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EVALUATION OF SKYLAB S190-A PHOTOS
FOR ROCK DISCRIMINATION
AND COMPARISON WITH ERTS IMAGERY

by

Daniel H. Knepper

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ABSTRACT

A suite of 12 lithologic contacts was studied on ERTS images, Skylab S190-A photographs, and high altitude color aerial photography to determine the information content and detectability of contacts on each type of image. The study shows that some criteria can be used for selection of optimum space images for geologic interpretation. With ERTS imagery, band 5 is the overall "best" band, and maximum information comes from band 5 images from combined summer and winter scenes. Of the Skylab S190-A photography, color photos are best and the season is not important. Skylab photographs are better than ERTS images for both information content and ease of interpretation.

CONTENTS

INTRODUCTION

Photographs acquired on the three Skylab Missions and multispectral scanner imagery from the ERTS (now Landsat) satellites are an abundant source of information for the geoscientist. Choosing data from this vast storehouse can be an expensive and time-consuming job if there are no criteria on which to base a selection. The purpose of this study is to determine if there are optimum images and photographs for discriminating lithologies.

A study was previously conducted to determine if band and time of year of ERTS imagery are significant factors in the ability of a photointerpreter to detect lithologic contacts, and, if possible, to determine which bands and times of year produce the best results. This study was described in Knepper (1974, p. 39-79).

The method used in the ERTS study was easily adopted to evaluating the detectability of lithologic contacts on Skylab S190-A photos, and, because of the methods used, a direct semi-quantitative comparison could be made between the detectabilities of lithologic contacts on these two types of remote sensor data. The results reported here may aid practicing geoscientists in intelligently choosing the most appropriate type of imagery and photographs for lithologic mapping.

METHOD AND APPROACH

Twenty-four known lithologic contacts in the Canon City region, central Colorado, were selected for study and evaluation on ERTS imagery. Of these twenty-four, twelve were selected for identical study and evaluation on Skylab S190-A photos to reduce the time consumed in the overall analysis procedure.

Each contact, or a specific portion of a contact, was defined and located on small-scale (1:100,000) positive color transparencies (Fig. 1), and the detectability (how easily seen) of each of the contacts on the photos was arbitrarily given a value of 1.0. This operation formed a common base reference for comparing detectabilities on ERTS images and Skylab S190-A photos directly.

The defined contacts were then studied on each band of 4 sets of ERTS imagery and 3 sets of Skylab S190-A photos acquired at different times of year (Table 1), and the detectability of each contact was evaluated relative to the reference color photos. These detectability values were always less than or equal to 1.0.

Neither the ERTS imagery nor the Skylab S190A photos were studied in stereo, since lack of stereo is the general case for much of the areal coverage of these data. Experience suggests that where stereo is available, the detectability values would be significantly higher than without stereo.

Figure 1. Reproduction of one of the small-scale color photos (NASA Mx 211, 31-0009) used to define geologic contacts for this study. Some contacts are identified. Each contact, by definition, has a detectability of 1.0 on this photography.

Table 1. ERTS imagery and Skylab S190-A photos of central Colorado evaluated in this study.

ERTS IMAGERY

	IMAGE I.D.	DATE ACQUIRED	BANDS
1.	1172-17141	11 Jan. 1973	4,5,6,7
2.	1028-17135	20 Aug. 1972	"
3.	1154-17143	24 Dec. 1972	"
4.	1334-17142	22 June 1973	"

SKYLAB S190-A PHOTOS

	MX	TRACK	DATE	FRAME	BANDS
1.	SL2	34	5 June 1973	014	Color, Color IR,
2.	SL3	34	3 Aug. 1973	003	Red, Green, IR 1 and
3.	SL4	34	29 Jan. 1974	351	IR 2 on all sets.

Evaluation of the detectabilities was performed on the 10" x 10" positive ERTS transparencies and the 70mm Skylab S190-A positive transparencies using a 1X to 7X magnifying glass and a 10X hand lens. The 4 sets of ERTS imagery were laid out in stacks on a light table according to image set. One image was chosen from each stack and the 4 images were evaluated relative to the color reference photo and to each other. Next, all four bands of one image set were evaluated relative to the color reference photo and to each other. Finally, the remaining images in each set were evaluated using the color reference photo and the previous evaluations as a guide. The same procedure was used to evaluate the Skylab S190-A photos. All the evaluations were performed without intentionally knowing the specific image or photo set and band being evaluated in order to try to reduce any conscious or unconscious bias in the evaluation procedure.

Occasional adjustments in the values of detectabilities for a given contact were necessary during the evaluation process. This occurred when a contact was found to have a detectability in between two previously evaluated images, but the two previous evaluations only differed by 0.1 (i.e.-no value to give the new image). The adjustments consisted of sliding the higher or lower detectabilities up or down, respectively, by a value of 0.1 in order to make room for the in-between image, rather than use fractions of a detectability point.

Table 2 is an example of a portion of the type of evaluation matrix that was constructed for the ERTS and Skylab data.

Table 2. Partial evaluation matrix generated during evaluation of detectability of lithologic contacts on ERTS imagery. J, January; A, August; D, December; Ju, June.

	CONTACT											
	1				2				3			
ERTS IMAGE	J	A	D	Ju	J	A	D	Ju	J	A	D	Ju
BAND												
4	0	.7	.1	.9	0	.4	.3	.7	0	.2	0	.1
5	0	.6	0	.8	0	.3	.3	.9	0	.4	0	.3
6	0	.4	0	.3	0	.6	.2	.8	0	.1	0	.2
7	0	.4	0	.2	0	.3	.1	.8	0	.1	0	.1

RELIABILITY OF DETECTABILITY EVALUATIONS

To test the reliability of the detectability evaluations, a second investigator was asked to produce a detectability matrix of the 12 lithologic contacts on the 3 sets of Skylab S190-A photos using the same monoscopic evaluation technique. When the matrix was completed, the detectability values for each corresponding photoset-contact-band were plotted as paired points and the best-fitting straight line was constructed using the least squares method (Fig. 2).

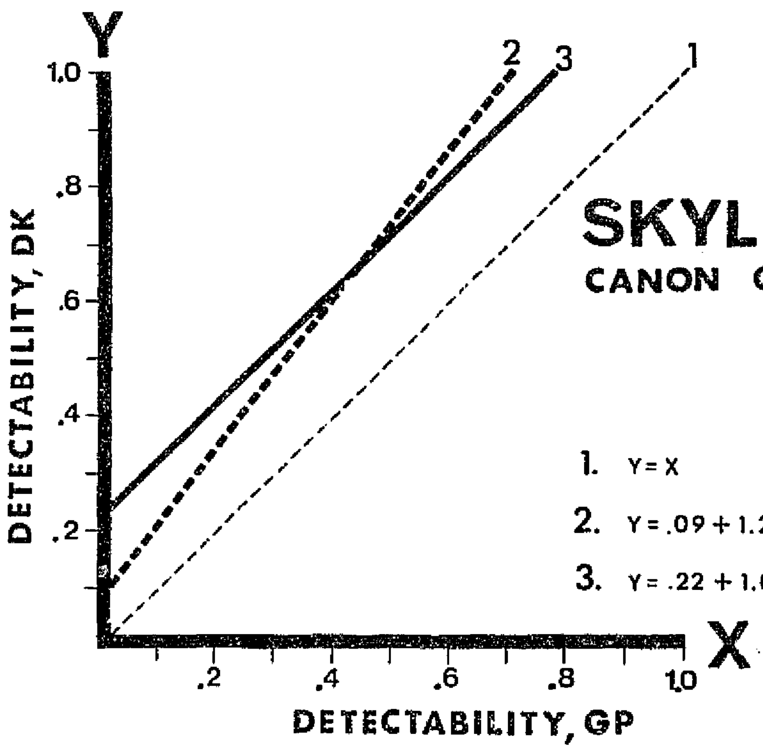

Figure 2. Least squares lines constructed for the detectability evaluations of the same contacts and photos made by two independent investigators, DK and GP. See text for explanation.

Line 1 is the line that would indicate perfect agreement between the two sets of evaluations; line 2 is the least squares line first constructed. Inspection of the plot indicated that something less than perfect agreement existed in the two sets of evaluations, so the two data matrices were re-examined to locate the major differences. The points of major disagreement were found where detectability values are very small, specifically, where a decision had to be made as to whether the lithologic contact was not detectable (detectability = 0.0) or barely detectable (detectability - 0.1).

To test this, all of the detectability data points where one of the data sets had a value of 0.0 or 0.1 were excluded from the data matrix and a new least squares line (line 3 in Figure 2) was constructed. The line (line 3) shows that there is very good relative agreement (slope nearly equal to 1), but a constant difference in detectability value of 0.22 between the two sets of evaluations.

The results of this test for reliability in detectability evaluations indicate that:

1. Except where the evaluators are forced to make a decision as to whether a lithologic contact _is_ or _is not_ detectable, good relative agreement can be obtained from two independent evaluators using the evaluation method described.

2. Evaluations made by two independent investigators can be directly compared if the detectability data are normalized.

STATISTICAL TESTS

After all the detectability evaluations were completed for the lithologic contacts, statistical tests were run on various subsets of the resulting data matrices. These tests compare the mean detectability of a data subset with the mean detectability of another subset, producing information as to whether the means are statistically different at a given level of significance (α value). Three types of tests were used:

1) Standard F-test at $\alpha = 0.05$

2) Confidence intervals at $\alpha = 0.05$

3) Duncan multiple-range test at $\alpha = 0.05$

The standard F-test and the Duncan multiple-range test are relatively rigorous statistical tests. Confidence intervals are useful in visualizing the variability between a large number of populations (Miller and Freund, 1965).

Inspection of the completed Skylab detectability data matrix and the mean values of detectability for the six bands of photography showed that detectabilities in the two black and white photo-infrared bands are so inferior to both ERTS imagery and the remaining Skylab bands, that further statistical testing was unnecessary. They are, therefore, excluded from the statistical analyses discussed below.

Six different subsets of the data matrices were analyzed:

(1) Overall band--to compare the relative usefulness of the bands

(2) Overall image set--to determine if the time of year the imagery or photography was acquired affects the detectability of contacts, regardless of band

(3) Overall contact--to determine if some contacts are easier to detect than others, regardless of band and time of year

(4) Contact/band--to determine if specific contacts are best detected on any particular band

(5) Contact/image or photo set--to determine if specific contacts are best detected on any particular image or photo set (time of year).

(6) Band/image or photo set--to determine if any particular band is best for a given image or photo set (time of year)

OVERALL BAND DETECTABILITY

The initial step in data analysis was to test the mean detectability (of lithologic contacts) between the four bands of ERTS MSS imagery and between the four bands of Skylab S190-A photography. The results of these tests are summarized in Figures 3 and 4. Initial F-testing was conducted to determine if statistical differences exist; further F-testing was used to determine where the statistical differences occur.

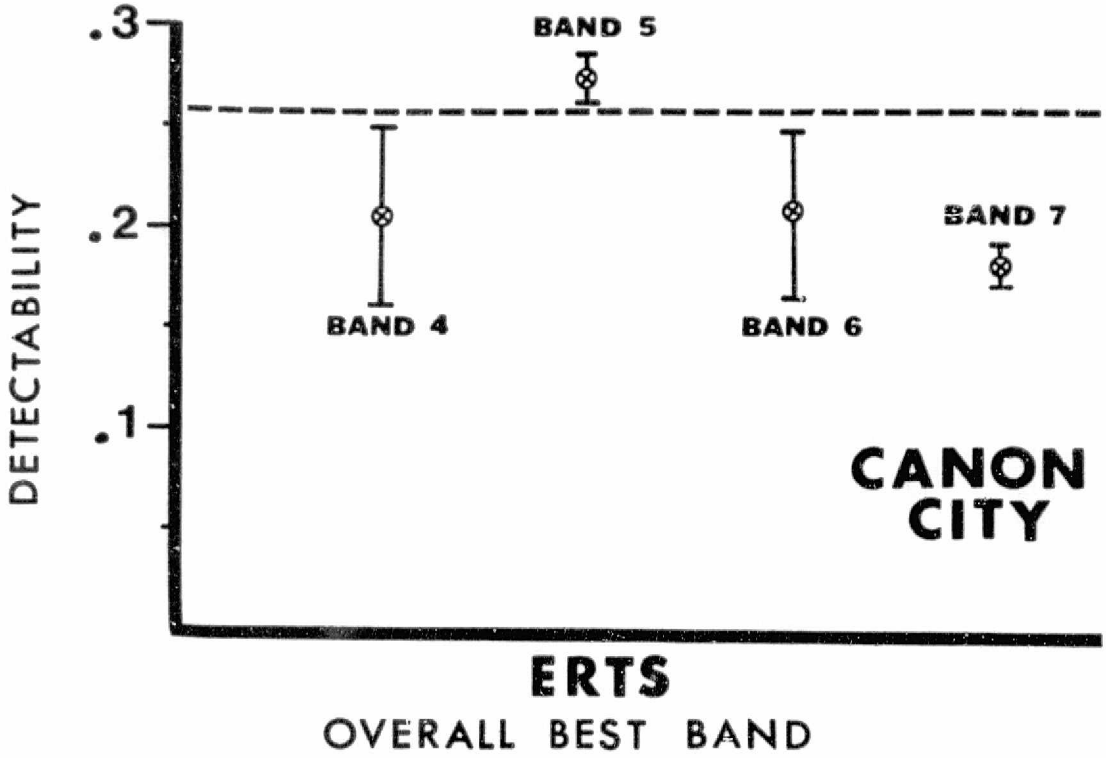

Figure 3. Confidence intervals of mean band detectability of ERTS images studied. Dashed lines indicate statistically separable bands at $\alpha = 0.05$.

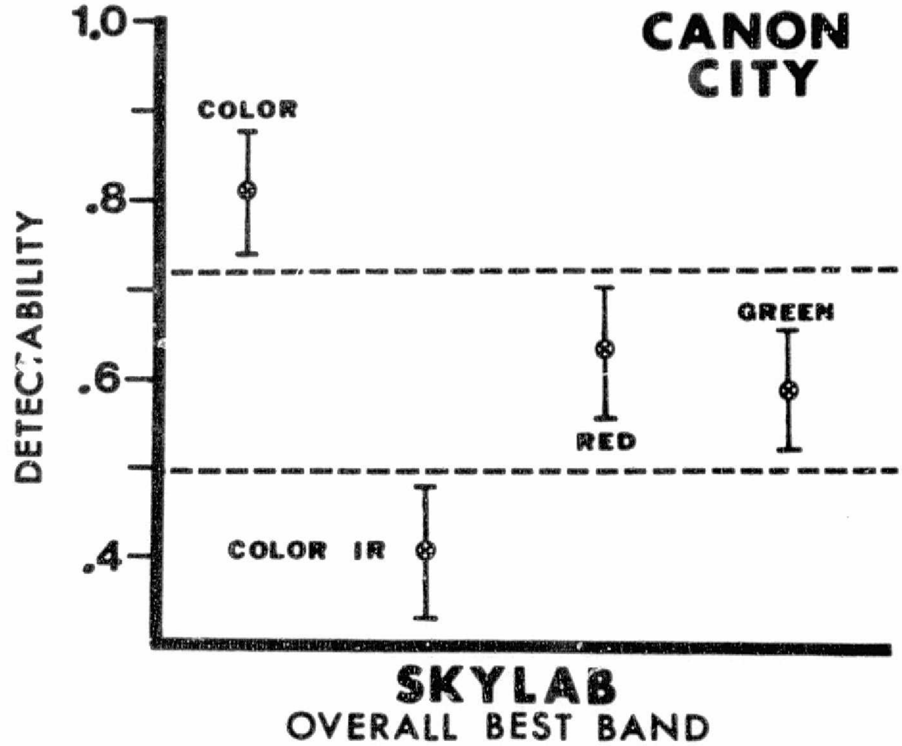

Figure 4. Confidence intervals of mean band detectability of Skylab S190-A photos studied. Dashed lines indicate statistically separable bands at $\alpha = 0.05$.

It is clear from these tests that the band of imagery and photography must influence the detectability of lithologic contacts. Band 5 (red) appears to be singly the "best" band for overall detection of lithologic contacts on ERTS imagery, while the remaining 3 bands are not statistically separable. S190-A color photography ranked the highest of the Skylab photos studied, with the red and green band photos in a statistically separable group below the color, but above the color infrared photography.

A moderate degree of caution should be exercised before extrapolating these results too far, since they represent only the general case. That is, all influences of image or photo set (time of year) and individual lithologic contacts are confounded in the analysis.

OVERALL IMAGE SET DETECTABILITY

It might be anticipated that the detectability of lithologic contacts in central Colorado would be highly sensitive to the time of year that the data were acquired, since the time of year affects many factors including sun azimuth and elevation, vegetation, snow cover, and soil moisture. The results of F-testing shown in Figures 5 and 6 indicate, however, that the time of year has no significant effect on the detectability on either ERTS images or Skylab S190-A photos. These relatively surprising results are

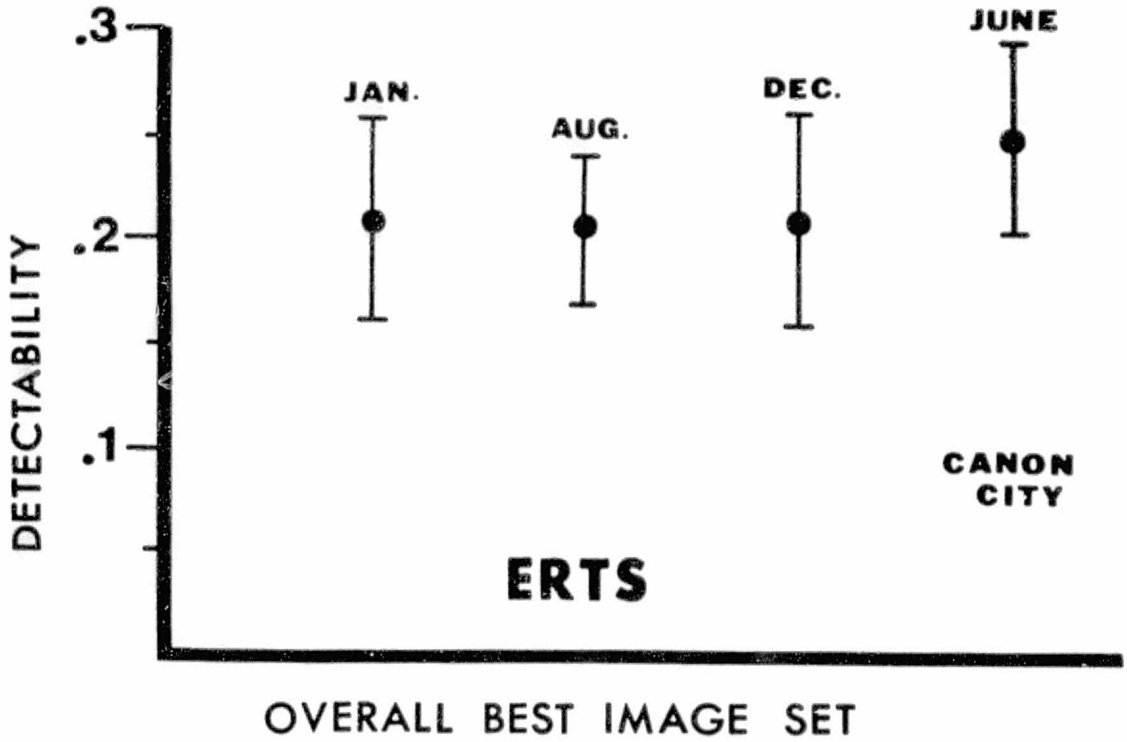

Figure 5. Confidence intervals of mean image set detectabilities of ERTS images studied. There are no statistical differences at $\alpha = 0.05$.

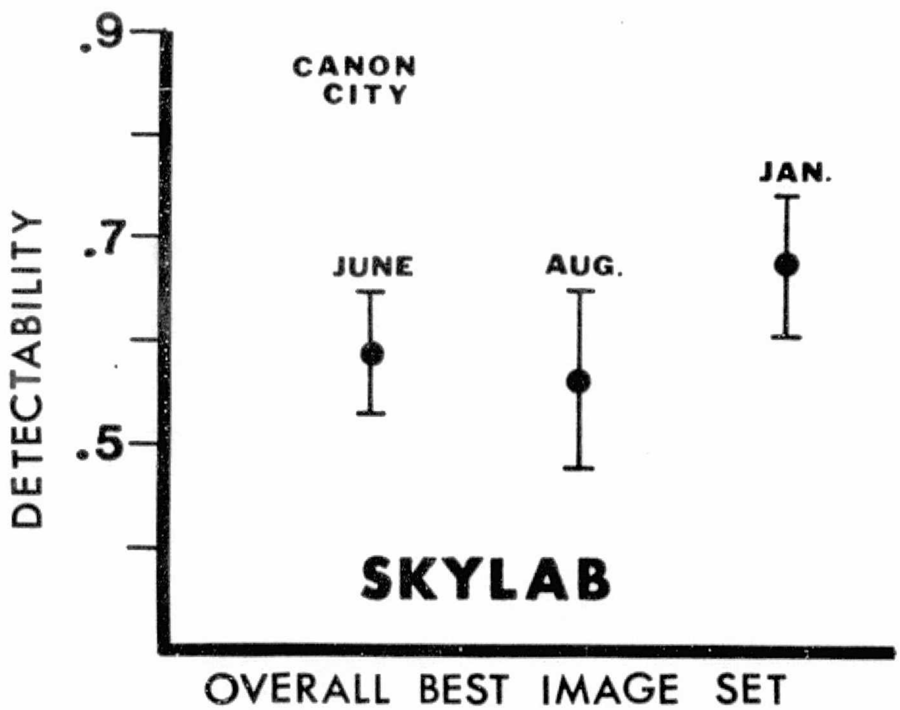

Figure 6. Confidence intervals of mean image set detectabilities of Skylab S190-A photos studied. There are no statistical differences at $\alpha = 0.05$.

discussed and, perhaps, explained in a later series of tests that compare the detectability of individual contacts as a function of time of year.

OVERALL CONTACT DETECTABILITY

Confidence intervals of the mean detectability of the lithologic contacts were constructed to examine their variation in detectability. The confidence intervals for those contacts studied on both ERTS and Skylab data are shown in Figure 7.

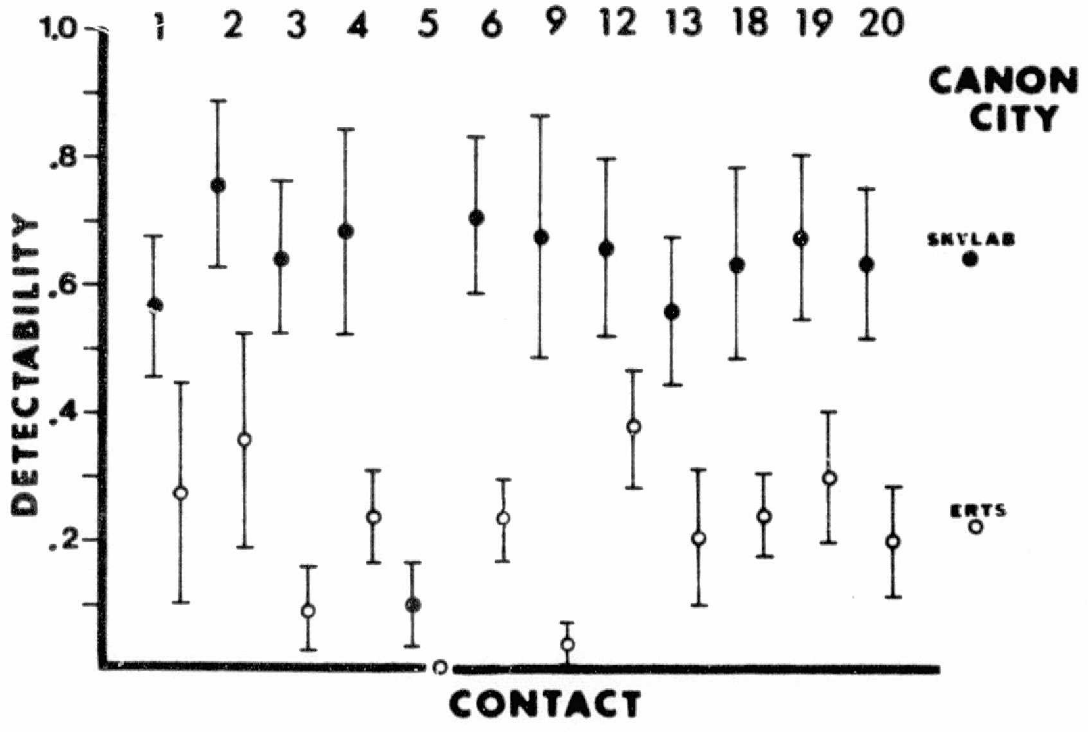

Figure 7. Confidence intervals of mean detectability of the 12 common lithologic contacts studied on both ERTS and Skylab imagery. $\alpha = 0.05$.

It is difficult to draw many conclusions from the plot in Figure 7, with the notable exception that detectabilities on the Skylab photography are consistently higher than on the ERTS imagery. The variations of mean contact detectabilities within the ERTS and the Skylab groups appear to be similar suggesting that some contacts are, indeed, more difficult or easier to detect than others. However, when the confidence intervals are replotted in order of decreasing $\bar{X}$, the order of the contacts is not the same for ERTS and Skylab S190-A (Fig. 8). The shifts are, by and large, minor and contacts

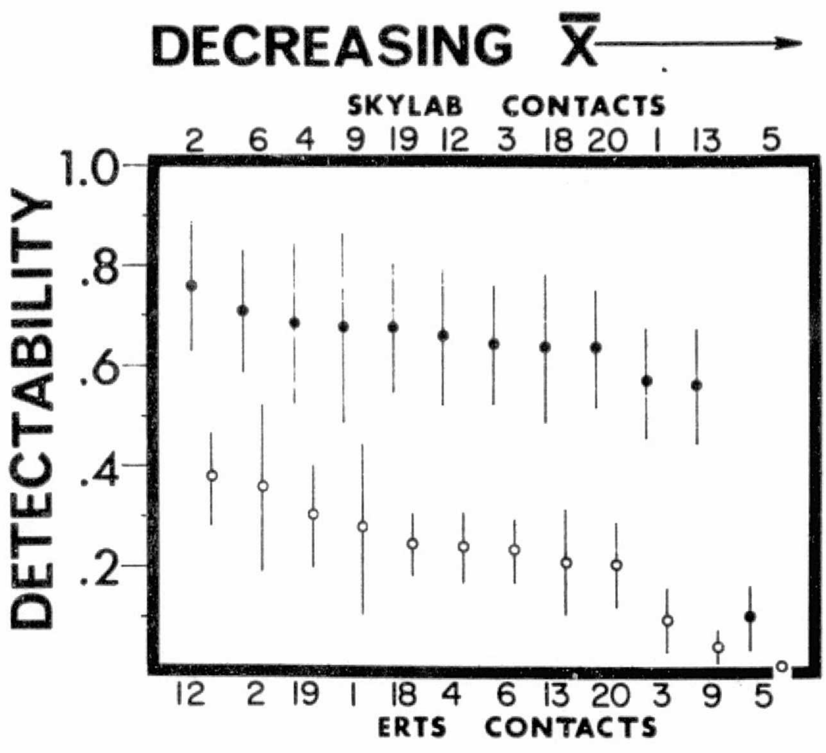

Figure 8. Confidence intervals of mean detectability of the 12 common lithologic contacts studied on both ERTS and Skylab S190-A imagery plotted in order of decreasing $\bar{X}$. $\alpha = 0.05$.

that are easy or difficult to detect on ERTS are also generally easy or hard to detect on Skylab S190-A. It should be noted that the range of the means, particularly those of intermediate value, is fairly small so that small variations in the original detectability evaluations could easily result in a shift in position of 4 or 5 positions.

INDIVIDUAL CONTACT DETECTABILITY

The mean detectability of each of the 12 contacts was statistically analyzed with respect to band and to month using the Duncan multiple-range test (Miller and Freund, 1965). This test can be used (1) to determine whether statistical differences exist between the measurements from several different populations and (2) to determine the relative order of the population measurements (best to worst; highest to lowest, etc.) where statistical differences exist. Similar results can be obtained by repeatedly testing pairs of measurements using the simple F-test, but the individual tests are not independent; a constant level of significance is maintained using the Duncan multiple-range test and the analysis takes less time.

CONTACT/BAND

The results of analyzing contact detectability as a function of band is shown in Table 3. None of the 12 contacts

Table 3. Number of contacts that are statistically more detectable on each band of ERTS and Skylab S190-A. Several contacts were found to be more detectable on statistically unseparable bands of Skylab S190-A photos.

BEST BAND FOR
EACH CONTACT

ERTS	SKYLAB
1. NONE = 12	1. COLOR = 2 2. COLOR, RED AND GREEN = 6 3. COLOR AND RED = 1 4. NONE = 3

is statistically easier to detect on a specific band of ERTS imagery; band does not appear to be important in contact detectability. But, in the test of overall band detectability previously described, band 5 was found to be statistically better. This discrepency is probably due to the difference in the number of observations (sample size) used in the respective tests. To analyze the effect of band on each individual contact, only 4 observations were used (1 from each image set). However, in analyzing the overall effect of band, a total of 96 observations of each band were available for analysis (4 image sets X 24 original contacts studied on ERTS only). In each test of individual contacts, the mean detectability in band 5 was consistently higher than the mean detectabilities in the remaining 3 bands, but this difference did not become statistically significant except when 96 observations were used.

Analysis of the Skylab S190-A photo detectabilities showed results similar to the overall band test (Table 3). 9 of the 12 contacts were statistically more detectable on 1 or more bands, and it is particularly significant that all of these contacts showed color photos in the highest rating.

CONTACT/MONTH

The results of analyzing contact detectability as a function of image set (month) is shown in Table 4. 9 of the

Table 4. Number of contacts that are statistically more detectable on each image set of ERTS and Skylab S190-A. Several contacts were found to be more detectable on statistically unseparable sets of ERTS imagery.

BEST MISSION FOR EACH CONTACT

ERTS	SKYLAB
1. JUNE = 2 2. JUNE OR AUGUST = 2 3. JANUARY = 4 4. DECEMBER = 1 5. NONE = 3	1. NONE = 12

12 contacts are statistically more detectable on one (or more) of the ERTS image sets. These results are interpreted as meaning that the surface expression (and image expression) of some of the contacts is best developed at one time of year, whereas other contacts are better seen at different times

of year. If these contacts and image sets are considered together, as was done in the overall image set analysis, these differences cancel out, indicating that there is no best image set (i.e. - not statistically separable).

Skylab S190-A photo detectabilities, however, apparently are not affected by image set (month) according to both the overall and individual contact analyses. An explanation of the dependence of ERTS and the independence of Skylab S190-A on image set may be contained in the spacial resolution differences between the two systems. The higher spacial resolution of Skylab S190-A photos may allow the subtle surface expression of contacts to be readily detected even at less than optimum times; the low resolution ERTS system may not be able to show these subdued contacts adequately.

INFORMATION CONTENT

Analysis of the detectabilities of the lithologic contacts does not tell anything about the information content of the various possible combinations of band(s) and image or photo set(s). Conceivably, an image with relatively low detectabilities may contain more lithologic information (more contacts detectable) than an image with high detectabilities. Therefore, the information content of the images and photos must be considered if the optimum imagery (most information with least number of images) is to be determined.

The detectability data contain a crude estimate of information content as follows:

(1) If a contact is detectable on a given image or photo (detectability greater than zero), then the information content of that image, for that contact, is plus one.

(2) If a contact is not detectable on the image or photo (detectability equals 0), the information content of that image or photo, for that contact, is zero.

The detectability data matrices can be converted to information content data matrices using the above criteria. Once the detectability data are converted, various subsets of the new matrices can be studied to determine the relative amounts of information that may be extracted using various combinations of band(s) and image set(s).

BAND/ALL IMAGE SETS

The information content of each band of imagery and photography shown in Table 5 is expressed in percentage of the 12 contacts that are detectable.

Table 5. Percentage of contacts studied that can be detected if a given band of imagery is studied in all the available image sets. Four ERTS images and three Skylab S190-A photos must be studied for each band.

ERTS	
Band 4	92
Band 5	92
Band 6	92
Band 7	92

SKYLAB S190-A	
Green	100
Red	100
Color	100
Color IR	100

Clearly, if an interpreter studied all the Skylab S190-A photos from a single band, he could have detected all of the 12 contacts studied. On ERTS imagery, however, only 92% of the contacts (11/12) could be detected from a single band of imagery. In addition, the interpretation of all 16 images (all bands in all image sets) would still allow only 92% of the contacts to be detected; one contact was not detected on any of the ERTS images, probably because of its small areal extent.

IMAGE SET/ALL BANDS

The information content of each set of imagery shown in Table 6 is expressed in percentage of the 12 contacts studied that are detectable.

Table 6. Percentage of contacts studied that can be detected if all the data from a given image set are interpreted. Four images must be interpreted in each image set.

ERTS

January	50
August	75
June	75
December	75

SKYLAB S190-A

January	100
August	100
June	100

The amount of information extracted by an interpreter decreases if ERTS imagery from only a single time of year is analyzed, however, the maximum amount of information (100%) can still be extracted if only a single set of Skylab S190-A photos are studied.

BAND/IMAGE SET

Obviously, the maximum amount of available lithologic information will be gained if each band of each image set is analyzed. But can this same information be found if only 1 or 2 specific images or photos are studied? To check this, matrices showing the information content of each ERTS image and Skylab S190-A photo were prepared (Tables 7 and 8) and the percentage of the contacts that can be seen on each image was computed.

Table 7. Percent contacts detected on single ERTS images.

PERCENT CONTACTS DETECTED ON SINGLE

ERTS IMAGES

	BAND 4 GN	BAND 5 RD	BAND 6 IR	BAND 7 IR
JAN	50	58	58	58
AUG	83	83	83	83
DEC	75	67	58	58
JUNE	83	83	83	67

ALL BANDS + ALL IMAGE SETS = 92%

Table 8. Percent contacts detected on single Skylab S190-A photos.

PERCENT CONTACTS DETECTED ON SINGLE

SKYLAB PHOTOS

	GN	RD	C	CIR
SL2 (JUNE)	100	92	100	100
SL3 (AUG)	100	92	100	83
SL4 (JAN)	92	100	100	100

The maximum amount of information that can be extracted from a single ERTS image is 83% (all bands of August and bands 4, 5, and 6 of June). 8 of the 12 Skylab S190-A photos provide 100% information content and, most notably, color photos provide 100% information on all 3 of the image sets. These results indicate that satisfactory lithologic mapping might be conducted using a single Skylab S190-A photo, while less than satisfactory results could be expected if only a single ERTS image was used. Clearly, the fewer the number of images it is necessary to study to gain the maximum amount of available information, the greater the savings in time and expense.

In order to check whether it may be possible to gain the maximum amount of information using only 2 specific ERTS images, the percent of contacts found considering each permutation of band and image set was computed. It was found that there were 37 pairs of images that would give 92% of the contacts studied--this is the same as when all 16 of the images were studied (i.e.- the maximum amount using these particular image sets). And significantly, each pair of images was a combination of a wintertime and a summertime image, thus pointing up, again, the dependence of the detectability of specific contacts on ERTS imagery to time of year (image set).

SUMMARY AND CONCLUSIONS

Interpretation of the results of the statistical analyses performed in this study cannot be casually extrapolated to all ERTS and Skylab S190-A data in all areas of the world for all lithologic contacts. To the contrary, these results pertain to only those lithologic contacts studied on the specific imagery and photos used. Indeed, it is not conclusively known whether the results apply equally well to all of central Colorado, even though a variety of types of contacts were studied. Agreement with empirical analyses of ERTS and Skylab S190-A data of central and western Colorado, however, suggest that the results are, at least, representative of this area.

The results of this investigation seem to warrant the following conclusions:

(1) The capability of a photointerpreter to detect lithologic contacts is consistently better on Skylab S190-A photos than on ERTS imagery. And of these photos, color photos seem to produce the most consistently good results.

(2) Overall, band 5 (red) seems to be best for detecting lithologic contacts on ERTS imagery. However, on a contact for contact basis, band of imagery seems to be of little importance.

(3) Overall, band is not important in detecting lithologic contacts on Skylab S190-A photos, except for the multiband photo-infrared photos which are extremely poor. On a contact for contact basis, however, detectabilities are somewhat better on the color, red, or green bands; no contacts appeared "better" on the color infrared photos.

(4) Detectabilities of lithologic contacts are sensitive to the time of year the ERTS images are acquired. Some contacts, according to their specific topographic, spectral, and vegetation characteristics, are selectively enhanced or subdued at certain times of year. The maximum amount of information can be gained by studying images from two contrasting times of year (summer and winter).

(5) Individual contact detectability appears to be insensitive to time of year on Skylab S190-A photos. Contrary to ERTS imagery, Skylab S190-A spacial resolution is good

enough that even subdued lithologic contacts, not detectable or poorly detectable on ERTS imagery, are readily detectable at less than optimum times of year.

(6) As few as 2 ERTS images may be studied to gain the maximum amount of information available. One image must be high sun-angle, snow-free and one must be at least low sun-angle. Even then, it is probable that all contacts detectable on Skylab S190-A photos of the same area will not be detected.

(7) A single Skylab S190-A photo, judiciously chosen, will provide as much information as several photos. Color photos seem to be the best choice, although other bands of Skylab S190-A photos may produce the same results; color infrared photography seems to be the worst choice (except for the black and white photo-infrared multiband photos).

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