SECTION 108

EVALUATION OF FACTORS AFFECTING RESOLUTION OF SHALLOW-WATER BOTTOM FEATURES

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INTRODUCTION

Interest in studying the shallow-water areas of the world and the affects of man's activities on these areas is increasing. As a result, aerial photography is becoming important as a means of improving the effectiveness of these shallow-water studies. To ensure good photography, the effects that factors such as submergence depth, sun angle, film and filter type, exposure, aircraft altitude, and polarization have on the photographic resolution of an underwater object must be determined.

Previous aerial photographic studies over water have either concentrated on the attenuation of light or have not considered the full range of variables. Recent work in this field has been performed photographing various subjects such as the deck of small submersible (1), colored and gray scale panels (2,3), and natural bottom features (4,5,6). In none of this work has an underwater resolution target been used.

TEST PROGRAM

To study the affects different factors have on aerial photography of underwater objects, a test program was carried out in the vicinity of the Tektite II habitat in Lameshur Bay of St. John Island in the Virgin Islands. The water in this area is very clear. A specially designed target (fig. 1) with resolution-bar dimensions of 4 by 12 feet, 2 by 6 feet, 1 by 3 feet, and 1/2 by 1-1/2 feet was used to evaluate the affects that the parameters mentioned previously have on underwater resolution. Divers from the Tektite project were used to develop the deployment technique for the target. During actual data collection, divers from the Cape Fear Technical Institute Research Vessel Advance II were used to position the target at depths ranging from 5 to 60 feet below the surface.

The 12- by 24-foot target was made buoyant, was positioned at the proper depth by four winches mounted at the corners of the target, and was fastened by cables to weights positioned on the bottom of Lameshur

Bay. This target was photographed from the selected altitude of 2000 feet for all parameters examined, with the exception of altitude variations, by a P3A aircraft. The aircraft was equipped with a 6-inch-focal-length RC-8 camera, four 3-inch-focal-length KA62 cameras, and four 80-millimeter-focal-length electric Hasselblad cameras. The RC-8 camera used a clear antivignetting filter and was loaded with a specially manufactured Ansco D500 color film that did not have the blue sensitive layer. One of the KA62 cameras used Kodak SO-397 color Ektachrome film, the other three KA62 cameras used Kodak 2405 highspeed Panchromatic film with Wratten 57, 47, and 25A filters. The camera equipped with the Wratten 47 filter malfunctioned during the mission. Three of the Hasselblad cameras used Kodak 2405 film with Wratten 2E and 47, Wratten 45, and Wratten 21 and 57 filters. The fourth Hasselblad camera used Kodak 2424 black and white infrared film and a Wratten 89B filter. The nominal transmittance of the filters used with the Kodak 2405 film is shown in figure 2. On one flight, the four Hasselblad cameras were replaced with a second RC-8 camera that was loaded with specially manufactured Kodak SO-397 color Ektachrome film without the blue sensitive layer. The submerged target was overflown with the aircraft heading north. For control, a duplicate resolution target was laid out on the beach so that the submerged target and then the beach target would be photographed.

AFFECTS OF VARIOUS FACTORS ON RESOLUTION

As expected, submergence depth was the most important factor affecting resolution. A careful examination of the original 2405 film with a 57 filter determined that for the target on the beach, the light-gray 1- by 3-foot bars, as well as the black 1- by 3-foot bars, were visible; but the black 1/2- by 1-1/2-foot bars were barely discernable. At a 5-foot submergence depth, the black 1- by 3-foot bars were visible; however, the light-gray 1- by 3-foot bars were not visible, the light-gray 2- by 6-foot bars were barely visible, and the black 1/2- by 1-1/2-foot bars were poorly defined. At a 15-foot submergence depth, the black 2- by 6-foot bars were visible, and the black 1- by 3-foot bars were poorly defined. At a 30-foot submergence depth, one of the black 2- by 6-foot bars is visible, but no trace of the black 1- by 3-foot bars could be seen. At a 45-foot submergence depth, the black 4- by 12-foot bar is still clearly visible. At a 60-foot depth, the target is barely visible, and there is only an indication of the black 4- by 12-foot bar.

A comparison of the affect that filters and color film have on resolution is given in Table 1. Except for the view taken with the Wratten 25A filter, it is difficult to discern any appreciable difference in the target resolution. Using the Wratten 25A filter, the target at the 30-foot submergence depth could not be imaged, although it was clearly visible at the 15-foot submergence depth. A more critical comparison of the filter performance by viewing the original negatives for all submergence depths (see Table 1) indicated that images obtained with the Ektachrome film (SO-397) were slightly superior to all the others. Those obtained with the 2405 film and following Wratten filters; 2E & 47, 57, and 21 & 57; were next and of equal quality. Images obtained with the 2405 film and Wratten 45 filter were slightly poorer still.

The images obtained with the specially manufactured Ansco D500 film, the specially manufactured Kodak SO-397 color Ektachrome film, and the Kodak SO-397 Ektachrome film were compared with the target submerged to 30 feet. Comparison of the two films without the blue sensitive layer as opposed to standard color film is hampered by the standard color film being exposed in a camera with a 3-inch rather than a 6-inch focal length. Even so, it was difficult to determine visually any significant difference in resolution.

With the target submerged 40 feet it was difficult to determine visually any difference in resolution due to sun angle changes as long as the target is not in the sunglint area. The main affect of varying sun angle is to increase the area of the frame covered by sunglint. The photographs in figure 3 were obtained with a 3-inch-focal-length camera. This figure shows the portion that was affected by sunglint. At the 56^{o} and 71^{o} sun angles, the photographs taken with the 80-millimeter-focal-length Hasselblad camera and a 56-millimeter film format were almost entirely covered by sunglint.

The affect that exposure has on resolution was determined with the target at a depth of 40 feet and the camera set for one-stop underexposure, normal exposure, and one- and two-stop overexposure on four successive overpasses. What was considered normal exposure had been determined by a sequence of test exposures made one month prior to the actual test program. The exposure that gave the best contrast for bottom features was chosen for normal exposure. (This was about two stops over normal land exposure.) Although the total film density varies for the one-stop underexposure, normal exposure, and one-stop overexposure, the resolution of the 4- by 12-foot bars on the target did not change. For the two-stop overexposure, little can be seen other than the boat on the surface.

The affect that aircraft altitude has on resolution is illustrated in figure 4. These photographs were taken with the target submerged 40 feet and the aircraft flying at 2000-, 4000-, and 12,000-foot altitudes. The examples used in figure 4 were taken with Kodak 2405 film and a Wratten 57 filter. The target can be readily identified in both the 2000- and the 4000-foot-altitude photography, but not in the 12,000-foot altitude photography, as a result of the low contrast between the target and the water so that the target is lost in the grain of the image. The 4- by 12-foot bar is distinguishable in the 2000-foot-altitude photograph but is difficult to distinguish in the 4000-foot-altitude photograph.

The effect of using a polarizing filter was determined with the target submerged to a 30-foot depth. A polarizing filter was oriented so as to cause a maximum reduction of glare from the water surface. The camera was opened up two stops to compensate for the polarizing filter. In both cases, the 4- by 12-foot bar is clearly visible in the photographs. There is a slight indication of the 2- by 6-foot bars in the photograph obtained without the polarizing filter.

DENSITOMETRIC ANALYSIS

To avoid subjectivity that may be inherent in the visual analysis of the film density tracings were made over the target using the original Kodak 2405 film exposed with the Wratten 57 filter. All readings made on the underwater target were normalized to readings made on the shore target using the following procedures: (1) For each photographic run density tracings were made of both the underwater and shore target, (2) from these tracing density values for the 4 x 12 foot white and the second 4 x 12 foot black bar were determined for the shore and underwater targets, (3) a relative density versus log exposure (E) curve (figure 5), made from density readings of a step wedge placed on the film before developing, was used to determine the relative log exposure values for both the black and the white bar, (4) a log contrast ratio was computed by subtracting the log E values of the white bar from the black bar, and (5) a normalized contrast ratio was then computed by dividing the underwater target contrast ratio by the shore water target contrast ratio. Results of these densitometer measurements are given in table II.

An indication of the amount of variability in the data is obtained by examining the contrast ratios for the four runs over the target at 40 ft. depth with the camera set for one stop overexposure. These contrast ratio varied from 0.047 to 0.100, a factor of two. However, two of the values were essentially the same, 0.070 versus 0.073 and bracketed the average value of 0.072 for the four measurements. Consistency of this contrast ratio with varying conditions other than depth can be evaluated by examining the remaining data for the 40 foot submergence depth. From this data it is seen that for one stop under exposure and two normal exposures at 34° and 46° sun angles contrast ratios were within the error brackets for the one stop overexposure data. The normal exposure values were very near the average of the one stop overexposure. It is apparent that conditions other than submergence depth have very little influence on the contrast ratio.

Changes of contrast ratio with submergence depth is shown in figure 6. In this figure all readings made at a particular depth were used regardless of the photographic conditions under which they were made. The circles indicate the average values while the error bars indicate the maximum and minimum values for that depth. From 5 ft. depth to 30 ft. depth there was a rapid decrease in contrast ratio. From 40 ft. depth to 60 ft. depth there was little change in the contrast ratio with this change only poorly correlating with depth. A smooth curve could be drawn through the error bar region showing a monotonic decrease in contrast ratio with depth.

Using a polarizing filter did not appear to improve the resolution of the underwater target as its contrast ratio was only 0.072 versus 0.140 for the un-polarized exposure made under the same conditions. A second contrast ratio value of 0.264 for a target at 30 ft. depth and no polarizing filter may be in error as the contrast value for the shore target was considerably lower than all other shore target contrast values.

Due to the large variations in the normalized contrast ratios for targets submerged at 40 ft. depth and the failure of the average contrast ratio to decrease monotonically from the 40 ft. depth to the 60 ft. depth it appears that the densitometric analysis of the photography is no more sensitive than the visual analysis.

CONCLUSIONS

As expected, the most important factors affecting resolution of bottom features are submergence depth and image scale on the original film. Small-sized bars or low contrast features (or both) disappeared quickly with submergence. As long as the film and filters recorded adequate energy in the 410- to 600-millimicron wavelength region, water depth penetration was not seriously affected. Resolution of bottom features was relatively independent of sun angle and exposure as long as sunglint was avoided and exposure was within plus or minus one stop of optimum. Use of a polarizing filter did not improve target resolution.

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TABLE I. ABILITY TO RESOLVE BARS ON RESOLUTION TARGET

SUBMERGENCE DEPTH FT.	WRATTEN FILTER TYPE WITH 2405 B&W FILM					EKTACHROME
	45	2E + 47	25A	57	21 + 57	
60	TARGET	TARGET	NOTHING	TARGET	4 X 12-	4 X 12-
45	4 X 12	4 X 12	NOTHING	4 X 12	4 X 12	4 X 12
30	2 X 6-	2 X 6	NOTHING	2 X 6	2 X 6	2 X 6
15	2 X 6+	1 X 3-	1 X 3-	1 X 3-	2 X 6+	1 X 3-
5	1 X 3-	1 X 3+	1 X 3+	1 X 3+	1 X 3+	½ X 1½

CODE 1 X 3 SMALLEST SIZED RESOLUTION BAR VISIBLE

1 X 3- BAR JUST BARELY VISIBLE

1 X 3+ BAR VERY CLEARLY VISIBLE

TABLE II. DATA FROM DENSITOMETER READINGS, 2405 FILM WITH W-57 FILTER, 2000 FEET ALTITUDE.

TARGET DEPTH (ft.)	FRAME NO.		DENSITY READINGS				CONTRAST RATIOS		NORMALIZED CONTRAST RATIOS	COMMENTS
			SHORE		UNDERW.					
	SHORE	UNDERW.	BLACK	WHITE	BLACK	WHITE	SHORE	UNDERW.		
5	169	168	1.62	2.77	1.27	2.53	4.74	4.63	0.980	
5	175	173	1.48	2.86	1.62	2.92	5.54	5.41	0.980	
15	179	177	1.43	2.70	1.43	1.81	4.95	1.14	0.230	
15	225	224	1.23	2.51	1.50	2.12	4.65	2.14	0.460	Clouds(?)
30	220	219	1.28	2.58	0.62	0.86	4.83	0.66	0.140	
30	230	229	1.67	2.74	0.89	1.07	4.70	0.34	0.072	Polarized
30	233	232	1.70	2.40	1.58	1.85	2.84	0.75	0.264	
40	003	003	1.65	2.67	1.47	1.59	4.20	0.30	0.071	34° sun angle
40	007	007	0.88	2.45	0.89	1.00	5.40	0.30	0.056	1 under exposed
40	015	015	2.00	3.30	1.59	1.70	6.40	0.30	0.047	1 over exposed
40	011	011	1.97	2.87	1.04	1.15	4.10	0.30	0.073	1 over exposed
40	023	023	2.00	3.01	1.31	1.48	4.60	0.46	0.100	1 over exposed
40	027	027	1.97	3.06	1.25	1.38	5.00	0.35	0.070	1 over exposed
40	031	031	1.13	2.53	1.55	1.65	5.10	0.30	0.059	
40	035	035	1.50	2.77	1.50	1.62	5.10	0.33	0.065	46° sun angle
45	213	212	1.32	2.61	1.24	1.37	4.85	0.36	0.074	Clouds (?)
45	216	215	1.35	2.67	1.15	1.34	5.05	0.50	0.099	
60	208	207	1.76	2.78	1.17	1.29	4.40	0.32	0.073	

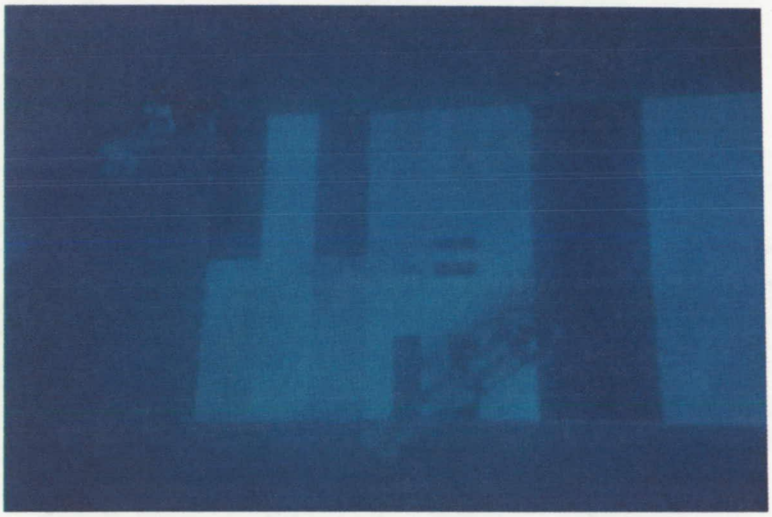
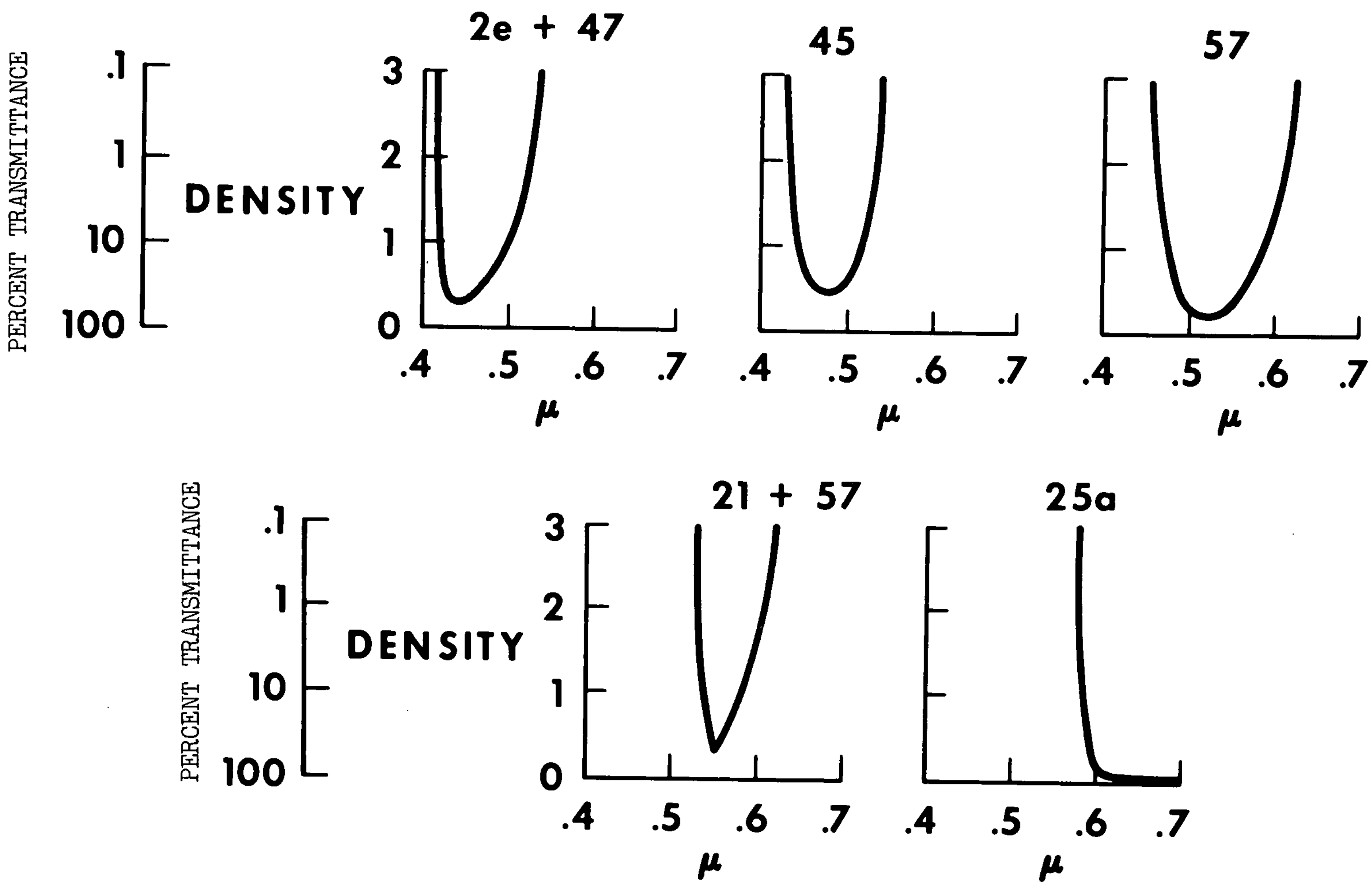
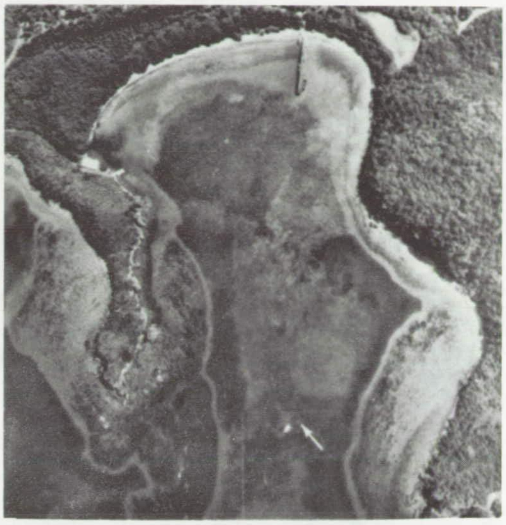


Figure 1. Target used in the test program.

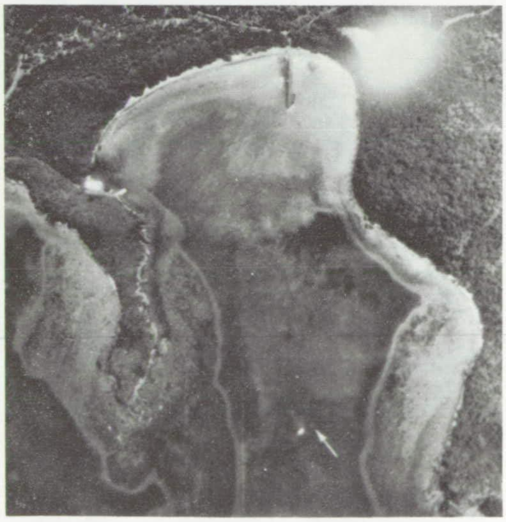


Fugure 2. Filters used in the test program. Kodak 2405 Panchromatic film used in all views.

34° SUN ANGLE



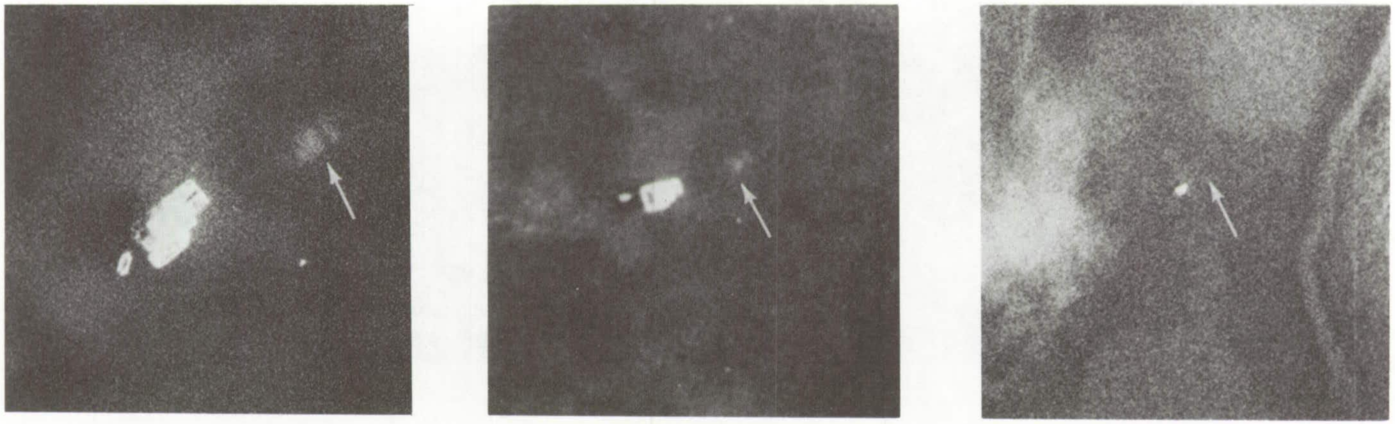
46° SUN ANGLE



56° SUN ANGLE

71° SUN ANGLE

Figure 3. Portion of 4-1/2 inch frame covered by sunglint with the sun at variuos angles.



2000 FT   4000 FT   12,000 FT

Figure 4. Effect that altitude has on resolution. The target is at 40 ft. submergence depth.

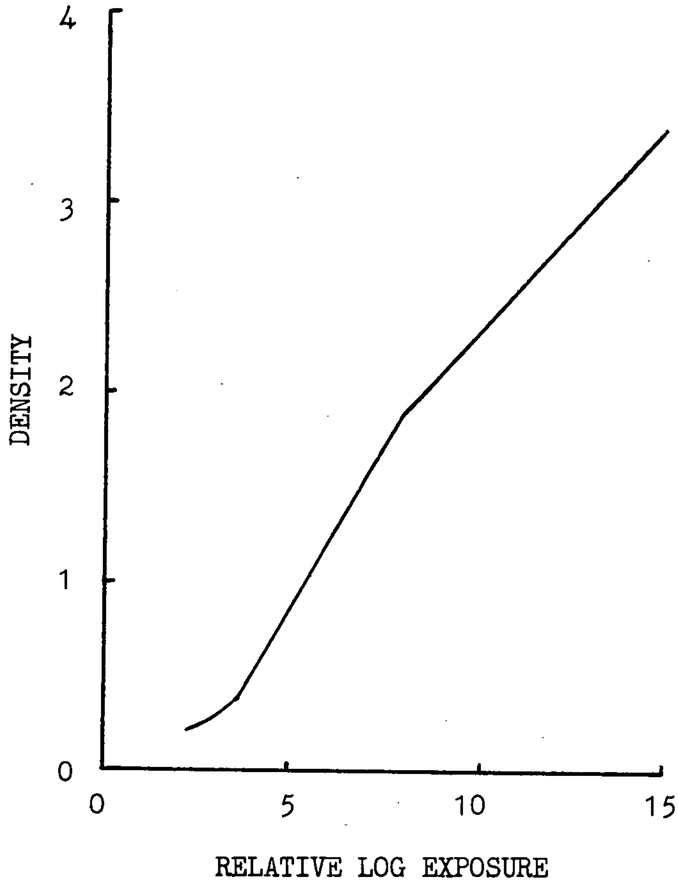


Figure 5. Density versus relative log exposure curve.

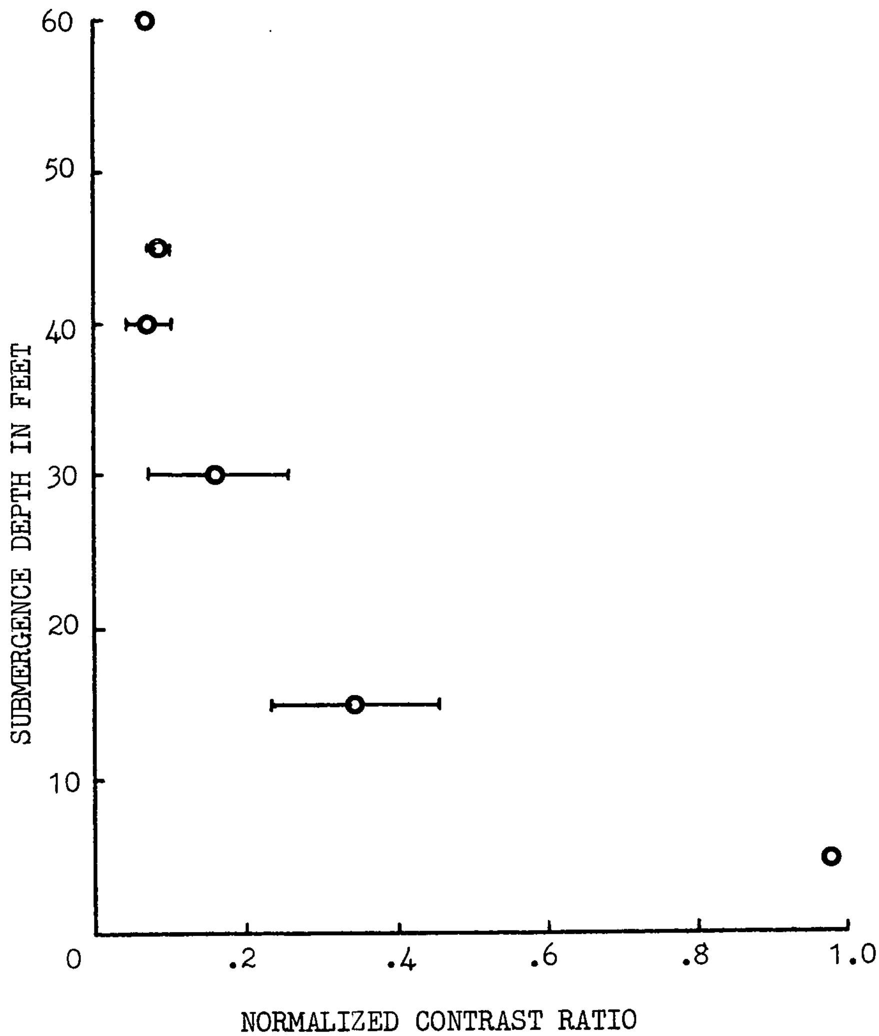


Figure 6. Depth of submergence versus normalized contrast ratio.