249	.231	.130	.143	.215	.206	.212	.212	.141	.132	.016
70	.227	1.367	.205	.197	.174	.164	.243	.271	.145	.167	.270	.241	.227	.247	.174	.154	.023
92	.222	1.337	.211	.193	.163	.160	.241	.265	.157	.163	.211	.235	.212	.242	.132	.151	.021
89B	.253	1.524	.252	.219	.193	.183	.283	.302	.169	.186	.230	.268	.251	.276	.235	.172	.036
87	.273	1.645	.261	.237	.203	.197	.297	.326	.183	.201	.259	.290	.334	.298	.239	.186	.034
87C	.258	1.554	.268	.224	.205	.186	.297	.308	.187	.190	.259	.274	.260	.281	.189	.176	.023
Average Column Error			.021		.010		.019		.014		.025		.022		.032		

Filter	Gorge Hills-Florence SE								Kassler					
	Fremont Fm.		Fountain Fm.		B Unit		D Unit		Fountain Fm.		Lyons Sandstone		Glennon Limestone	
	M	C	M	C	M	C	M	C	M	C	M	C	M	C
NF	.265		.112		.172		.137		.146		.237		.329	
47B	.138	.158	.081	.067	.117	.103	.113	.082	.101	.087	.148	.141	.232	.196
57	.210	.235	.096	.099	.171	.152	.148	.121	.109	.129	.194	.210	.319	.291
25	.298	.307	.169	.130	.209	.199	.192	.159	.184	.179	.256	.274	.357	.381
2C	.233	.251	.103	.106	.156	.163	.135	.130	.118	.138	.220	.224	.330	.311
8	.253	.268	.103	.113	.147	.174	.127	.139	.119	.148	.246	.240	.235	.333
15	.293	.255	.119	.108	.159	.166	.130	.132	.118	.141	.239	.228	.338	.317
22	.282	.310	.151	.131	.183	.201	.171	.160	.151	.171	.237	.277	.356	.385
70	.202	.362	.215	.153	.207	.235	.210	.187	.315	.200	.295	.324	.373	.450
92	.299	.354	.189	.150	.199	.230	.203	.183	.247	.195	.259	.317	.357	.440
89B	,403	.404	.243	.171	.233	.262	.226	.2$9	.272	.223	.336	.361	.460	.501
87	.384	.436	.243	.184	.216	.283	.231	.226	.289	.240	.346	.390	.450	.541
87C	.383	.412	.253	.174			.284	.213			.394	.368	.395	.512
Average Column	.057		.045		.030		.029		.050		.030		.060	

for any spectral band the data can be treated as normally distributed and simple statistics can be used, and most significantly, determined that an impractically large number of observations is required in order to select best filters. With this foundation, we shall discuss what this statistical analysis means with regard to rock discrimination by multiband photography.

Concerning the general applicability of the conclusions drawn, the formations considered have not been selected in a manner that would allow statistical inferences to be made about all rocks, or even all sedimentary rocks. However, there is no geologic reason to suspect that the rocks and formations considered have unique reflectance properties with regard to other sedimentary rocks. Therefore, the conclusions drawn apply in detail only to the formations considered; however, generalizations of conclusions are probably valid for most sedimentary rocks.

The conclusion to be drawn from the previous section is that no practical numerical

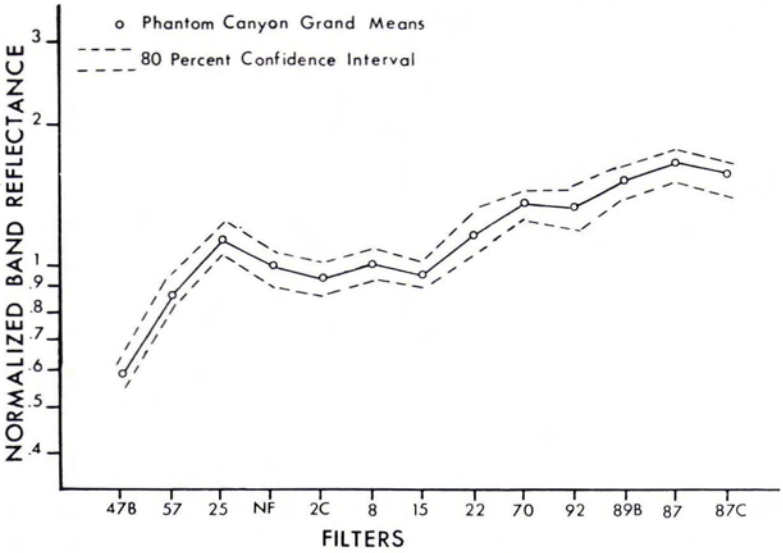

FIG. 10. Normalized band reflectance. *Normalized* means all means were divided by the *NF* mean band reflectance. The *NF* band was selected because the *NF* band averages over the full spectrum. All observed mean band reflectances are not different from the means shown in this graph at 95-percent confidence.

basis exists for selecting any particular spectral band as best for rock discrimination and, in most instances, little numerical basis exists for selecting better spectral bands. Therefore, information useful for the design of multiband photography *cannot* be obtained from the type of *in situ* spectral measurements considered here. Therefore the designed multiband photography concept does *not* have a practical numerical basis from which the concept can be applied to rock discrimination.

This implies that the information content of all spectral bands, or combinations of bands, should be the same.

Finally, the 13 mean band reflectances can be calculated by knowing one of those means. Therefore, similar differences of band reflectance exist between all the spectral bands for any two formations. Thus, there is (are) no best band(s) for sedimentary rock discrimination where the residual soils and rocks are observed.

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