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SUBJECT

Report of

Attempts to Measure Visibility at Sea

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by

E. O. Hulburt

NAVAL RESEARCH LABORATORY

WASHINGTON, D. C.

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NAVY DEPARTMENT
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Report

of

Attempts to Measure Visibility at Sea.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

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Prepared by:

E.O. Hulburt, Principal Physicist,
Superintendent, Physical
Optics Division.

Approved by:

H.M. Cooley, Captain, USN, Director.

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ABSTRACT

"Visibility" is defined to be the maximum distance at which a ship or object of considerable size can be seen in daylight at sea as governed by the amount of haze in the atmosphere. There exists at the present time no satisfactory method of measuring visibility by means of apparatus on a single ship. Twelve different suggestions or attempts to devise a method are described, all of which were unsuccessful and unpromising. The difficulty lies in the fact that, although the effects of haze are readily discernible when looking through several miles of atmosphere, they are exceedingly difficult to detect by looking through, or making measurements on, a relatively few yards of atmosphere.

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APPENDICES

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AUTHORIZATION

1. The problem was authorized by the Hydrographic Office second endorsement H4-9(170052) of 6 September 1932.

Reference: (a) NRL Report No. H-1036, "The Problem of Visibility," of 7 March 1934.
(b) "Visibility in Meteorology" by W.E.K. Middleton, University of Toronto Press, 1935.
(c) Director, NRL, ltr. C-H4-4 of 18 May 1936 to BuOrd.

(See also Hydrographic Office third endorsement of 7 April 1936, and Bureau of Navigation letter L1-2/NP14(47) of 5 August 1936.)

INTRODUCTION

2. "Visibility" may be defined as the maximum distance at which an object can be seen. In general, it depends on the haze in the atmosphere and on the color and illumination of the object and the background. Visibility also depends upon the size of the object and on such factors as the keenness of the observer's eyesight, the quality of his binoculars, etc. Rather than to discuss trivial factors of this sort, we may eliminate them and clarify the notion of visibility by defining "visibility" to be the maximum distance at which a ship or object of considerable size can be seen in daylight at sea as governed by the amount of haze in the atmosphere. Defined in this way, the visibility is an important quantity to the mariner, military or non-military.

3. A method of measuring visibility at sea is desirable, and a method which would require apparatus only in the space of a ship would be particularly desirable. Several methods, all unsuccessful, were tested at this Laboratory during the years from 1927 to 1933, the results being described in reference (a). Since 1933, a number of other methods have been examined experimentally; all have been found to be unreliable or too difficult to attempt under ship-board conditions. In the present report are given brief descriptions of all the methods which have been considered, mainly to reduce future repetition of unpromising or discarded proposals. The conclusion is reached, and may be stated in advance, that there exists at the present time no satisfactory method of measuring visibility by means of apparatus on a single ship, and that no method yet proposed can be regarded as even promising. The difficulty lies in the fact that although the effects of haze are readily discernable when looking through several miles of atmosphere, they are exceedingly difficult to detect by looking through, or making measurements on, a relatively few yards of the atmosphere.

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DIRECT ABSORPTION METHOD

4. The method involves the measurement of the light absorption of a sample of the atmosphere by apparatus on the ship from which is inferred the visibility at considerable distances from the ship. Conceivably the apparatus consists of a constant light source at a fixed distance, say, 100 feet, with a suitable photometric device for measuring its brightness. The method, however, demands an accuracy difficult, indeed practically impossible, of attainment in the laboratory or on shipboard. The method depends on the questionable assumption that the atmosphere over a wide area have the same optical characteristics as the shipboard sample. Attempts to use the method at this Laboratory with a 200 yard base line have failed.

POTENTIAL GRADIENT AND DUST COUNT METHODS

5. The atmospheric potential gradient is known to vary with the visibility and has been suggested as a possible means of visibility determination. However, from various researches[1] the conclusion has been established that one could distinguish between thick fog and clear atmosphere by an atmospheric potential measurement, but that thin hazes could not be so distinguished. The same conclusion holds for dust counts or droplet counts of samples of the atmosphere.

1. Chree, Proc. Roy. Soc., 95, 210 (1919); Wait, Terr. Mag., 36, 125 (1931); Schweidler, Jahrb. f. Rad. u. Elekt. 18, 1 (1921).

HUMIDITY METHOD

6. A measurement at atmospheric humidity has been suggested as a means of determining visibility. However, humidity has no direct relation to visibility, for the visibility may be good with humidity high or low and the visibility may be poor with humidity high or low.

SEA-SKY BRIGHTNESS METHOD

7. The method is based on the fact that for the sea ruffled by a breeze the relative brightness of the sea and sky near the horizon varies with the visibility; for a clear atmosphere the sea is much darker than the sky and for a hazy atmosphere the sea brightness near the apparent horizon approaches that of the sky. A small instrument was devised to measure the sea-sky brightness ratio and was calibrated against known visibilities at sea (reference (a)). Subsequent tests have shown that the method on the whole was unreliable, for the instrument readings varied with the state of the sea and the cloudiness of the sky as well as with the visibility, and therefore could not be used as exact criteria of visibility.

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DIP OF HORIZON METHOD

8. The apparent horizon moves closer to the observer and the dip of the horizon decreases as visibility decreases. Therefore, a measurement of the dip has often been suggested as a means of determining visibility. In order for the method to be useful the observer must be at a considerable altitude. This is shown in Table 1

Table 1

	Height of Eye	
	120 Feet	240 Feet
Distance	Dip	Dip
0 miles	90°	90°
3	24'	46'
4	19'	36'
5	16'	30'
6	14'	25'
7	13'	22'
8	12'	20'
9	11'	19'
10	11'	18'
11	11'	17'
12	11'	16'

which gives the dip to the nearest minute of arc at various distances for the observer at 120 feet and 240 feet above sea level. Assuming that the dip may be measured to two minutes of arc, it is seen from the table that the dip method may be useful for visibilities from 0 to 5 miles for a height of eye of 120 feet and for visibilities from 0 to 8 miles for a height of eye of 240 feet. Since heights above 180 feet are rarely available on ships, the method is not useful beyond about 7 miles. It is not known whether the method has ever been tested. It is not known how accurately one can measure the dip of an apparent horizon in haze.

SKY POLARIZATION METHOD

9. It is known that the polarization of the sky is most complete when the air is very clear and becomes increasingly incomplete with increasing haze. However, the haze may be uniformly distributed through the atmosphere or may be confined to a high level or to a low level. In these three cases the state of sky light polarization might be the same and the sea level visibility very different. Therefore, sky polarization is not a satisfactory measure of visibility. Furthermore, the method would be complicated by the fact that the amount of sky polarization varies with the angle from the sun; all measurements would have to be made at, or reduced to, the same solar angle, With a cloudy sky there is no polarization and the method would fail entirely.

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BLUENESS OF SKY METHOD

10. The blueness of the sky is dependent on the amount of haze in the sky. A blueness measurement, however, is not useful for a visibility determination for the same reasons as were given in the sky polarization case.

SCATTERING CHAMBER METHOD

11. The method depends on the scattering of light by air and by particles in the air. It was given preliminary test in this Laboratory and the conclusion was reached that the method would be difficult to carry out in a practicable manner under shipboard conditions.

12. A diagram of the apparatus is shown in Plate 1. A beam of light from a 500 watt tungsten lamp was focused by a lens L into a black box B about two feet long. The beam was limited by diaphragms so that it did not touch the sides of the chamber, and passed into the light trap H where it was absorbed. A side tube with a small telescope N enabled an observer to see the beam scattered by the air in the chamber against the black background provided by the light trap K. The entire apparatus and observer were in a dark room.

13. When air, as free from dust particles as possible, was passed into the scattering chamber the beam, although faint, could be readily seen by an observer with dark-adapted eyes. When air with dust was passed into the chamber, the beam became much brighter. Thus, the experiment merely demonstrated the familiar fact that the scattered light from relatively pure air can be seen, and that the intensity of the scattered light is enormously increased by very small amounts of particles in the air. In fact, the method is well known to be sensitive in rendering visible very small amounts of scattering particles.

14. Conceivably, one could arrange a means of measuring the brightness of the scattered beam; the relation between this and the density of scattering particles, and hence the visibility, could be determined. The apparatus would then be a "visibility meter." However, no further investigation of the method has been made because of some apparent difficulties. The apparatus would require a dark room on shipboard with close access to the open air. A sample of the open air would have to be drawn continually through the scattering chamber without altering its optical properties. Dust or impurities exuded by the ship would affect the air in the scattering chamber and mask the effects of the haze particles in the air. How serious these difficulties might be can not be said, but they might be insurmountable.

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SEARCHLIGHT BEAM METHOD

15. The beam of a searchlight is the light scattered by the air molecules and haze particles of the atmosphere. The brightness of the beam, as viewed by an observer to one side, depends on the amount of haze. At distances less than a few hundred feet from the searchlight the brightness increases with increasing haze. This is true during the day as well as at night. However, in the day time the beam is not visible because it is so feeble in comparison with daylight.

16. Dr. Ross Gunn of this Laboratory proposed and carried out the following experiment. A searchlight beam, produced by a 500 watt tungsten lamp at the focus of a 12-inch parabolic reflector, was chopped at a frequency of 25 cycles per second. A receiver near the searchlight was focused to receive the light scattered backward from the beam. The receiver consisted of a sensitive caesium oxide photoelectric cell at the focus of a 12-inch parabolic mirror. The cell was connected to an amplifier of voltage amplification 80,000 tuned to the frequency of modulation of the beam. In this way it was hoped to detect the beam in the presence of daylight. Tests on the roof of the Laboratory showed that the beam was not intense enough to be detected when the air was clear or hazy and that detection began only when thick fog occurred. It appeared that to achieve detection, and hence measurement, of the beam when the air was clear enough for the visibility to be greater than 1 mile, there would be required a much more powerful modulated searchlight and amplifier than were used. This would necessitate such large, elaborate and extremely sensitive apparatus that no further investigation of the method has been made.

ULTRA-VIOLET ABSORPTION METHOD

17. Measurements in this Laboratory[1] of the absorption of ultra-violet light by the atmosphere showed that for wave-lengths below 2700A haze produces a considerable increase in absorption above that of a clear atmosphere. The increase was sufficient to be measureable with a base-line of 150 feet. Therefore, a measurement of the atmospheric absorption of ultra-violet light in the spectral region below 2700A might be suggested as a means of measuring visibility. However, the known performance of existing ultra-violet producing and measuring equipment permits the statement that such measurements can not be made within the requirements of shipboard practicality.

1. Dawson, Granath and Hulburt, Physical Review 34, 136, 1929.

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GRAYING OF A BLACK HOLE METHOD

18. If a black object is observed from a distance in daylight it appears grayish, and not black, because of the daylight scattered to the observer by the air column between him and the black object. The amount of "graying" of the black object increases with the amount of haze in the air column and with the length of the column, i.e., the distance between the observer and the black object; it also depends on the amount of daylight and the position of the sun relative to the air column.

19. Since the amount of "graying" depends on the haze in the atmosphere and hence on the visibility, it may be suggested as a means of measuring visibility. Experimentally a truly black object is made by a box blackened on the inside with a hole on one side, the diameter of the hole being small in comparison with the dimensions of the box; the hole is the black object.

20. An experiment was arranged to investigate the possibilities of the method. Two boxes, one considerably larger than the other, with holes in their sides, were placed 30 feet and 150 feet from the observer and nearly in line with the observer, the larger box being at the greater distance. The black holes were observed with a small telescope. Thus, in the telescope the observer saw two dark spots. The spot at the greater distance was supposed to appear grayer than the nearer spot. Actually it did appear grayer (or lighter) than the nearer spot, but only when the haze was sufficient to reduce the visibility below one mile. When the air was sufficiently clear so that the visibility was greater than one mile the "graying" of the distant spot relative to the near spot became too slight to detect with certainty, and much too slight to measure.

21. It was concluded that the method was not reliable unless a base-line considerably longer than 150 feet were available. However, a long base-line requires a large box in order that the distant spot be large enough to be seen. For example, for a distance of 500 feet the hole in the box should be at least 4 feet in diameter, and the box should be at least 10 feet on a side. These considerations have precluded further examination of the method, although the method is perhaps the most feasible of any which have been proposed.

METHOD BASED ON THE RELATIVE BRIGHTNESS OF ANOTHER SHIP

22. A variation of the method just described was suggested in reference (c) which envisaged the use of another Navy ship at a known distance, say two miles. Since it seemed impracticable to place on the other ship for photometric purposes a black spot 30 feet or more in diameter, it was thought to be of value to determine whether the other ship itself could be used as a photometric object. Conceivably, the visibility apparatus would then consist of a telescope on one ship equipped with a photometric attachment

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containing a suitable gray spot of a fixed brightness; the telescope would be pointed at the other ship and the brightness of the other ship would be measured relative to that of the gray spot; this might be a function of the haze in the atmosphere and hence of the visibility.

23. The method has been subjected to a preliminary test using, not another ship, but a group of trees on shore. The results have indicated that the method can not be made to yield reliable measurements of visibility.

24. The experiments were carried out at the Naval Proving Grounds, Dahlgren, Virginia. From a lookout post there a good view was obtainable of various headlands and objects along the Potomac River from which the actual visibility could be determined by noting the most distant object which could be seen. At the same time it was possible to select two wooded areas nearly in line, one area being about 500 yards from the observer and one area about 4000 yards from the observer. These are sketched in Plate 2(a). A small photometer was used which consisted of a 6-power telescope and a gray optical wedge. The field of view of the photometer is shown in Plate 2(b). The optical wedge could be slid across the upper half of the field of view, the lower half remaining clear; the position of the wedge was read on the scale in the lower edge of the field of view. The optical transmission of the wedge varied from 20 per cent at one end to 65 per cent at the other. A green color filter was placed in the eyepiece of the telescope to remove any marked color differences of the wooded areas; actually there were no great color differences.

25. The telescope was mounted at the lookout post and was focused on the wooded areas so that the distant area was seen in the optical wedge of part of the field of view and the near area was seen in the lower or clear part of the field of view; this is sketched in Plate 2(c). If the distant wooded area was brighter than the near area due to intervening haze, the optical wedge was slid along until it darkened the distance area to the same brightness as that of the near area. The reciprocal of the transmission of the wedge gave the ratio R of the brightness of the distant area to that of the near area. For example, if the wedge transmission for the equal brightness setting were 0.40, the distant area was 2.5 times as bright as the near area, i.e., R = 2.5.

26. It was supposed, (a) that with a clear atmosphere R would be somewhere near 1, provided the two wooded areas each received the same sky or sun illumination; (b) that in the case of haze the distant area would be brighter than the near area, i.e., that R would be greater than 1; and (c) that R would increase with increasing haze or decreasing visibility.

27. A portion of the measurements by a number of observers during days of various visibilities is given in Plate 3 in which R is plotted as ordinate against the visibility as abscissa. It is seen that on a general average R increased with decreasing visibility.

[redacted]

However, it is evident from the manner in which the points scatter that for the same value of visibility R varied within wide limits, so wide that the measurement was an entirely unsatisfactory indicator of the visibility. Analysis of the data of individual observers showed that the scatter of R was mainly due to difficulty in making the photometric balance with accuracy because of the poor photometric qualities of the wooded areas. These did not possess the smooth and uniform brightness which is necessary when one is trying to adjust two fields of light to equal brightness.

28. The photometer and optical wedge were as good as those employed in laboratory apparatus where an accuracy of determination of R to better than 5 per cent may be obtained. In contrast with the conditions of the above field experiment, in a laboratory apparatus the fields of light are uniform and the observer and photometer are in a dark room carefully screened from all disturbing light. Now, a ship at sea is a much more variable and erratic photometric object than a wooded area on shore, and since the latter was unsatisfactory, it is concluded a fortiori that the ship would be unsatisfactory for photometric purposes.

CONTRAST METERS

29. During the World War there were developed three meters called "visibility" meters. It would be better to term them "contrast" meters. The meters were all based on the same principle and were developed independently by Jones[1] of the Eastman Kodak Company in America, by Wigand[2] in Germany, and by Bennet[3] in England (the Bennet-Cassella Visibility Meter). The meter consisted of a telescope through which the object and the background were viewed. Then a series of absorbing screens were placed over the field of view until the scene became so indistinct that the object was just discernible. The thickness or number of the absorbing screens gave a measure in arbitrary units of the "visibility" of the object, or more exactly, "the contrast of the object with the background." Two of the meters used ground glass screens and one used a dazzle light which could be thrown into the field and the intensity increased until the object was just blotted. As far as is known, none of the three instruments has been used in connection with the measurement of visibility at sea.

1. Jones, Phil. Mag. 39, 96, 1920.
2. Wigand, Phys. Zeit. 20, 151, 1919; 22, 484, 1921; 25, 212, 1924.

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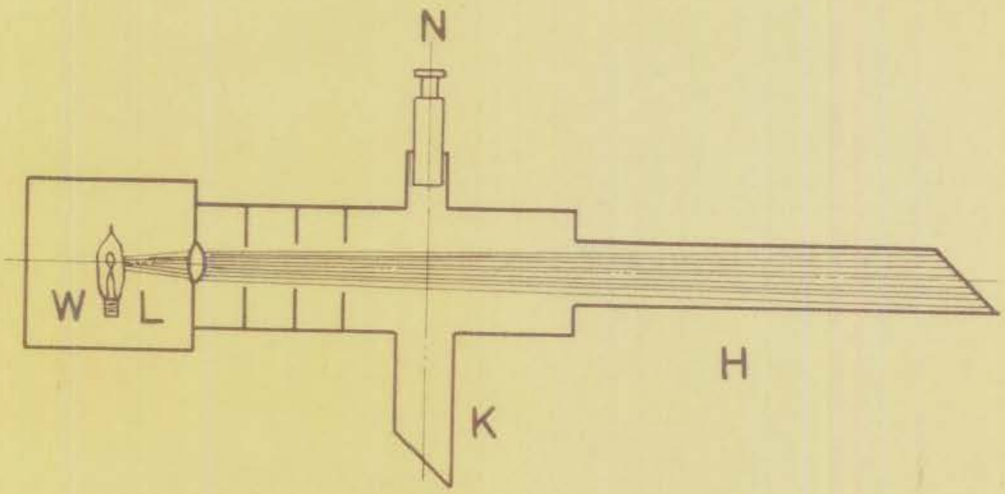


PLATE 1

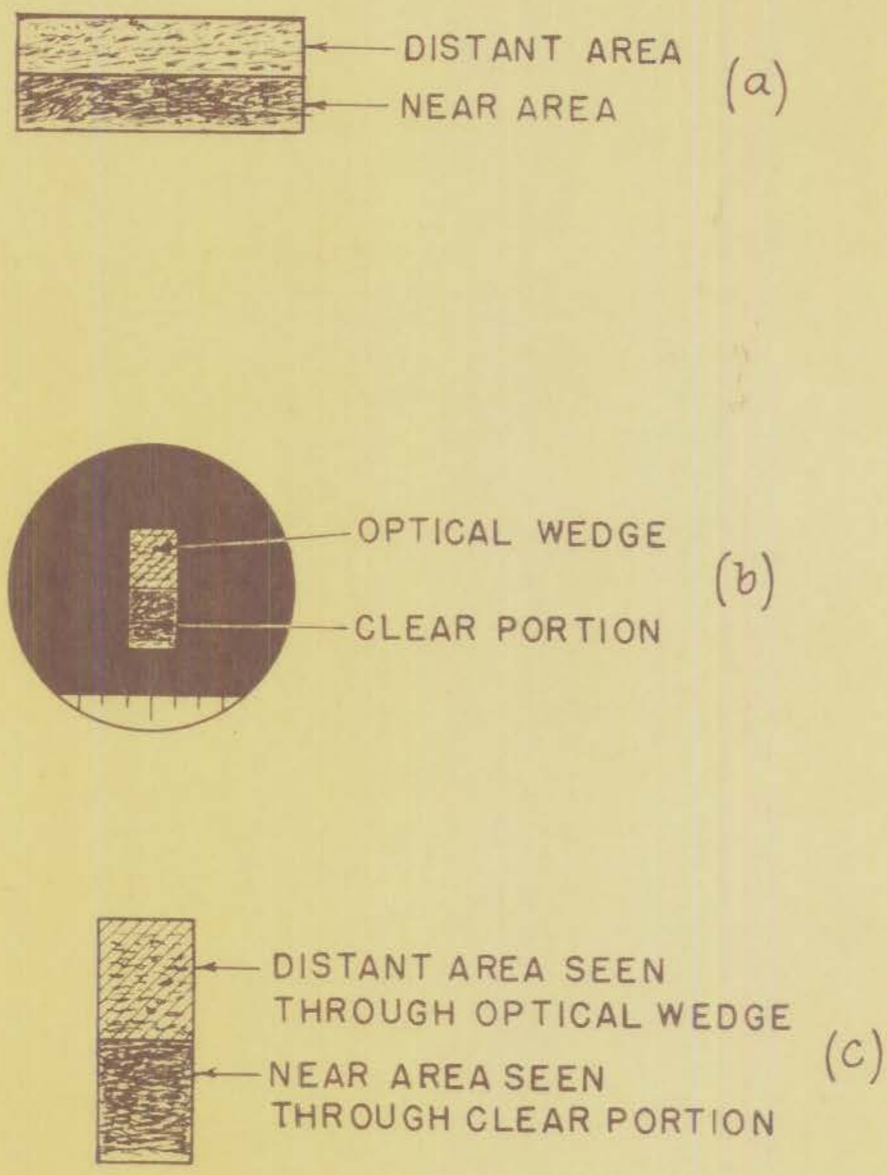
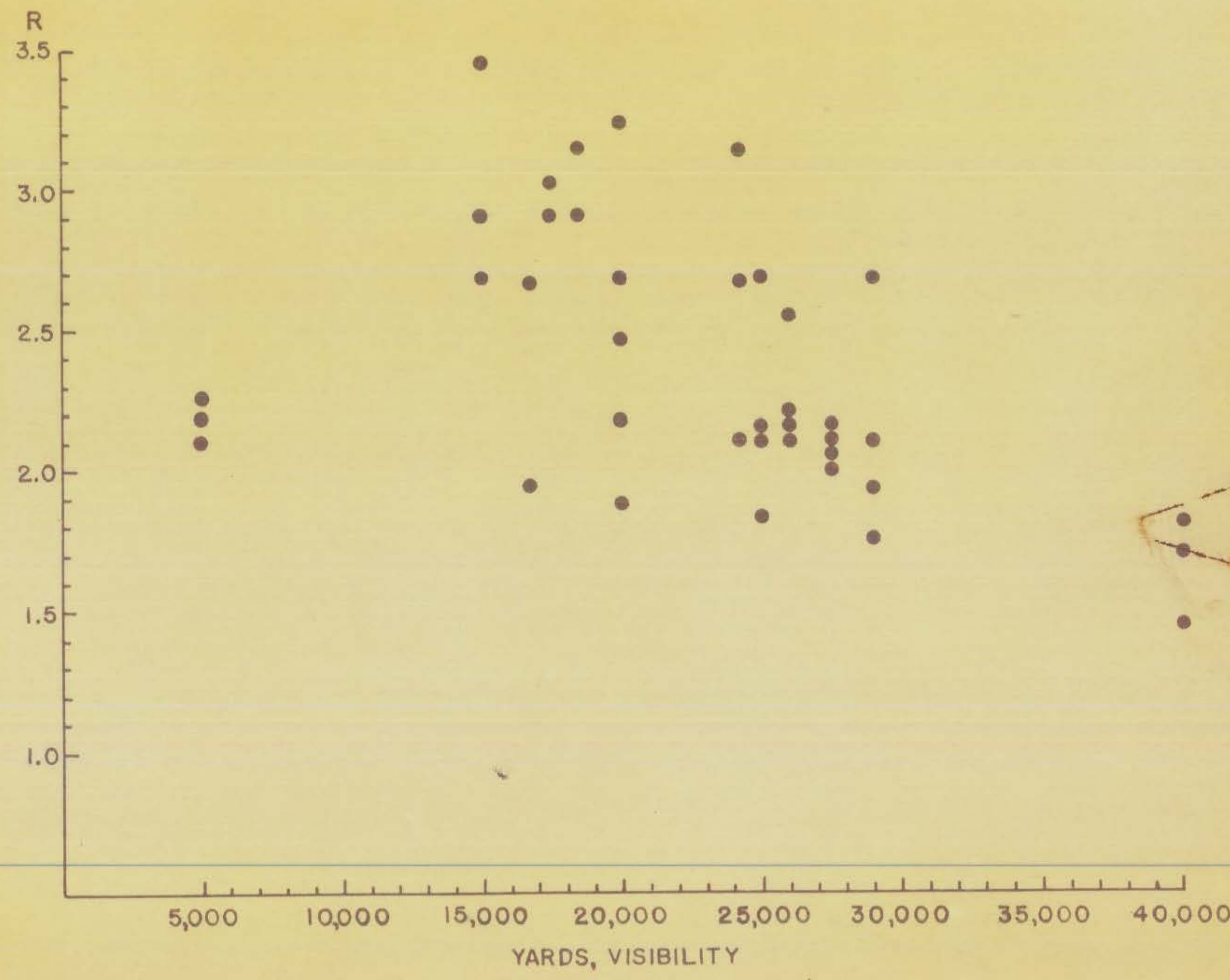

DISTANT AREA
NEAR AREA
(a)
OPTICAL WEDGE
CLEAR PORTION
(b)
DISTANT AREA SEEN
THROUGH OPTICAL WEDGE
NEAR AREA SEEN
THROUGH CLEAR PORTION
(c)

PLATE 2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3.0
2.5
2.0
1.5
1.0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
YARDS, VISIBILITY

PLATE 3