SOME GEOLOGICAL CONSIDERATION ON SPECTRAL ANALYSIS TECHNIQUES AND THEIR USE IN THE INTERPRETATION OF THE AEROMAGNETIC DATA OVER PORT HARDY, BRITISH COLUMBIA*

by

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ABSTRACT

The mining potential of the Northern section of Vancouver Island, off the coast of British Columbia, is being reconsidered by the industry after the Utah Construction discovery in the Port Hardy area.

The Alice Lake sheet, number 1737G of the Geological Survey of Canada Aeromagnetic series, is discussed. The data have been passed through a series of filters after digitizing and each set of parameters is discussed.

An attempt is made to the interpretation of the magnetic anomalies and to establish their geological significance.

The construction of mathematical models to approximate geological situations has always been a favourite game for the geophysicist. Provided certain conditions and limitations are borne in mind at all times, such a game may be played with relative success. The major limitation being that nature is simple, but not as simple as Galilei wanted it to be.

It is quite easy however, for the mathematician to be carried away in his calculations, and to lose contact with the geological problem on hand. The purpose of this paper, which is specifically directed to the interpreter, is to show, with an example, how certain techniques may be of assistance in solving some of the possible real situations.

The Island Copper discovery, by the Utah Construction and Mining Company, has recently focused the interest of the exploration industry on the northern tip of Vancouver Island, and for that reason the Alice Lake area (south of Port Hardy) has been selected for the present example.

Figure (1) is the geological map available to the author at the onset of this interpretation. It was published as a preliminary map, in 1962, by the British Columbia Department of Mines. A brief analysis of its features will suffice for our purpose.

The younger sediments are to be found towards the southwest of the map. As we move in that direction we encounter the Karmutsen Group, basically the product of middle Triassic volcanic activity; then the carbonatic Quatsino formation and finally, the Bonanza Group, again of volcanic origin. Some Cretaceous sandstones are present and some acidic intrusions contemporary to the Coastal Batholite. As for structure, the

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main faults active on the area are parallel to the regional trend and appear to have influenced to a great extent the present topographic relief.

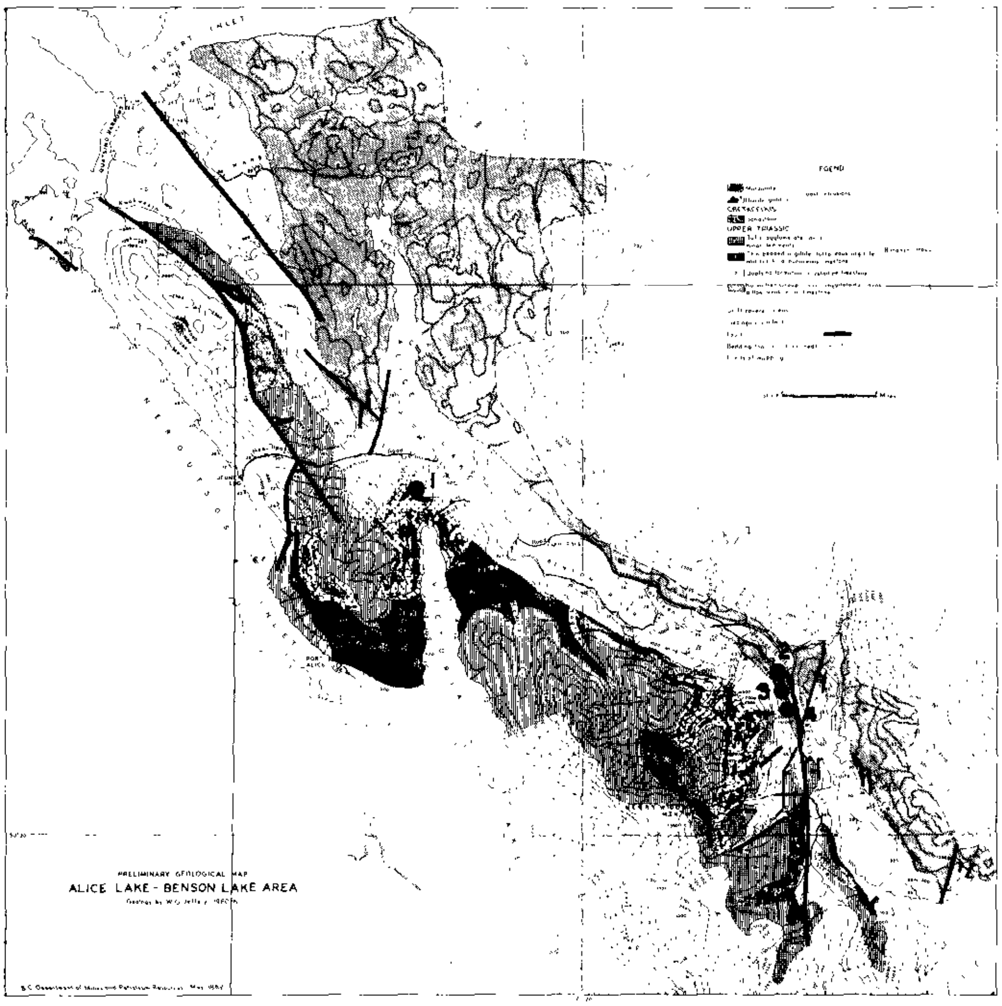


FIGURE 1

Finally, it may be of interest at this stage to point out the major mineral discoveries to date as they appear on the geological map.

Number one is the June property dating back to the beginning of the century and producing gold, silver, copper and iron from the metamorphosed zone between the granodioritic intrusion and the Quatsino limestones. Number two is the Old Sport Mine, producing copper and iron concentrate as a result of the dioritic intrusion through the Vancouver Group, and finally, numbers three and four are the approximate locations of the Coast Copper and the Empire Development properties which are excellent producers of iron minerals. Again here, the literature indicates the occurrence at the contact of the pluton with the Quatsino Group.

The Geological Survey of Canada has recorded the total magnetic field over the area with an airborne proton magnetometer during the summer of 1962. The flight elevation was kept as close as possible to 1,000 feet of ground clearance but not without severe difficulties due to the nature of the terrain. The data was corrected for diurnal variation by automatically subtracting the field recorded at the monitor station.

Figure (2) is the reproduction of the total field over the area contoured at a fifty gammas interval. The large feature dominating the central portion of the map is the anomaly caused by the high susceptibility rocks forming the Merry Widow Mountain. Some of the local variations may be attributed to topographic effect; basically the anomaly reflects the monzonite-gabroic intrusion.

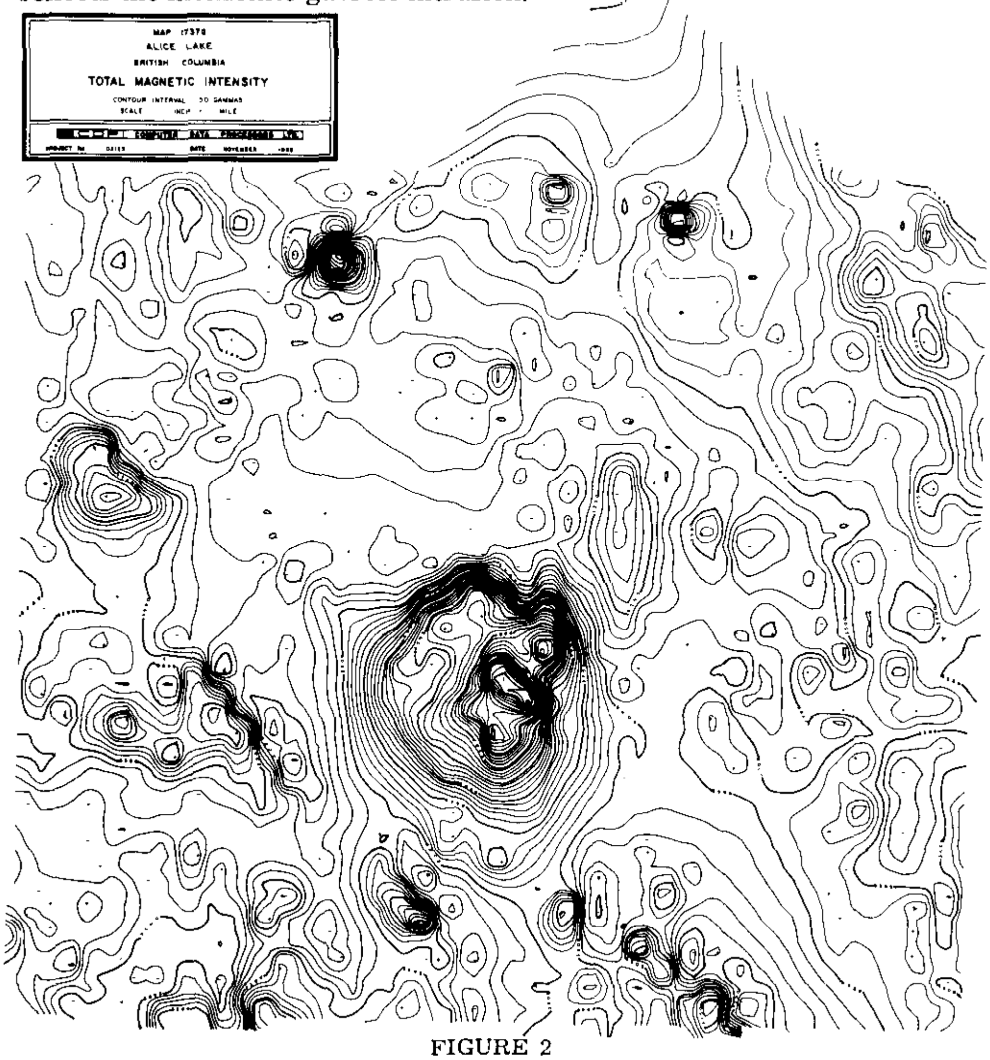


FIGURE 2

The field being so strongly affected by the above closure, further processing of the data had to be based on the application of some digital filters. Their characteristics and effect on the map being considered will form the object of the rest of this paper.

A Second Vertical derivative of the Total Intensity map was obtained by using Rosenbach's coefficients. The amplitude response of this particular set is optimum when compared to the amplitude response of the theoretical operator. The attenuation is very strong (of the order of 21 to 12 dB down) for frequencies of less than 1/8 of a cycle per grid square. In our case, this would correspond to anomalies larger than 2½ miles. Enhancement begins for the 1½ mile anomalies and less. Figure (4) represents the machine contoured map obtained through the

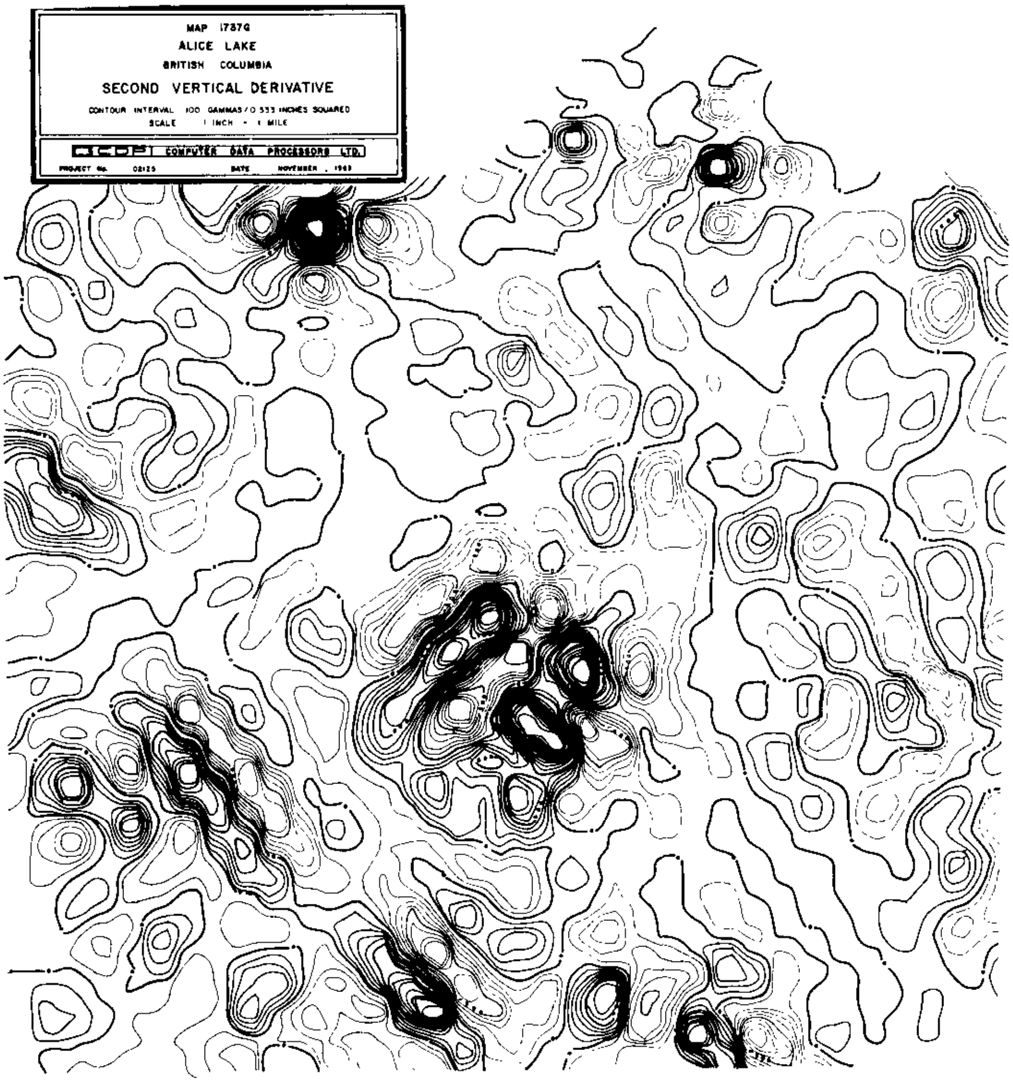


FIGURE 4

above computations. Most of the relevant anomalies are of the order ¾ of a mile to 1 mile in lateral extent and they have been enhanced by six to nine dB up. The result is structurally of great significance. The method has brought out a low through the Merry Widow Mountain corresponding to the upper Triassic plate trapped between the dioritic intrusion and the monzonite. It has also considerably enhanced the northwest-southeast trend barely visible on the Total Intensity. Two further faults may be implied in addition to the existing trend. We will consider their geological significance after a more objective confirmation of their existence.

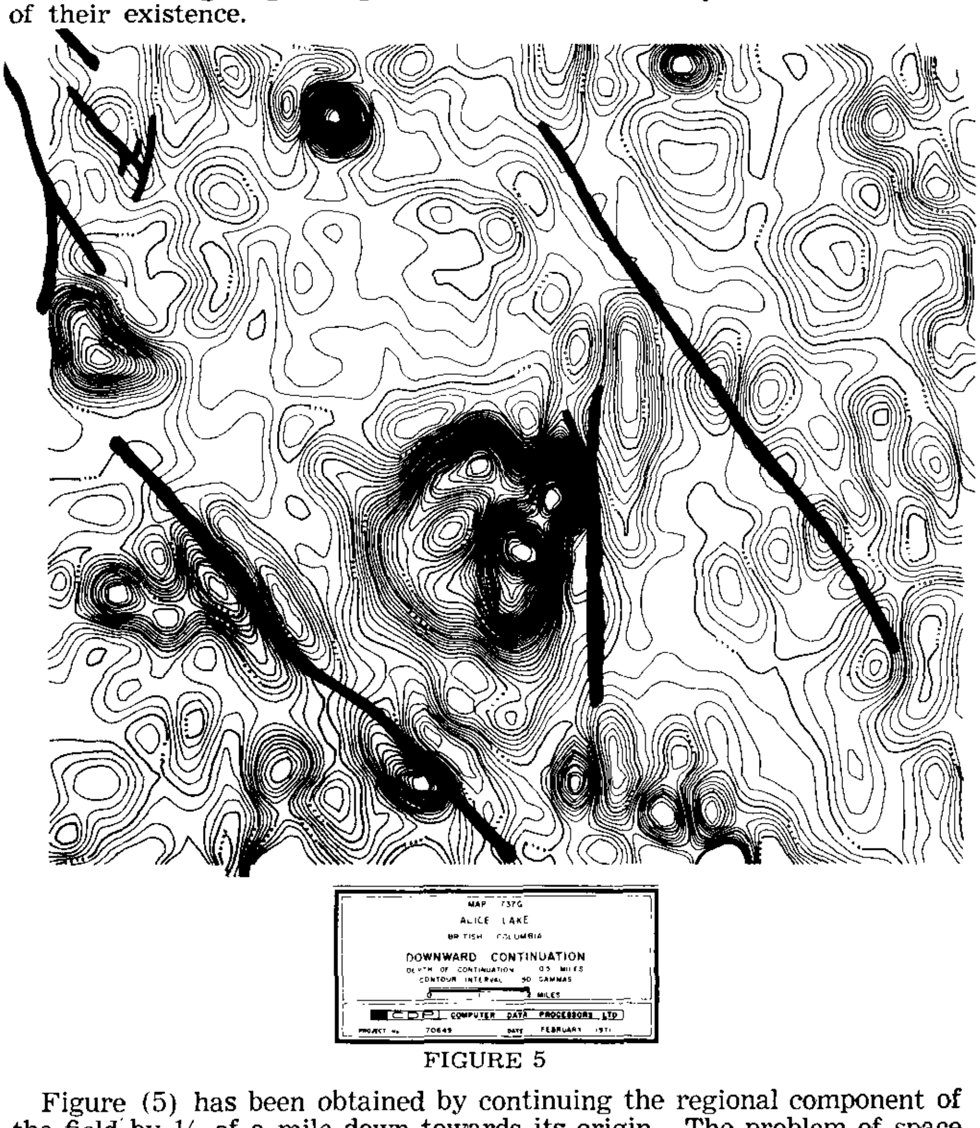


FIGURE 5

Figure (5) has been obtained by continuing the regional component of the field by ¼ of a mile down towards its origin. The problem of space domain Downward Continuation projection is the loss of data at the edges of the map which is proportional to the diameter of the operator being used. Among the various available coefficients, Henderson's proved to be the closest to the amplitude response of the theoretical filter, even after the renormalization meant to reduce the complete set to 2 rings.

The Downward Continuation operator is a simple linear multiplier of the amplitude spectrum. For a single grid interval continuation and a spatial frequency as low as half a cycle, or in our case a ½ mile anomaly, the signal is already amplified by 27 dB's. It is essential, therefore, to measure the spatial frequencies on the Total Intensity map before attempting the field projection; particularly in the frequency domain where we are making full use of the multiplier. The measuring of the spatial frequencies is a very simple proposition and can be made with a pair of dividers, by comparing the size of the anomaly under analysis to the scale of the map and to the grid interval used for the preliminary work. Charts showing the actual response of various coefficients are available in the literature and some references are given in the appendix.

The modified Henderson set tends to flatten out after ¼ of a cycle spatial frequency, which is, after all, highly desirable unless we can efficiently remove the residual component before the operation. Other sets may not have this characteristic and it may be advisable to convolve the operator with a simple high cut filter before attempting the downward projection.

The faulting, observed on second derivative, has been marked on the Downward Continued map. The Western fracture is very likely responsible for the preservation of the upper Triassic and Cretaceous sandstones and tuffs to the southwest of the Merry Widow Mountain. The crystalline limestones of the preceding Quatsino formation in fact reappear on the up-thrown side of the fault at a much higher elevation, justifying a possible intense erosion of the region in post-Cretaceous time.

The author does not have direct geological information on the area, but from the throw of the fault, which has been measured from modelling to be about fifteen hundred feet, and from the actual behavior of the total field, he expects the Quatsino formation to cover completely the lower part of the map to the southwest of the fault. As for the other major lineation to the northeast, it may be attributed to a basement fault not showing through the Karmutsen; modelling through master curves techniques gives a depth to the center of the fault of approximately 3,000 feet below the surface.

Further, it may be noted that in addition to the structural trends, the method has enhanced a strong north-south lineation which just happens to be in line with the Old Sport Mine and the Coast Copper and the Empire Development properties.

It has been mentioned above that the secret of a successful downward field projection is the effective separation of the regional from the residual field components. Quite apart from any other considerations, theoretically we can only continue a directional component of the field; somehow the topographic effects, the remnant magnetization and all possible shallow sources have to be eliminated from the total field before the application of the operator. There are various ways of obtaining this separation, both in the space and in the frequency domain. Trend surface is a typical space domain method; a simple high-low cut filter would be the equivalent in the frequency domain.

A bandpass filter, however, together with any circular operator, should be regarded with the highest degree of suspicion by the interpreter as these filters not only have the tendency of destroying geological trends but may well create non-existing anomalies in a process that could be described as the opposite of grid aliasing. In the one case, broad spatial sampling will tend to eliminate the higher spectral components. In the other, bandpassing the higher spectral components will induce false, low spatial frequency anomalies on the map. When using a very narrow bandpass, the result of the inverse Fourier Transform is very close to a simple sinusoid with the same period of the particular anomaly that one is attempting to preserve. Let us not forget, however, that the simple sinusoid will cycle at equal intervals regardless of the actual field conditions. The components that zeroed out the periodicity of the low frequency signal have been eliminated from the power spectrum with the result of letting through to the space domain a series of equally spaced highs and lows which bear little, if any, relation to the geology of the area.

The best thing to do for the interpreter at this time is to throw up his arms and let the data select its own filter. The theory of the logarithm separation of the power spectrum has been elsewhere discussed and some references are given in the appendix. For the purpose of this paper, it will suffice to say that it is possible to design a directional, or geologically biased, filter operator simply by picking the intersection between the two straight lines defining the logarithm of the power spectrum through a number of oriented vertical sections of the data.

Before doing this however, the last chore for the geophysicist is the selection of the actual data matrix.

Most automatic methods of calculating two dimensional transforms require a "base 2" square matrix; the selection of the grid interval thus becomes of the greatest significance.

The spectrum of the data is unique for a particular sample interval and the abundance of its high components is somewhat inversely proportional to the size of the grid box. However, the introduction of high frequency grid noise is always preferable to aliasing as it can be easily bandpassed or otherwise filtered out; therefore the smallest possible grid, compatible with the data spacing, is always advisable. Often the total area cannot be handled with one single determinant and the interpreter will have to choose between selecting a whole encompassing matrix, representative of his data, a rather dangerous step, or designing his filter on a great number of matrices. This second approach is more accurate and generally preferable since data characteristics may change considerably from one side to the other of the same map.

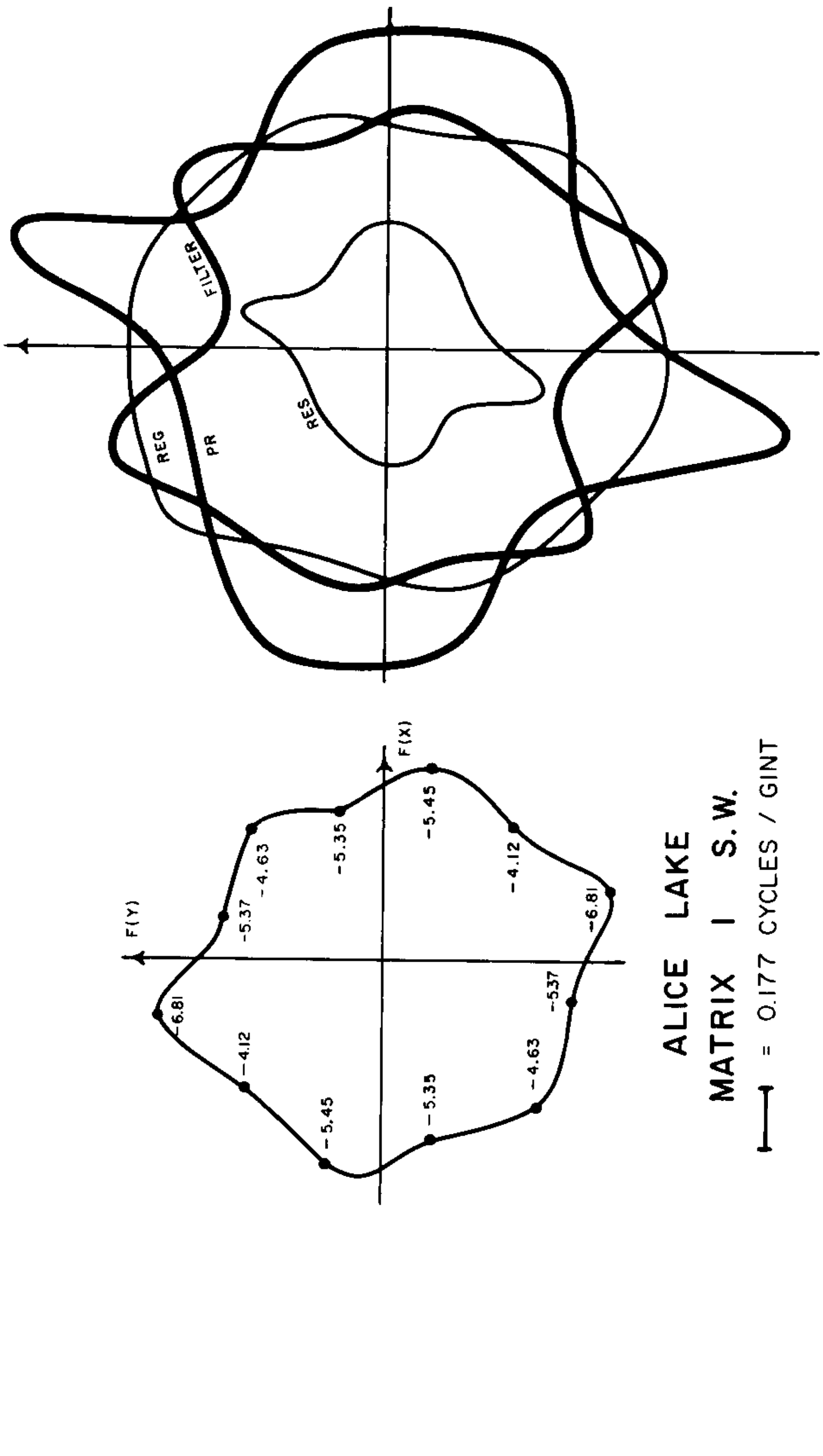
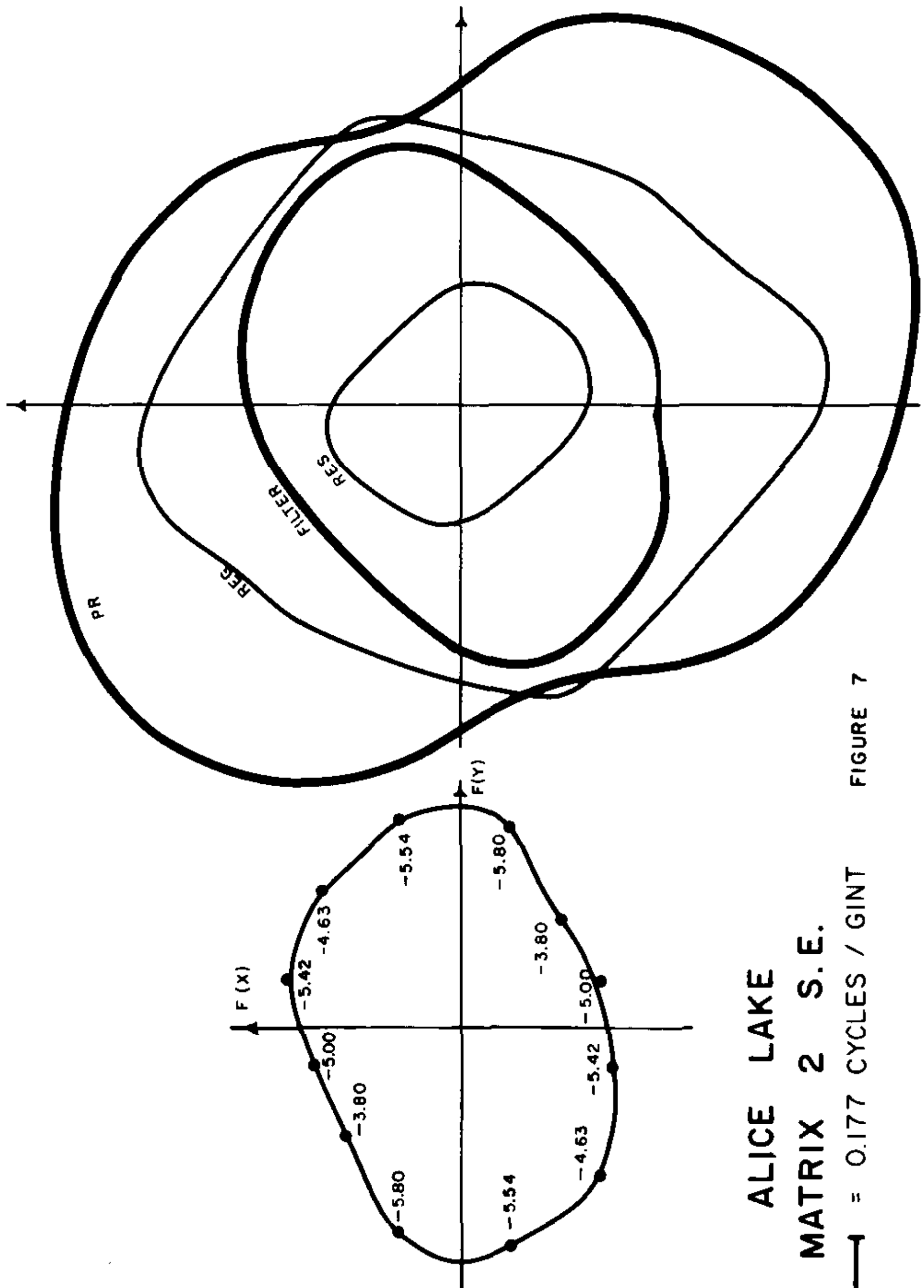

FILTER
REG
PR
RES
F(X)
F(Y)
-5.45
-5.35
-4.63
-5.37
-6.81
-4.12
ALICE LAKE
MATRIX I S.W.
= 0.177 CYCLES / GINT

FIGURE 6



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MATRIX 2 S. E.

= 0.177 CYCLES / GINT

FIGURE 7

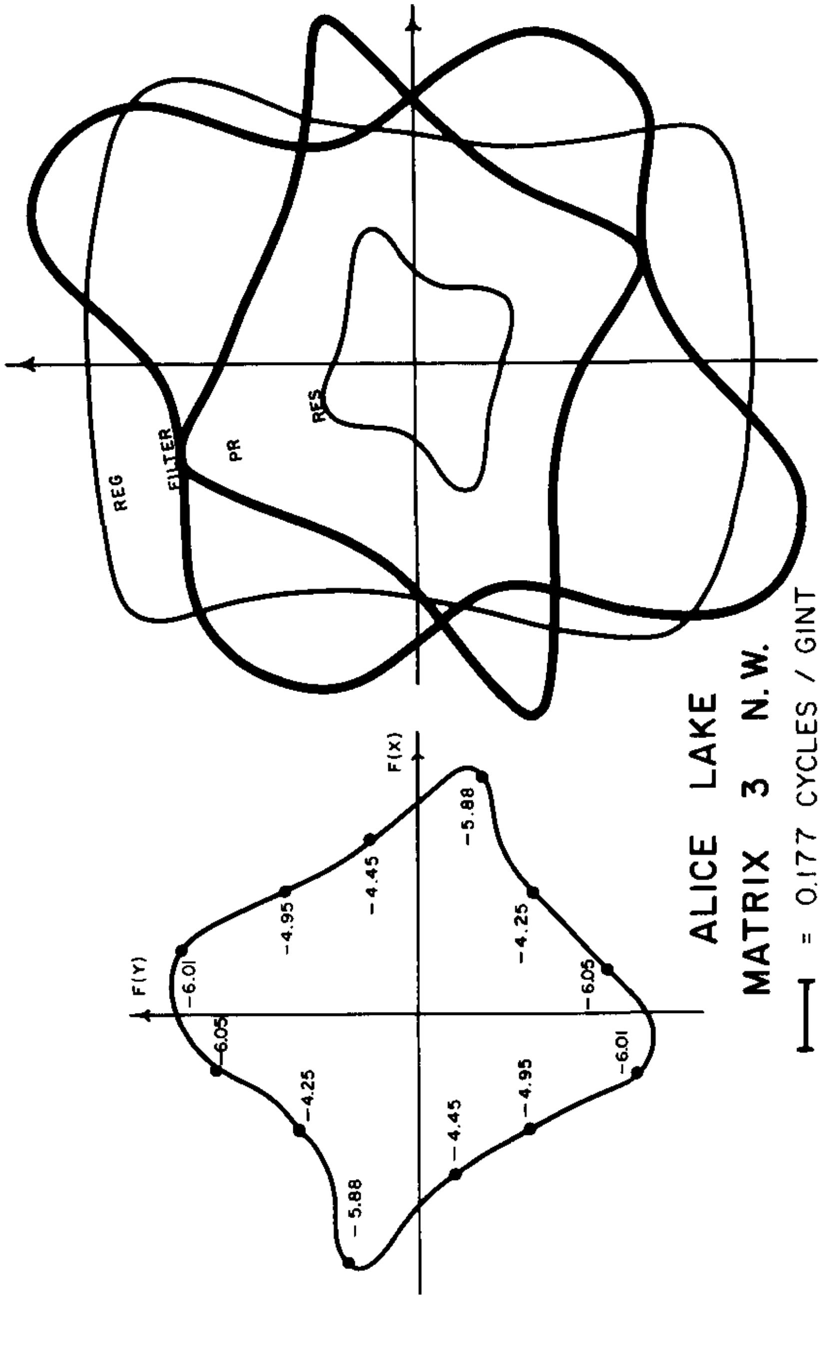
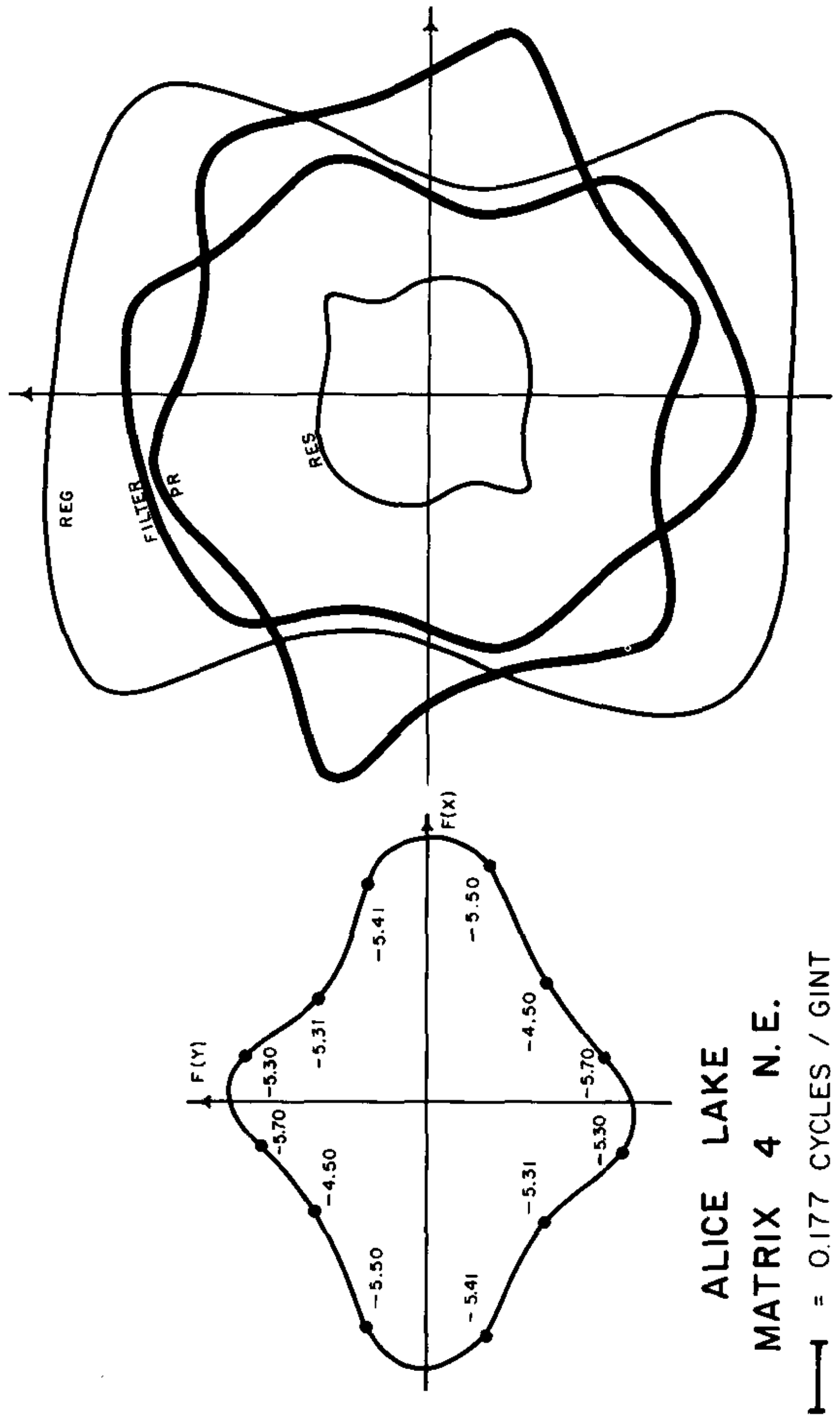

REG
FILTER
PR
RES
F(Y)
F(X)
-6.01
-4.95
-4.45
-5.88
-4.25
-6.05
-6.05
-4.25
-5.88
-4.45
-4.95
-6.01
ALICE LAKE
MATRIX 3 N.W.
= 0.177 CYCLES / GINT

FIGURE 8



ALICE LAKE
MATRIX 4 N.E.
⊢ = 0.177 CYCLES / GINT

FIGURE 9

The Alice Lake sheet was divided into four (64 X 64) matrices with sufficient overlap to guarantee a safe return to the space domain and Figure (6) to Figure (9) represent the spectral configuration of each data block from the Southwest to the Northeast corner. The left-most plot of each figure represents the line of separation between regional and residual components as we move around the power spectrum at different azimuths with an increment of 30 degrees. The two axis represent frequencies per grid square in the X and Y directions and the posted numbers indicate the attenuation for that particular angle in decibells down.

The somewhat more complicated plot to the right shows the actual filter in bold and the components used in the calculations; the regional and residual depths to the equivalent layer and their power ratio obtained with the expression:

$$(E_{r1} - E_{r2} \;\; F_{r1}/F_{r2}) \;\; (1 - F_{r1}/F_{r2})^{-1} / (E_{d1} - E_{d2} \;\; F_{d1}/F_{d2}) \;\; (1 - F_{d1}/F_{d2})^{-1}$$

where E_{di} and E_{ri} represent respectively the energy level of any particular point on the Regional and Residual logarithmic component of the spectrum and F_{di} and F_{ri} their relative frequency coordinate.

The filter is an inverse relation of the power ratio.

There are a number of possible observations to be made on the above four figures; for example, how different each curve is from a circle and how strong is the trend correlation of the first and third matrix with the western half of the map. Figure (11) is a plot of the regional component only, after filtering, and trends, far from appearing dampened, have been enhanced by the process. Matrix 2 and 4 represent the eastern block and, as one would expect from the geology and from the total field intensity, show less character than the previous two.

Furthermore, it may be observed how the actual filter parallels the Regional-Residual separation line in the spectrum that appears to the left of each figure; in other words, if this latter is a true representation of the inflection point as we move around the transform plane, and this depends on the quality of the data and on the expertise of the one who is picking the spectral sections, the operation yields a truly geologically oriented filter which will honour structural trends and possible geological contacts.

Finally, Figure (10) is the plot of the residual field component or the difference between the Total Intensity and the Regional map. The added feature of spectral separation is that very little is lost in the filtering process; whatever does not appear on the one component should be present on the other one. The result is a Regional free map combining topography and other high frequency noise with all shallow sources producing spike-like closures.

To the interpreter, the direct comparison of these last two maps is of the greatest significance. Any residual anomaly should be checked against the Regional and the surface relief map to ascertain its nature and in order to discriminate against topographic effects.

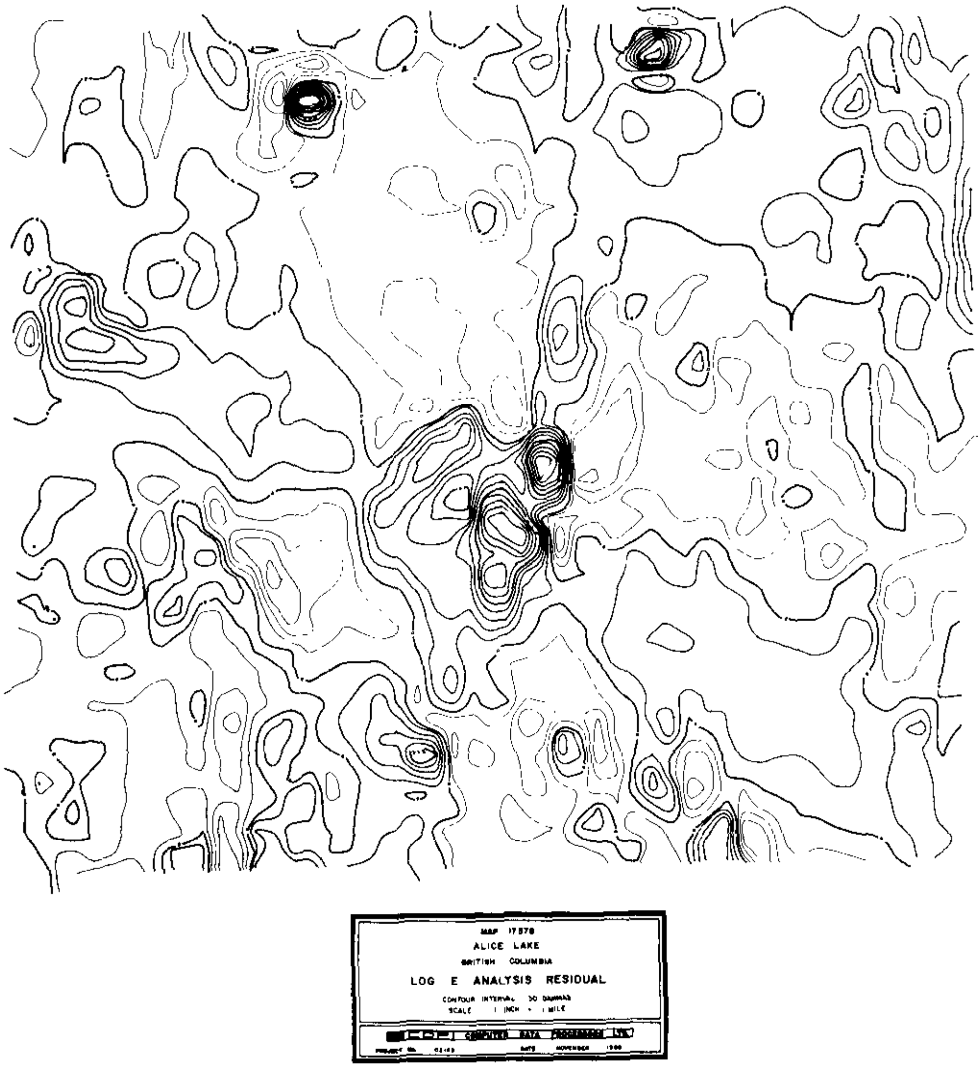

ALICE LAKE
BRITISH COLUMBIA
LOG E ANALYSIS RESIDUAL
SCALE 1 INCH = 1 MILE

FIGURE 10

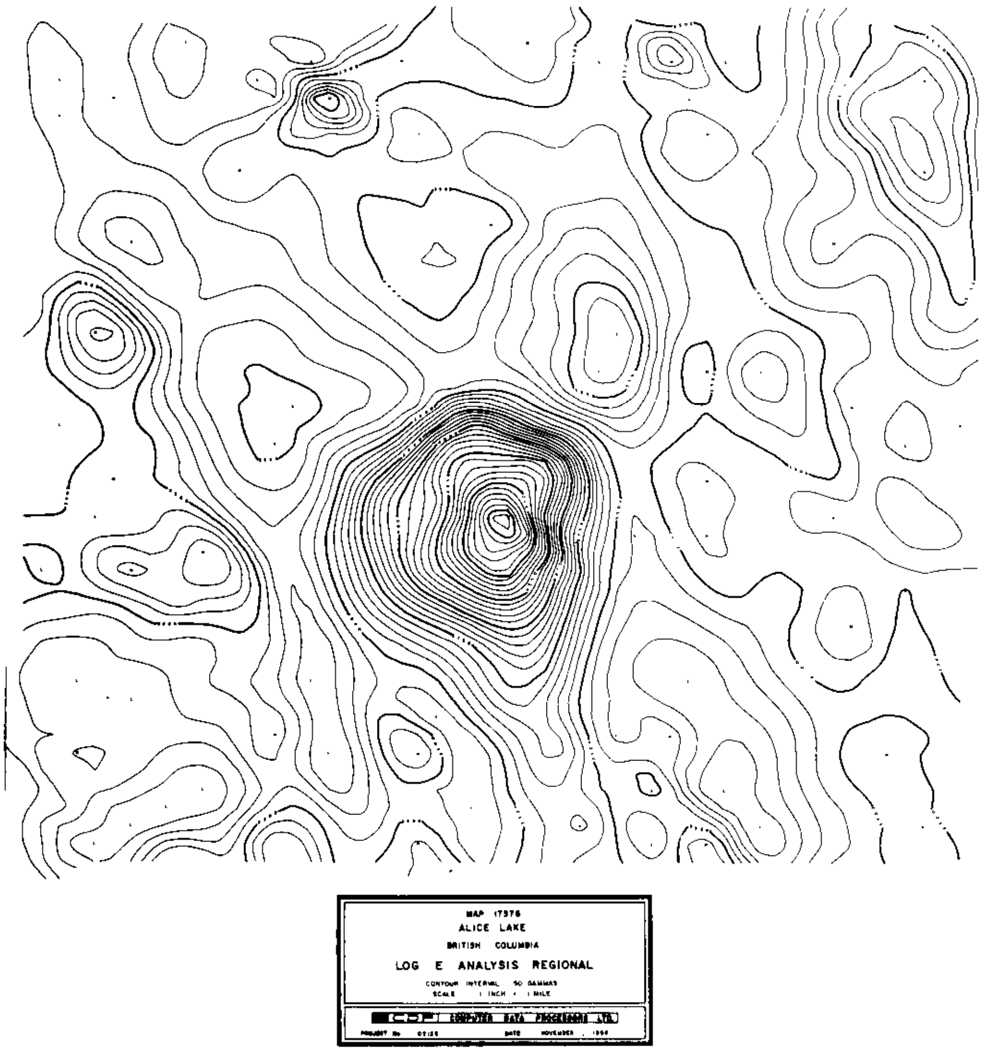


FIGURE 11

In our example, the analysis has confirmed a true trend to the north-east of the Merry Widow Mountain, extending across the Benson River between the eastern flank of the Quatsino peak and Maynard Lake. Geologically, this is very feasible since it would mean extending to the north the faulted region and the contact which has proved to be rich in iron ore to the South between the Karmutsen lavas and the Cretaceous sandstones.

Furthermore, the residual map shows two prominent closures in the north-eastern corner, their mineral potential should be investigated since their location on the western side of Castle Mountain is analogous to the previously discussed area and particularly because their anomalous magnetic energy appears to be due almost entirely to a very shallow source.

REFERENCES

DEN BOER, J. C., Some Exploration Applications of the Two Dimensional Transform. 1968, Journal of the C.S.E.G., Vol. 4, p. 6-31.

——, Personal communications.

BOLTON, R. G., Computer Interpretation of Aeromagnetic Maps. 1969, Proceedings of the North West Mining Conference, Spokane, Washington.

DARBY, E. K., DAVIES, E. B., Analysis and Design of Two Dimensional Filters for Two Dimensional Data. Geophysical Prospecting, Vol. 15, Sept. 1967.

GRANT, F. S., WEST, G. F., Interpretation Theory in Applied Geophysics. 1965, McGraw Hill.

HENDERSON, R. J., A Comprehensive System of Automatic Computation in Magnetic and Gravity Interpretation. Geophysics, Vol. 25, No. 3, 1960.

LINDSETH, R. O., The Nature of Digital Seismic Processing of Geophysical Data. 1967, Journal of the C.S.E.G., Vol. 3, No. 1.

——, Recent Advances in Digital Processing of Geophysical Data. 1970, Special publication.

MARGHERITA, L. V., Display Techniques as an Aid to Aeromagnetic Interpretation. 1970, Proceedings of the Third Symposium in Mineral Exploration, University of British Columbia.

NAIDU, P. S., Statistical Structure of the Aeromagnetic Field. 1970. Geophysics, Vol. 35, No. 2.

ROBINSON, E. A., TREITEL, SVEN, Principles of Digital Filtering. Geophysics, Vol. 29, p. 394-404.

SPECTOR, A., GRANT, F. S., The Power Spectrum Approach to the Analysis of Aeromagnetic Maps. 1968, 38th Annual Meeting of Society of Exploration Geophysicists.

——, ——, Statistical Models for Interpreting Aeromagnetic Data. Geophysics, Vol. 35, No. 2.

SYBERG, F. J. R., A Fourier Method of Regional-Residual Separation and Downward Continuation of Potential Field Data. 1969.

YOUNG, M. J., RUGG, E. S., Island Copper Deposit, B.C. Annual Convention of the C.I.M.M., Kamloops, B.C., October 1970.

ZURFLUEH, E. G., Application of Two Dimensional Linear Wave Length Filtering. Geophysics, Vol. 32, No. 6.