GEOPHYSICS, VOL. 53, NO. 12 (DECEMBER 1988); P. 1587–1591, 5 FIGS.

Directional spectral analysis and filtering of geophysical maps

Freyr Thorarinsson*, Stefan G. Magnusson‡, and Axel Bjornsson§

ABSTRACT

The detection of linear anomalies in map data is facilitated by studying the two-dimensional power spectrum, because the directivity of the energy in the map is preserved in the Fourier transform. The lineaments associated with individual peaks in the spectrum are then separated from the map data by directional filtering and studied independently of other map features.

Gravity and magnetic maps from an active rift area in southwestern Iceland are analyzed in this manner. The agreement between the filtered maps is good and they fit the observed tectonic features quite well.

INTRODUCTION

Interpretation of potential fields by modeling is often hindered by the lack of uniqueness in the inverse problem and the difficulty in separating an anomaly of interest from the data. Analysis by grid operators, such as upward and downward continuation or derivative calculations, avoids those problems but the results may have limited diagnostic geologic value.

This paper describes how directional spectral analysis can be applied to gravity and magnetic maps in order to detect linear anomalies representing tectonic features. The lineaments are then separated from the map data by directional filtering and studied independently. This approach to anomaly separation reduces the ambiguity inherent in potential field interpretation but is, of course, limited to linear features. However, it is applicable to the analysis of lineation in all kinds of maps.

THE ANALYTICAL PROCEDURE

The process can be broken down into several steps. The first step is to prepare the space-domain data for spectral analysis. Irregularly spaced data are gridded, and unwanted regional gradients are removed. The data are also windowed prior to power spectrum calculations to reduce leakage or edge effects. In the examples that follow, we have consistently removed a least-squares linear gradient from the data and applied a Hanning window to the data.

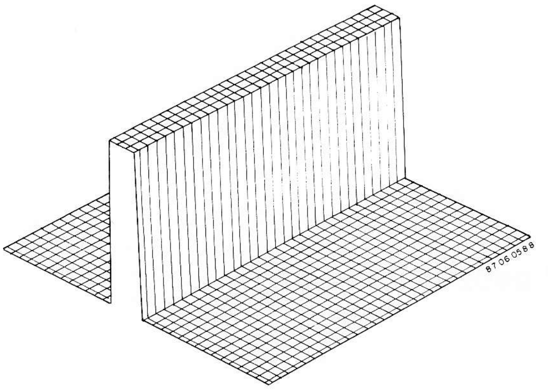
The second step is to Fourier transform the space-domain data to produce complex-valued frequency-domain data. As usual, we replace each complex number with the square of its magnitude to obtain a power spectrum of the data for display. A good introduction to two-dimensional (2-D) Fourier transforms of digital data is given by Clement (1973).

For our purposes, the important property of the Fourier transform is that features with a given direction in the space domain are transformed into a feature with only one direction in the frequency domain; i.e., the directivity of the energy is preserved in the transform. It should be noted, however, that linear features in the power spectrum are perpendicular to the linear space-domain features which they describe; i.e., a "fence" running north-south in the space domain corresponds to a sinc function lying east-west in the frequency domain. This feature is depicted in Figures 1a and 1b.

The third step is the directional analysis, i.e., to determine from the power spectrum what directions (if any) contain large enough portions of the total map energy to constitute a signal. This is, as far as we are concerned, the main contribution of our processing technique. The directional analysis may either be performed directly on the power spectrum; or an energy rosette can be calculated by integrating the power spectrum from the center out to some chosen frequency value. The first approach is employed here, but the latter method would, for example, allow the combination of the spectra of two grids of the same data rotated through 45°, thus reducing the effect of leakage upon the analysis.

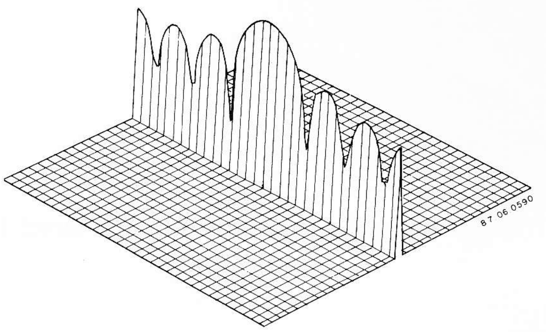
The fourth and final step in the analytical process is to locate on a map in the space domain the phenomena which cause the energy peaks of interest in the power spectrum. Feature location is accomplished by applying a fan filter to the complex data in the frequency domain and inverse Fourier transforming the result. The procedure is zero-phase filtering, which does not distort the location of spatial amplitude peaks;

Manuscript received by the Editor July 27, 1987; revised manuscript received May 2, 1988.
*Formerly Iceland National Energy Authority; presently Haaleitisbraut 123, 108 Reykjavik, Iceland.
‡Formerly Iceland National Energy Authority; presently Institute for Geophysics and Meteorology, University of Cologne, Koln, West Germany.
§Iceland National Energy Authority, Orkustofnun, Grensasvegur 9, 108 Reykjavik, Iceland.



(a)

FIG. 1a. A N-S running fence function in the space domain.



(b)

FIG. 1b. The Fourier transform of the fence function of Figure 1a is an E-W running sinc function in the frequency domain. The sinc function is shown as a power spectrum, in decibels.

but applying the filter to pass nonexistent anomalies will create spurious lineaments in the resulting map. This last step, directional or strike filtering, was suggested by Fuller (1967); Fuller's paper inspired some of our work. Fuller, however, used space-domain filters and was not concerned with a quantitative analysis of directionality.

THE TEST AREA

To demonstrate the process, we have chosen gravity and airborne magnetic data from the Hengill geothermal area in southwestern Iceland. This high-temperature geothermal area is situated on an active rift zone, and the geology is characterized by the active Hengill central volcano and a fault and fissure swarm running through it (Björnsson et al., 1986; Saemundsson, 1978). The test area is square (14 km × 14 km), and the gridded rows and columns of data are 32 × 32. Its location is shown in Figure 2.

THE GRAVITY MAP

Figure 3a shows a Bouguer gravity map from which a linear least-squares regional has been subtracted. The best Bouguer density was found by Nettleton's method to be 2330 kg/m^3. The map is based on 134 gravity stations that are evenly but irregularly distributed over the area and 74 stations just outside the map boundaries (Björnsson et al., 1986).

Figure 3b shows the power spectrum of Figure 3a in decibels. Disregarding the N-S striking remnants of leakage in the signal, the power spectrum is an ellipsoid with a main axis pointing approximately N40°E. This would agree with the direction of the fissure and dike swarm, which strikes N30–35°E on the surface.

Figure 3c shows the negative values (corresponding to lower densities) passed through a fan filter with cutoff at 40° ± 20°. The fissure swarm is clearly delineated, and a dextral displacement is suggested in the center of the lineament.

THE AIRBORNE MAGNETIC MAP

Figure 4a shows an airborne magnetic map of the test area, flown at a constant altitude of 800 m above sea level. The NNE-SSW running flight lines were 500–700 m apart, without tie lines, and measurements were made at 600 m intervals (Björnsson and Hersir, 1981). The gridded data displayed here are based on 714 stations inside the test area and 464 stations just outside it.

Figure 4b shows the power spectrum of the aeromagnetic map after the removal of a linear least-squares regional and the application of a Hanning window. The dominance of the NE-SW striking trend is quite strong, as could be expected over an active fissure swarm. Also worth noticing are the apparently isolated peaks in the NW and SE corners of the power spectrum. These are, in fact, a continuation of the NE-SW ridge in the spectrum, and indicate aliasing in the gridded data. Aliasing effects are perhaps most easily realized if one imagines the power spectrum in Figure 4b repeats itself endlessly in all directions (Clement, 1973).

Figure 4c shows the positive part of the magnetic field passed through a fan filter with cutoffs at N20°E and N60°E, the same as in Figure 3c. Since the fissure swarm is associated with Quaternary volcanism, a positive magnetic anomaly is associated with it. The inclination of the local magnetic field is about 70°; its present-day declination is about N25°W.

Figure 5 shows the magnetic high superimposed on the gravity low. Both anomalies follow the fissure swarm south of the Hengill central volcano, but north of the volcano they part. The gravity anomaly is shifted to the east, where another section of the volcanic system is located. A separate magnetic anomaly is associated with that system. The main magnetic anomaly is shifted west, where there are indications of recent rifting and subsidence on the fissure swarm. This pattern agrees with the gradual westward movement of activity in this volcanic system, movement which has previously been noted in geologic reports on the area, although the details of the process involved are still poorly understood.

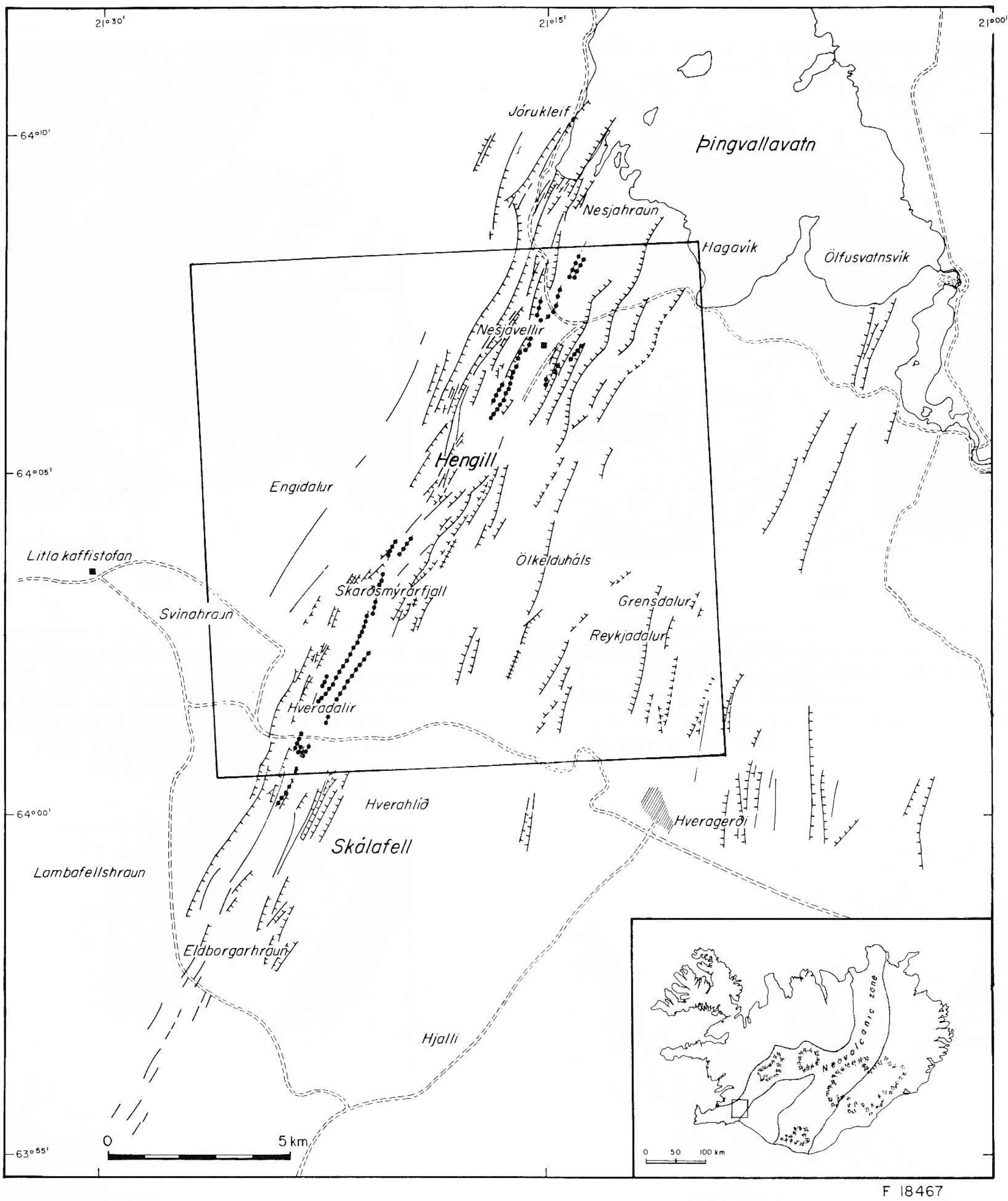


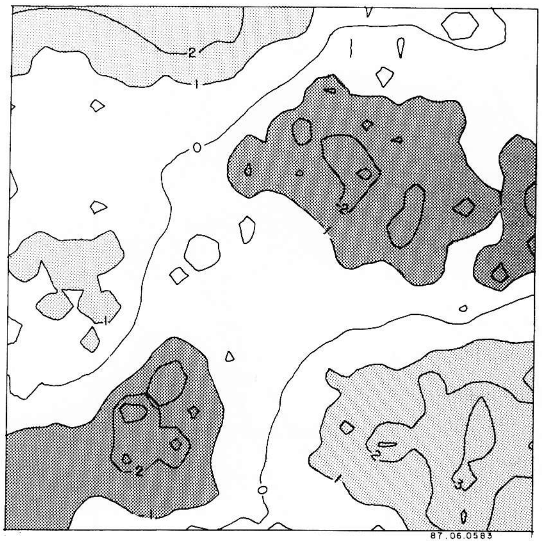
FIG. 2. The square box shows the location of the test area on the Neovolcanic zone (shaded on insert) in southwestern Iceland. The area is characterized by the Hengill central volcano and the associated NE-SW fissure swarm, as well as by high-temperature geothermal activity. Also indicated are some faults and an eruptive fissure which run NE-SW and transect the fissure swarm at the central volcano.

DISCUSSION

We have demonstrated that linear signals of tectonic origin are detectable and separable from potential field maps by analyzing their 2-D power spectra and applying directional filters to the maps based on the spectral analysis. Such reliable anomaly separation greatly facilitates the interpretation of lineation in a map. It could, for example, allow for 2-D modeling of gravity and magnetic data in terms of tectonic structures with reduced ambiguity.

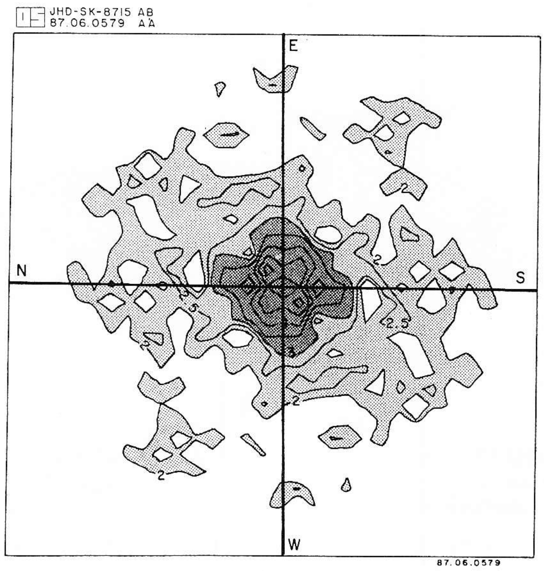
The pitfall in this approach is that any anomaly passed through a suitable fan filter clearly becomes a lineament in the resulting map. A strike-filtered anomaly should therefore meet several criteria to prove its authenticity. The lineation must be a significant feature in the power spectrum; the anomaly should be geologically reasonable; and the lineament should be perceptible on the unfiltered map. In short, reasonable care should be taken so as not to create or overinterpret false anomalies.

The filtered maps shown in the article demonstrate the abil-



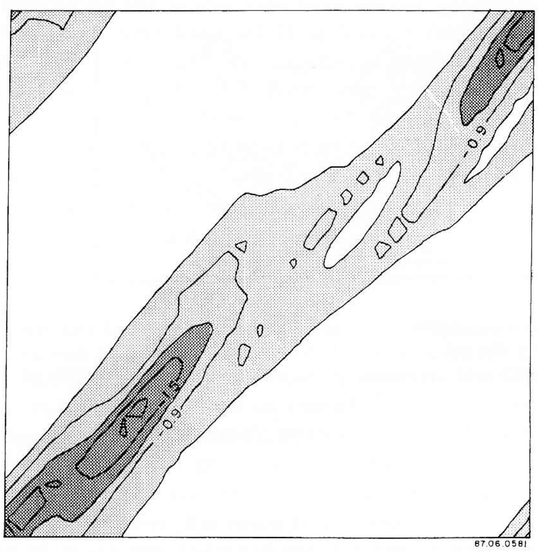
(a)

FIG. 3a. A Bouguer gravity map with Bouguer density 2330 kg/m^3. The contour interval is 1 mGal.



(b)

FIG. 3b. The power spectrum of the gravity map. The general elongation of the spectrum in the NE-SW direction (i.e., upper left to lower right corner) reflects the fissure swarm. Two isolated peaks of higher frequencies in the upper right-hand and lower left-hand quadrants indicate a lineament transverse to the swarm. Contour interval is 0.5 dB.



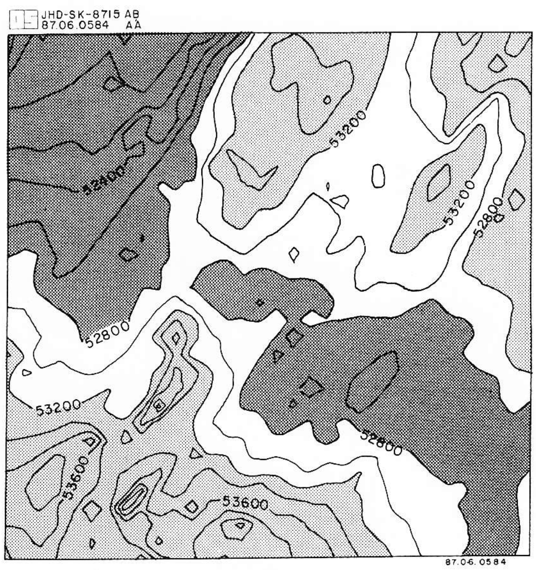
(c)

FIG. 3c. The gravity map after directional filtering along N40°E. Only the negative-valued contours are shown. The anomaly follows the southern and eastern branches of the fissure swarm. Contour interval is 0.3 mGal.

ity of directional filtering to separate significant lineaments from the rest of the data, as manifested in their agreement with each other and with the surface geology in the area. The success of directional analysis and filtering in this instance rests on the geologic fact that the tectonics control the pattern of volcanism in the rift zone, which in turn is generally accompanied by a gravity low and a magnetic high, quite visible in the unfiltered data as general trends.

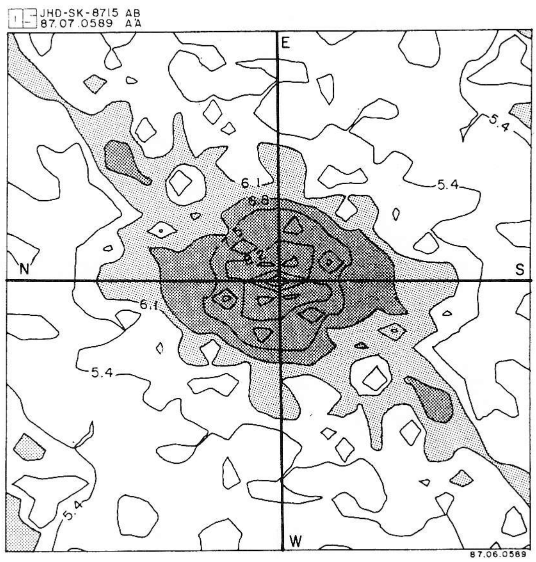
REFERENCES

Björnsson, A., and Hersir, G. P., 1981, Geophysical reconnaissance study of the Hengill high temperature geothermal area, SW-Iceland: Geoth. Res. Coun. Trans., **5**, 55–58.



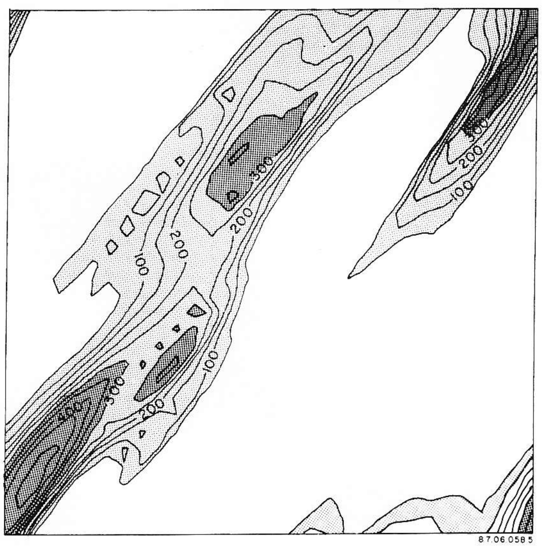
(a)

Fig. 4a. An aeromagnetic map of the test area, flown at a constant altitude of 800 m. Contour interval is 0.2 μtesla.



(b)

Fig. 4b. The power spectrum of the aeromagnetic map. The NE-SW striking lineation clearly dominates the spectrum. Note the isolated highs in the upper right and lower left corners. These are actually a continuation of the NE-SW "ridge" in the spectrum and are caused by aliasing in the gridded data. Contour interval is 0.6 dB.



(c)

Fig. 4c. The aeromagnetic map after directional filtering along N40°E. Only the positive-valued contours are shown. The main anomaly follows the southern and western branches of the fissure swarm, while a smaller anomaly is associated with the eastern branch. Contour interval is 50 ntesla.

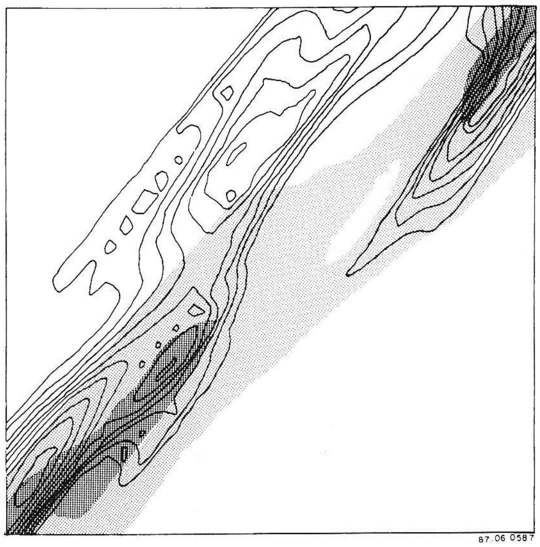


Fig. 5. Comparison of the filtered gravity and aeromagnetic maps. The contour lines show the magnetic high (cf., Figure 4c) while the shaded area depicts the gravity low (cf., Figure 3c).

Björnsson, A., Hersir, G. P., and Björnsson, G., 1986, The Hengill high-temperature area SW-Iceland, regional geophysical survey: Geoth. Res. Coun. Trans., **10**, 205–210.

Clement, W. G., 1973, Basic principles of two-dimensional digital filtering: Geophys. Prosp., **21**, 125–145.

Fuller, B. D., 1967, Two-dimensional frequency analysis and design of grid operators, *in* Mining geophysics, **2**: Soc. Expl. Geophys., 658–708.

Saemundsson, K., 1978, Fissure swarms and central volcanoes of the neovolcanic zone in Iceland: Geolog. J., **10**, 415–432.