GEOPHYSICS, VOL. 33, NO. 2 (APRIL, 1968), P. 329-336, 7 FIGS.

OPTIMUM DIRECTION OF SURVEY LINES†

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The pattern of a magnetic anomaly varies with the dip of the inducing field. For an aeromagnetic survey intended to discover induced dipole sources, the best flight direction is defined as the one offered maximum target width by an anomaly. This direction may depend on the amplitude of the anomaly. A method is proposed for estimating efficiency of direction for a range of anomaly amplitudes.

The efficiencies of lines bearing north, northeast, and east are compared. At the equator, lines bearing north are twice as efficient as lines bearing east. With increasing inclination, the advantage of lines bearing north disappears at dips of about 20 degrees. Lines bearing northeast are chosen for dips between 20 and 70 degrees. Flight direction is unimportant for dips greater than 70 degrees.

INTRODUCTION

In planning an aeromagnetic survey, line spacing, height, and direction must be decided. Papers have been directed to the question of optimum spacing by Agocs (1955) and Parasnis (1966). Optimum direction has been a matter of less concern, because it is usually controlled by the geological structure of the region. The general rule is to fly across the strike, remembering that in equatorial regions east-west lines should be avoided, (Reford and Sumner 1964).

Magnetometer surveys are now used in many different kinds of search. It is interesting to take the simplest model, the induced dipole, and determine optimum survey directions for it. Traditionally the dipole has been the model for a small ore body. Results for it also apply to other compact objects, such as buried articles of archaeological interest. Because the pattern of the anomaly changes with magnetic dip, the optimum survey direction also changes.

In this paper anomaly patterns are plotted for different dips, and the optimum direction for each is determined by inspection. The quality sought in an "optimum direction" is defined first. In practice an anomaly is evident only as a deflection on a recording chart; the question of whether such a deflection is recognized as an anomaly, or is ignored, encroaches on the difficult ground where geophysical interpretation changes from a science to an art. However to be able to proceed with this work quantitatively, it is necessary to have a simple criterion for the detection of an anomaly, in terms of which direction is optimized. What follows is based on the criterion of "target width," which is defined in terms of the auxiliary parameter of "discrimination level".

PRODUCTION OF ANOMALY MAPS

To enable the determination of optimum direction, anomaly patterns were produced. These were total field maps for an induced dipole, for all magnetic latitudes. In the calculations which followed Hall (1959), the usual assumption was made, that the anomalous field was much less than the inducing field. The variation with latitude of the strength of the earth's field, which induces the anomaly being sought, was taken as that of a sphere with a central magnetic moment (Chapman and Bartels, 1940, p. 11).

A network of values of the anomalous field was printed out by computer for each dip. The values were contoured by hand, and thus patterns were quickly produced. Sample members of the set are shown in Figure 1. The anomalous field strength is marked in units of p/h^3, where h is the depth of burial, and p is the dipole moment induced in the source by the earth's field at the equator. In fact, the absolute values of the anomaly patterns are not important. It is sufficient to note that the

† Presented at the 35th Annual International SEG Meeting, Dallas, Texas, 1965. Manuscript received by the Editor 27 June 1967.

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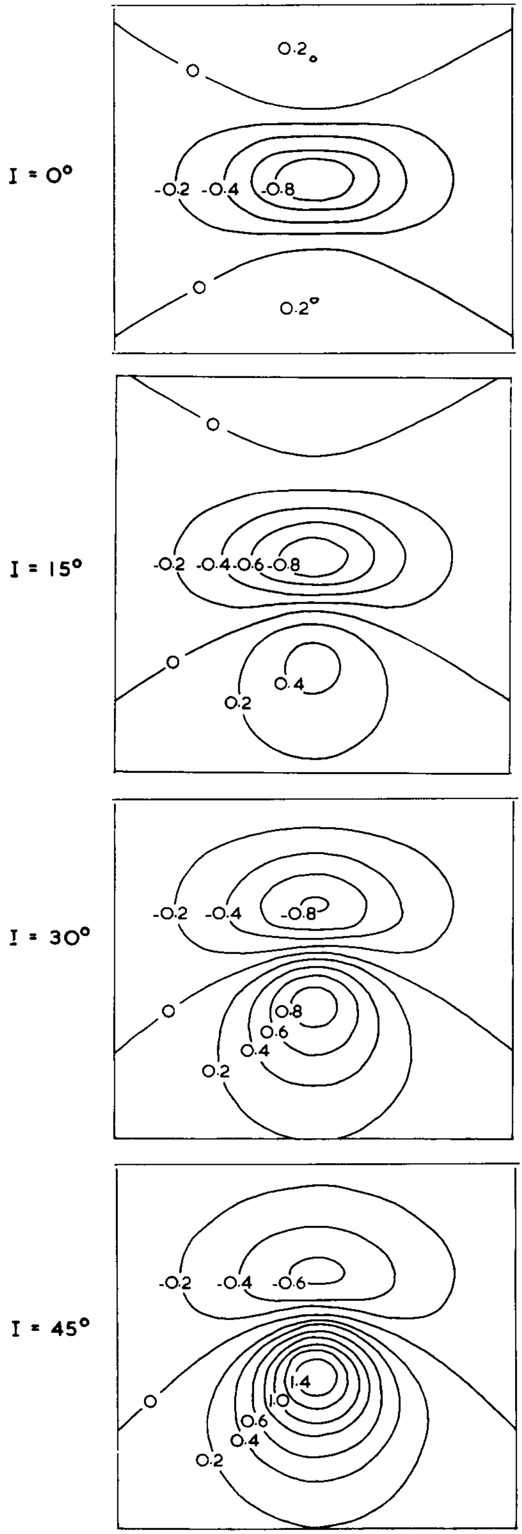

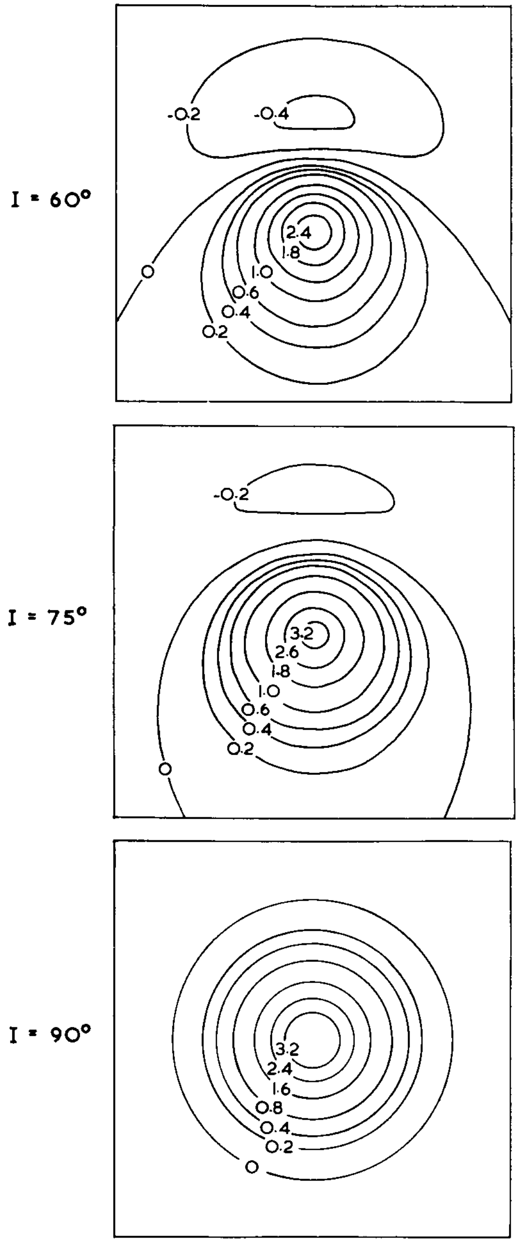

FIG. 1. Total-field magnetic anomalies of a dipole source at different dips (I) of the inducing field. Each pattern covers an area of four units by four units, where a unit of length is equal to the depth of burial of the source. North is to the top of the diagram.

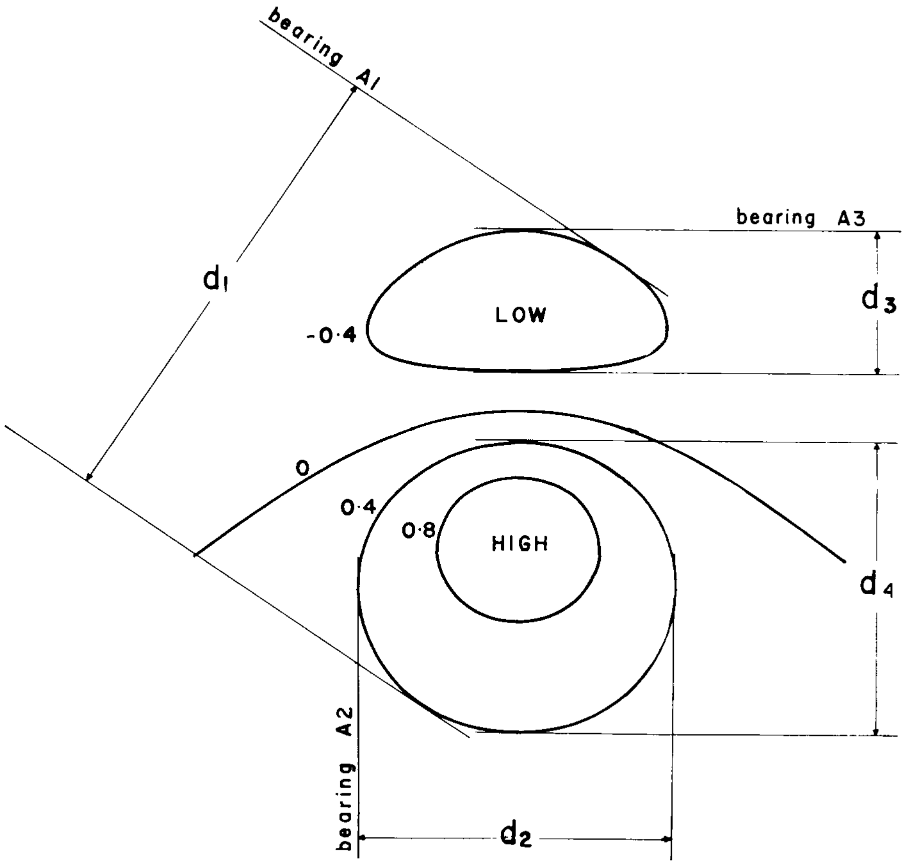

FIG. 2. Target widths of three different directions for a discrimination level of 0.4.

patterns are for the same source body, placed in the same environment at different points on the surface of the earth.

PARAMETERS USED IN THE ANALYSIS

Discrimination level S

We make the simplifying assumption that whether an anomaly is detected depends only on the magnitude of the field variation recorded by the survey instrument. We take positive and negative variations to be of equal significance. The discrimination level is then the magnitude which must be exceeded for the anomaly to be found. In general, a random traverse across an anomaly does not provide a diagnostic profile. More work may be required to map the anomaly to the required degree of accuracy. As defined here, the anomaly is considered detected by the initial traverse, if the field variation recorded is sufficient to provoke the necessary further investigation.

In practice, a discrimination level would be in units of magnetic field strength, such as gammas. For this study, we use the units of the anomaly maps of Figure 1. Consequently for any given survey, a lower discrimination value indicates a stronger anomaly, or a more lax interpretation criterion. The discrimination level may be set either by the interpreter, as in a survey for minerals over shield rocks where the magnetic pattern is disturbed everywhere, or by the limit of instrument resolution, as in the case of an airborne search for an object floating on an ocean.

Target width W

Target width is defined for a given discrimination level and a given direction. It is the projection of the anomaly onto a line at right angles to the flight direction. For example in Figure 2, directions A_1, A_2, and A_3 have target widths d_1, d_2, and (d_3+d_4) for the discrimination level of 0.4.

Best direction Ab

We take the best direction to be that offered maximum target width; it is therefore defined in terms of a particular discrimination level. This definition is adopted in the interests of simplicity, and some interpreters may consider that a best flight direction should possess other qualities, such as a measure of the horizontal gradient or "sharpness" of the measured deflection.

Due to the symmetry of the anomaly patterns, directions need be quoted in the range zero to $\pi/2$ only. Radians have been used for measuring direction to avoid confusion with dip, which is quoted in degrees.

Efficiency rating E

The probability that an anomaly will be found is proportional to the target width it offers the survey aircraft. This will generally depend on the flight direction. The efficiency of a direction is determined for a given discrimination level in the following way:

Let the maximum target width be W_{max}, and the target width of direction A be W_A. Then the efficiency of direction A is

$$E_A = \frac{W_A}{W_{max}} \times 100$$

We arbitrarily treat direction as unimportant, if the direction of minimum efficiency has a rating of not less than 95.

RESULTS

Two interesting facts are apparent from the contour maps, (Figure 1). Firstly, the peak-to-trough amplitude of the anomaly due to the same source body increases by a factor of about 3.5 from the equator to the pole. Secondly, for a discrimination level greater than one, the region of

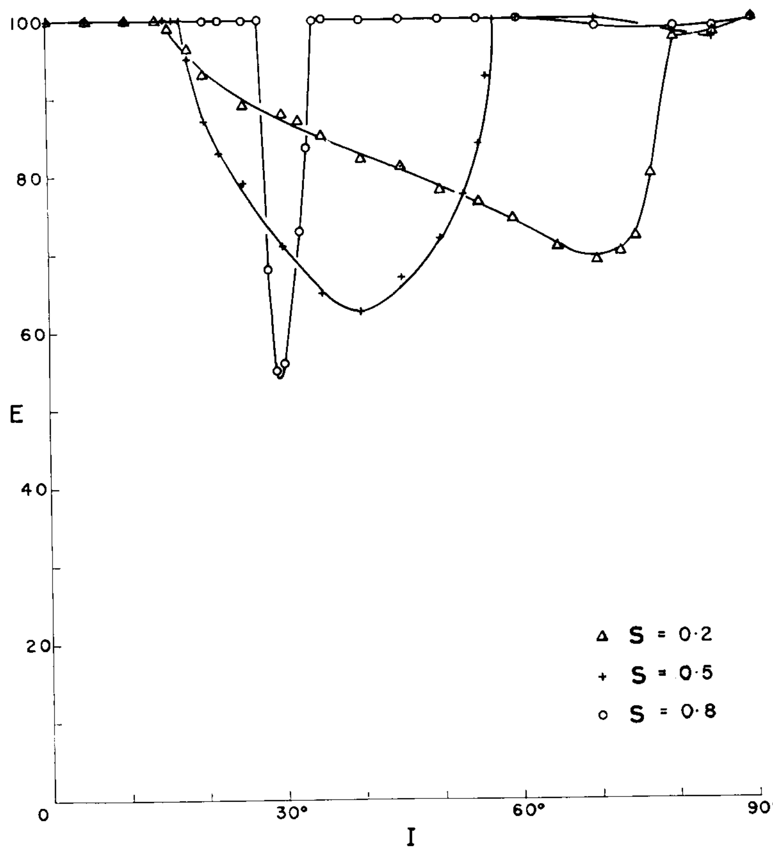

FIG. 3. The variation of efficiency rating E with magnetic dip I for a flight line of bearing zero.

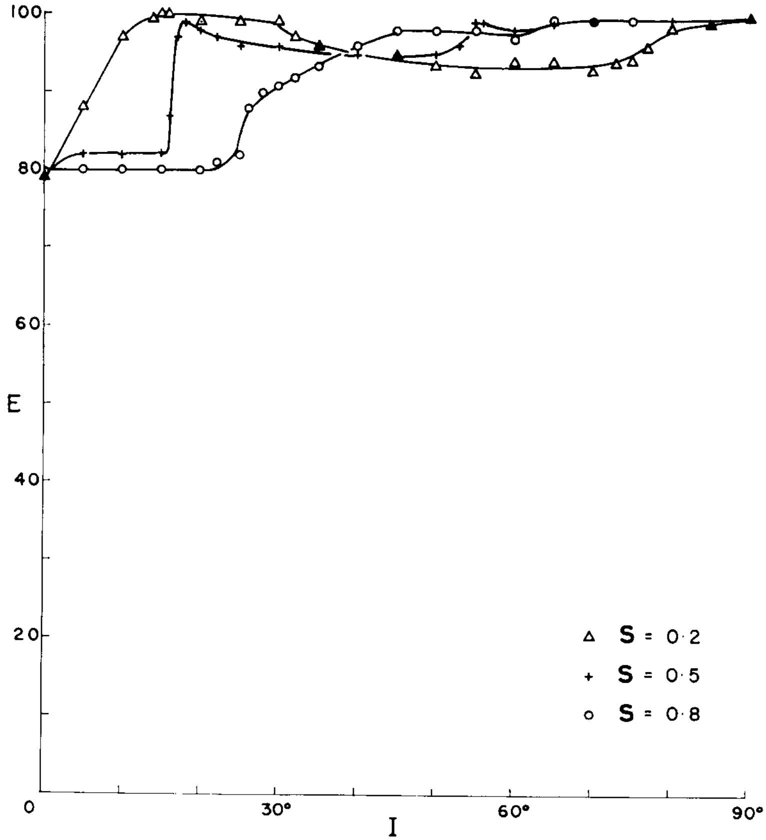

FIG. 4. The variation of efficiency rating E with magnetic dip I for a flight line of bearing $\pi/4$ radians.

the negative trough will not be detected at any latitude. Because all contours on the positive peaks are nearly circular for field values above one, direction is unimportant for this level of discrimination, and the anomaly will not be found for dips of less than 35 degrees.

Target widths were measured from the anomaly maps. Efficiency ratings for lines bearing zero, $\pi/4$ and $\pi/2$ radians were computed for discrimination levels of 0.2, 0.5, and 0.8. Best flight directions were found by inspection. The results are presented in Figures 3 to 6. The points plotted are subject to the experimental errors possible in contouring the original maps, and in measuring target widths. Maximum error of any particular value is estimated to be 5 percent.

The discrimination level of 0.2 applies in the case of a strong anomaly surveyed by a sensitive detector. The discrimination level of 0.8 applies in the case of a weak anomaly, and is near the limit of 1.0, above which direction is unimportant.

DISCUSSION

In Figure 6, the curves for the three discrimination levels form a family, of which the 0.2 member is typical; the other two have degenerated. The features of the 0.2 curve are as follows. For zero dip, the best direction is zero. With increasing dip the departure of best direction from zero is related to the growth of the positive peak of the anomaly pattern, and the eventual decrease of best direction from $\pi/2$ is related to the diminishing importance of the negative trough. When the negative 0.2 contour vanishes from the pattern, direction becomes unimportant.

The graphs show the superiority of north-south lines for dips of up to 20 degrees, and the unimportance of direction for dips above 70 degrees. In the range between 20 degrees and 70 degrees, however, the choice of direction is not simple; because it varies for different levels of discrimination. In general, there is no a priori reason for biasing a survey in favor of the detection of

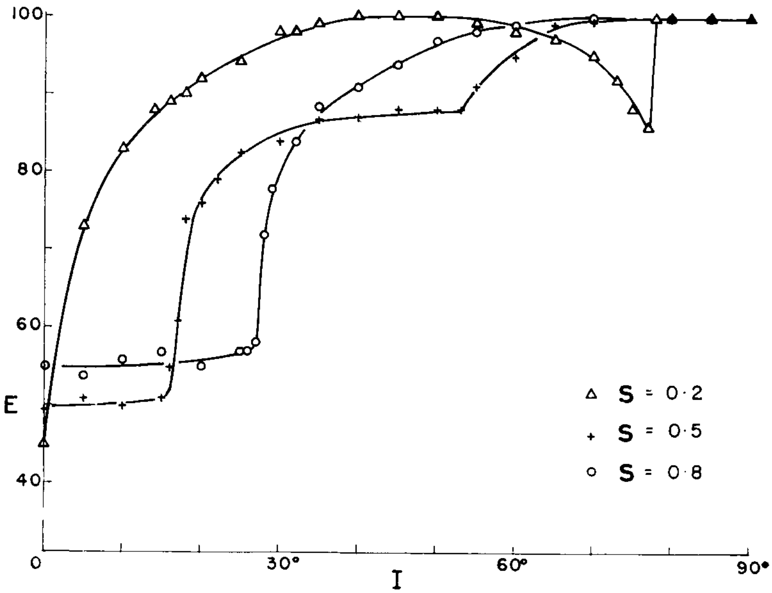

FIG. 5. The variation of efficiency rating E with magnetic dip I for a flight line of bearing $\pi/2$ radians.

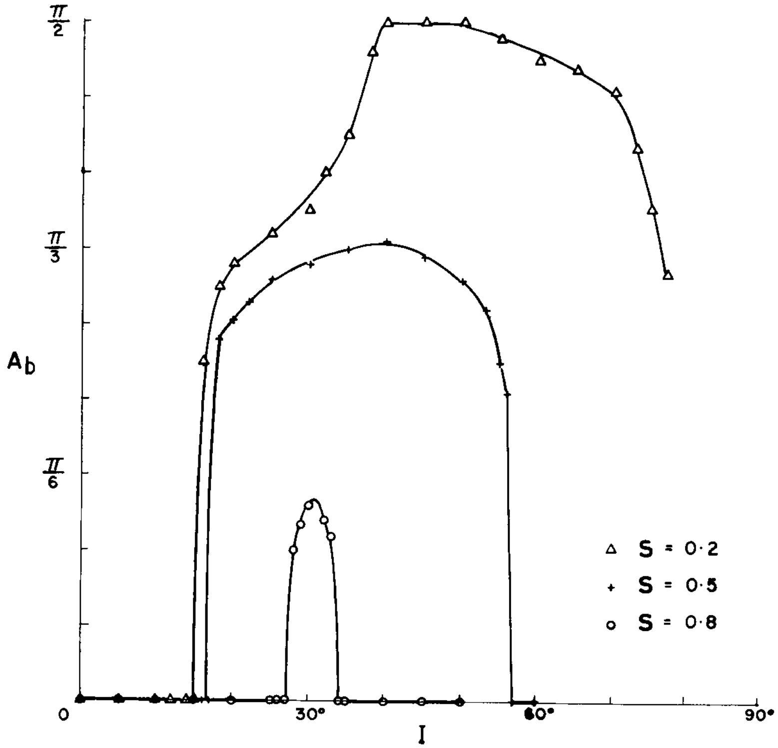

FIG. 6. The variation of best direction Ab with magnetic dip I for different values of discrimination level S. The curves are not drawn in the regions where direction is unimportant.

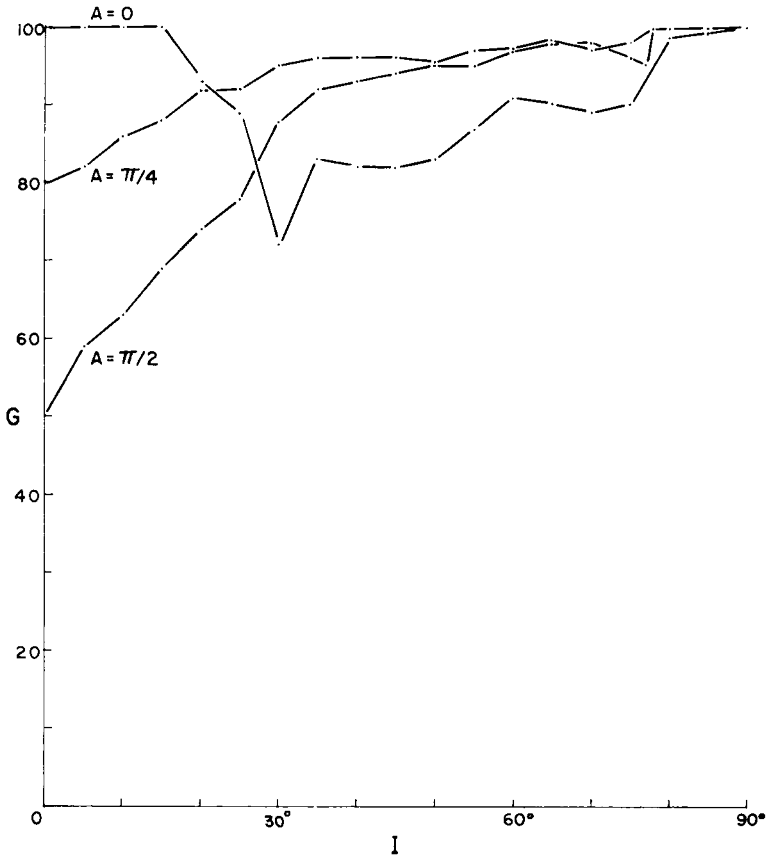

FIG. 7. The variation of the general efficiency rating G with magnetic dip I for three different directions. Three different discrimination levels ($S=0.2$, 0.5 and 0.8) have been used in the calculation of each point.

anomalies of certain strengths. A direction favorable for all discrimination levels is needed. Of the three directions investigated, comparison of Figures 3, 4, and 5 shows that the $\pi/4$ direction is best in the range of 20 to 70 degrees.

If for a particular search, "importance factors" for different discrimination levels are postulated, a parameter G for general efficiency of direction may be defined. This parameter rates the efficiency of a direction in terms of not just one, but all, discrimination levels.

If

S_t, $(t=1, 2, \cdots, T)$ are the discrimination levels for which importance factors are postulated,

$i(S_t, I)$ is the importance factor for the discrimination level S_t at dip I,

and

$E(S_t, A, I)$ is the efficiency rating of the direction A for the level S_t at dip I,

$$G(A, I) = \frac{1}{T} \sum_{t=1}^{T} iE$$

and for any given dip, that direction which maximizes G is the optimum direction.

If we apply the efficiency ratings of Figures 3, 4, and 5, and take the simple case for which

$$S_1 = 0.2, \quad S_2 = 0.5, \quad S_3 = 0.8$$

$$T = 3$$

and $i(S_t, I) = 1$ for all S_t; the computation of G for the cases of $A=0$, $\pi/4$, and $\pi/2$ results in Figure 7. The directions for which G is a maximum agree with the optimum directions chosen above.

CONCLUSION

If an aeromagnetic survey is seeking an induced dipole source, optimum flight line direction may be determined by prior study of anomaly patterns. Exactly what constitutes an optimum direction may be a matter of opinion. For the system proposed on the basis of target width, optimum direction is north-south for dips of up to 20 degrees, northeast-southwest for dips between 20 degrees and 70 degrees, and unimportant above 70 degrees. Other directions in the neighborhood of $\pi/4$ have not been fully investigated; however, it is doubtful if efficiency would be much improved. The results apply equally well to seaborne surveys carried out under the same circumstances.

Maps showing the variation of dip with latitude and longitude over the surface of the earth are widely available. A recent determination was published by Cain et al (1965).

ACKNOWLEDGMENTS

The work in this paper was done in the Department of Geophysics at the University of Western Ontario. It developed from discussions with Dr. W. Domzalski, a visiting lecturer in 1964, from whom the author acknowledges much benefit. Mr. J. Neophytou and Mr. A. Judge contributed to the work.

Dr. D. Davies, Dr. F. S. Grant, and Dr. D. H. Hall are thanked for suggestions, and the National Research Council of Canada is thanked for financial support.

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