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Enhancement of Fault Anomalies by Application of Steerable Filters: Application to Aeromagnetic Map of Part of Ifewara Fault Zone, Southwestern Nigeria

G.C. Onyedim
Department of Physics, Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract: Subtle potential-field signatures of brittle faults and fractures necessitate detailed data processing, using a wide variety of anomaly-enhancement techniques and display parameters. As a class of oriented linear filters, steerable filters are used in many vision and image processing tasks such as edge detection, textural analysis, motion analysis and pattern recognition. In this study, steerable filters were applied in six different azimuth directions to enhance magnetic anomalies due to faults in part of the basement complex of southwestern Nigeria. Unlike the original unfiltered image, the filtered images facilitated easy delineation of linear features which were interpreted as fractures in the area. The major fracture directions identified were NNE-SSW, NE-SW, NW-SE and ENE-WSW. The NNE-SSW trending Ifewara fault shows clearly as a fault zone.

Key words: Magnetic anomalies, steerable filters, fractures, faults

INTRODUCTION

An important objective in the structural interpretation of geophysical data is to map joints and faults. These features are characterized by their distinct linear or curvilinear nature and therefore can be identified through lineament interpretation of processed potential field data or enhanced remotely sensed images.

Traditionally, potential field data are displayed in the form of contour maps. On such maps, joints and faults appear as elongate closed contours, nosings in the contours, abrupt terminations of contours and discontinuities in the contour pattern. Faults of regional dimensions are characterized by alignments of the contour features listed above. Direct interpretation of joints and faults on contour maps using the above signatures can be tedious and time-consuming, particularly for large areas. The problem is further compounded even for small areas if the dynamic range of the potential field anomaly associated with the fault is small.

Subtle potential-field signatures of brittle faults and fractures necessitate detailed data processing, using a wide variety of anomaly-enhancement techniques and display parameters. Which methods will produce the most geologically meaningful results is often hard to know in advance. The final choice of processing and display options depends on which types and aspects of anomalies one aims to enhance, as well as on extensive experimentation.

Blakely and Simpson (1986) developed a method of mapping geologic contacts using boundary analysis of potential field data by calculating the horizontal gradient of the field. Fedi and Flori (2001) introduced the Enhanced Horizontal Derivative (EHD) method to determine the horizontal locations of source boundaries. Onyedim and Ogunkoya (2002) presented a manual method of processing topographic contour maps to facilitate interpretation of lineaments/faults. The same method can be applied to potential field contour maps. In the case of data with limited dynamic range, the integration of a method for determining source boundaries, such as the EHD method (Fedi and Flori, 2001) and a suitable image display method, such as the shaded relief with a user defined illumination direction.

Various image processing and enhancement methods are now being applied to geophysical data to facilitate interpretation. This is possible because such data are either acquired or can be converted into the digital form through digitization. This is the case with aeromagnetic data.

This study introduces a class of orientation filters known as steerable filters. They are used in vision and image analysis to enhance features such as edges, which form the basic model representation of joints and faults. As an example, the aeromagnetic data of part of Ilesha area, where the Ifewara Fault outcrops, were subjected to steerable filtering to enhance magnetic anomalies associated with the faults in the fault zone.

STEERABLE FILTERS

As a class of oriented linear filters, steerable filters are used in many vision and image processing tasks such as edge detection, textural analysis, motion analysis and pattern recognition. Their basic behaviour with regard to representation of an orientation may be examined by computing an orientation map: the squared filter response as a function of filter orientation. They were first introduced by Freeman and Anderson (1991a, b) and have been used by Laine and Chang (1995). As in all directional filters, the effect of the application of steerable filters is to enhance features of an image in a defined arbitrary direction while minimizing the effects in other directions.

In his study on computational edge detection, Canny (1986) identified the desirable quantities of a feature detector and proposed an appropriate optimal criterion. Based on this, he developed a general approach to derive the optimal detector for specific image features such as edges. One approach employs 1D operators approximated by simple first and second order differentials of the Gaussian. For 2D images, the 1D operator is applied orthogonal to the feature boundary while smoothing in the perpendicular direction (i.e., along the boundary). An alternative to the differential approaches to orientation independent feature detection was provided by Freeman and Adelson (1991) on the use of steerable filters.

Steerable filters are directional filters. For an arbitrary angle θ_a of the filter, the impulse function can be expressed as a combination of basis functions $h^{\theta i}(x,y)$, i =1,2,…..,M as follows (Freeman and Adelson, 1991a, b):

$$h^{\theta a}(x,y) = \sum_{i=1}^{M} k_i(\theta_a) h^{\theta i}(x,y) \qquad (1)$$

where $k_i(\theta_a)$, $1 \le i \le M$ are the filter coefficients. The scheme used to implement Eq.1 is shown in Fig. 1. It is also necessary to define which functions h (x,y) can satisfy Eq. 1 and the nature of the interpolation functions $k_i(\theta)$. Let h be any function which can be expanded in a Fourier series in polar angles θ as

$$h(r,\theta) = \sum_{n=-N}^{N} a_n(r) e^{jn\theta_a} \qquad (2)$$

where $r = (x^2 + y^2)^{1/2}$ and $\theta = \arg(x,y)$ in polar coordinates. The steering condition (Eq. 1) holds for functions expandable in the form of Eq. 2 if and only if the interpolation functions $k_i(\theta)$ are the solutions of,

$$e^{i l \theta_a} = \sum_{i=1}^{M} e^{i l \theta_i} k_i(\theta_a) \qquad 0 \le l \le N \qquad (3)$$

Thus, any directed impulse response of the input data can be obtained by using Eq. 1 to 3.

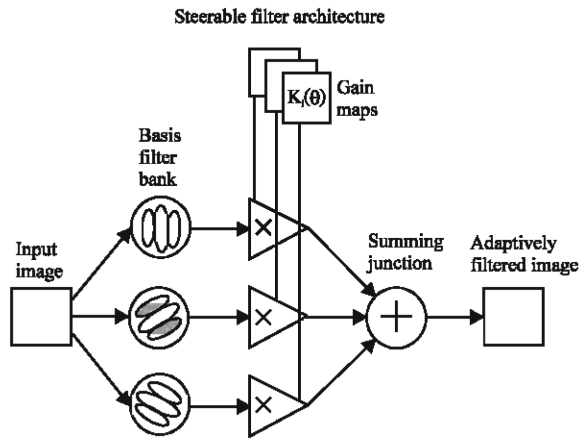

Fig. 1: Scheme for the implementation of the steerable filter

In practice, there are many $h^{\theta i}$ functions that can be chosen as impulse response functions. For the purpose of processing digital image data for edge detection, Freeman (1992) suggested the use of the 2-D Gaussian function described by

$$h(x,y) = \exp\{x^2 + y^2)/2\} \qquad (4)$$

Noting that the basis functions for θ = 0° and 90° are the derivatives of the Gaussian function along the x and y directions, respectively, we then have

$$h^{\circ}(x,y) = -2x\, h(x,y) \qquad (5)$$

$$h^{90}(x,y) = -2y\, h(x,y) \qquad (6)$$

Therefore, for any arbitrary angle θ, the directed impulse response of the input image is a linear combination of the basis functions, thus

$$h^{\theta}(x,y) = \cos\theta\, h^{\circ}(x,y) + \sin\theta\, h^{90}(x,y) \qquad (7)$$

APPLICATION TO AEROMAGNETIC DATA OF PART OF ILESHA AREA, SOUTHWESTERN NIGERIA

Faults within the Ifewara fault zone around Ilesha in southwestern Nigeria do not show distinctive anomalies on gravity and magnetic maps. The reason for this may be ascribed to the small dynamic range of the anomalies resulting from very low density or magnetic susceptibility contrast between the fault rock and the host rocks. However, lineament interpretation of aerial photographs, radar and satellite images combined with field mapping show that the area is characterized not by a single defined fault but a fault zone (Odeyemi, 1995; Onyedim and Ocan,

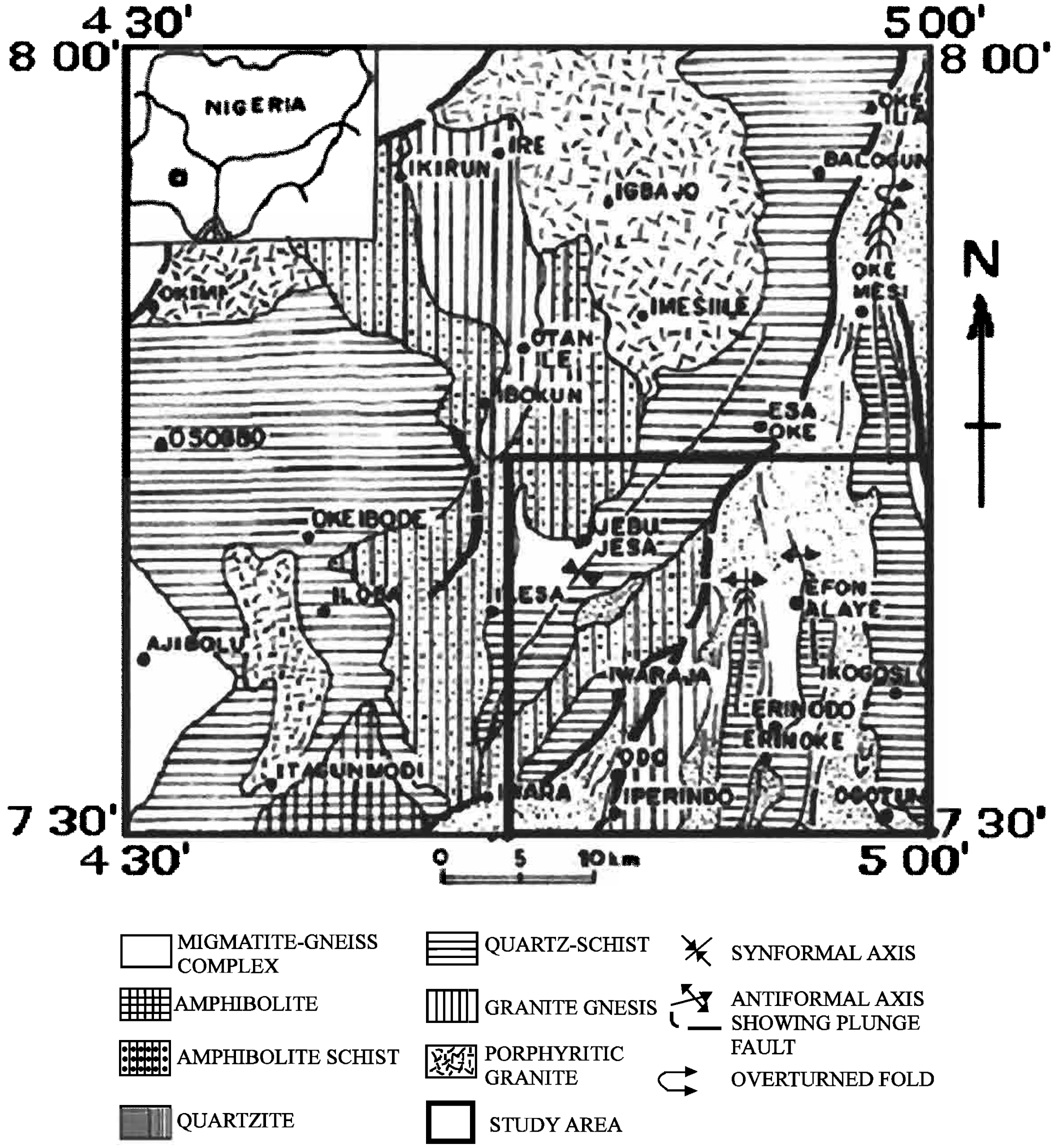

Fig 2: Geological map of the area around Ilesha, southwestern Nigeria. The study area is demarcated with thick lines

1998). It is therefore necessary to explore methods of enhancing the very subtle magnetic/gravity anomalies so as to facilitate easy identification of the faults within the zone.

The area chosen for analysis is part of the Precambrian of southwestern Nigeria collectively referred to as the Basement Complex. It is bounded by longitudes 4° 45' and 5° 00' and latitudes 7° 30' and 7° 45'. As shown on the geological map in Fig. 2, the area is underlain by rocks which are members of the two major petrological groups of the Basement Complex: the migmatite-gneiss-quartzite complex and the Ife-Ilesha Schist Belt. These are intruded by rocks of the Older Granite Suite.

The Ifewara fault subdivides the area into two contrasting structural domains. The western portions are dominated by the NNE-SSW trending shear system- the Ifewara Fault zone in which the main structure is a NNE-SSW trending mylonitic foliation. Here, most of the lithologic boundaries are tectonic (Boesse and Ocan, 1988). On the geological map of the area (Fig. 2), the Ifewara fault bifurcates into an inverted V in its southwestern portion. To the east of the area are ridges of quartzite and quartzo-feldspathic gneisses which are parallel to this structural trend. North and west of this region, the foliation has a dominantly NNW-SSE trend.

PROCESSING AND ANALYSIS OF AEROMAGNETIC DATA

Magnetic data for the area was taken from aeromagnetic map sheet 243 S.E. published by Geological Survey, Nigeria. The aeromagnetic data were acquired at a norminal flying altitude of 500 ft (about 152 m) with the flight lines spaced 2 km along the directions 150°/330° and tie lines spaced 20 km in the direction 60°/240°. The regional correction was based on IGRF (1974).

The map was digitized along flight lines and the resulting data was interpolated unto a 0.5 km grid using a program based on the minimum curvature method (Webring, 1981). In order to emphasize local and surface features, which are of interest in this study, a second order regional surface was removed from the gridded data to generate the residual magnetic intensity values shown as shaded relief and contoured maps in Fig. 3a and b, respectively. On the residual map, the total intensity values vary from 320 nT to 960 nT. A comparison of the geological map and the aeromagnetic map shows that the only obvious magnetic expressions of the fault are the observed nosings of the contours in Fig. 3b with a NNE-SSW trend in the western portion.

The gridded aeromagnetic data were subjected to steerable filtering using a short computer code to implement Eq. 5 and the scheme in Fig. 1. An important consideration in any form of edge detection analysis is the mode of display of the results. In this study, the results shown in Fig. 4 are presented in the form of shaded relief images. These images were created by shining a false sun on the magnetic map and treating the magnetic values as elevations. The artificial sun elevation (β) was fixed at 30° above the horizon for all the images while the azimuth (ϕ, measured positive clockwise from geographic North), was given a value orthogonal to trend of the features to be emphasized on a given image (i.e., $\beta = \theta + 90°$).

To model the directional filtering effects of the steerable filter on the magnetic dataset, various values were used to simulate different impulse response functions as defined in Eq. 7. For each angle, the shaded relief version of the Steerable Filtered Image (SFI) was plotted and examined for its enhancement attributes. Figure 4 shows the results obtained for θ equal to (a) 15°, (b) 30°, (c) 45°, (d) 70°, (e) 90° and (f) 135°.

RESULTS AND DISCUSSION

Compared to the unfiltered image and contour map in Fig. 3, the steerable filtered images (SFIs) in Fig. 4 are quite informative. Figure 4a and 4b for θ equal to 15° and 30° reveal the full extent of features trending NNE-SSW. Comparison with the geological map in Fig. 2 shows that the main feature with this trend in the area is the Ifewara fault. The SFIs however show that the fault is characterized by several segments of different lengths and therefore suggestive of a fault zone rather than a single defined discontinuity in the rock fabric. Figure 4c also demonstrates that faults trending NE-SW are also present in significant numbers. In a study of the relationship between SPOT imagery lineaments and geological fractures in the area west of the present study area,

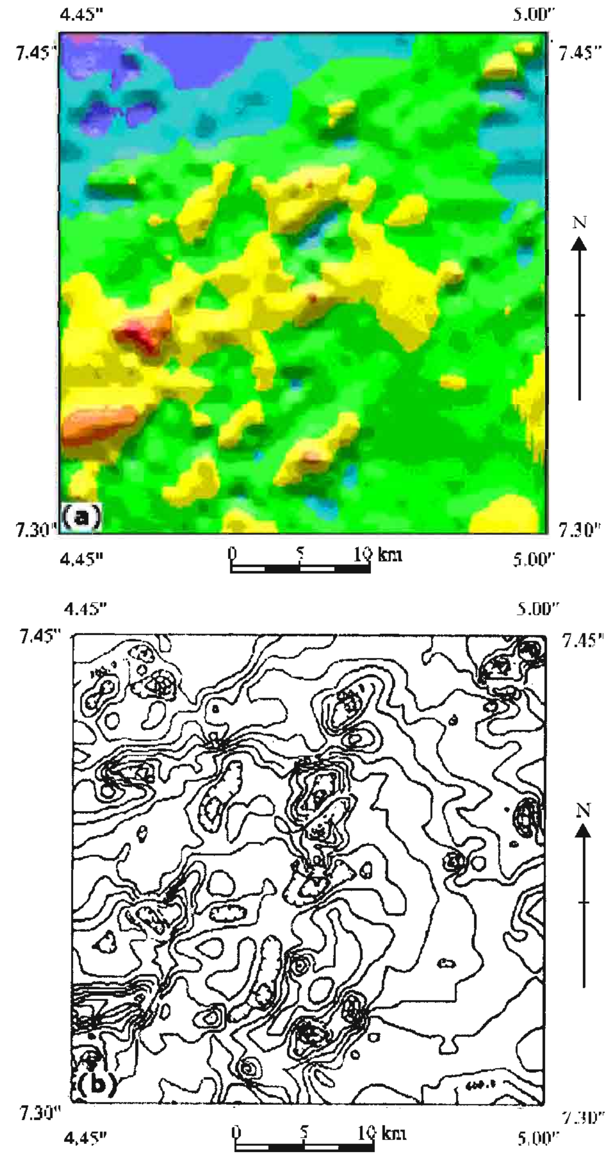

Fig. 3: The residual magnetic field of the study area after removal of a second order regional is shown as a (a) shaded relief image and (b) contour map

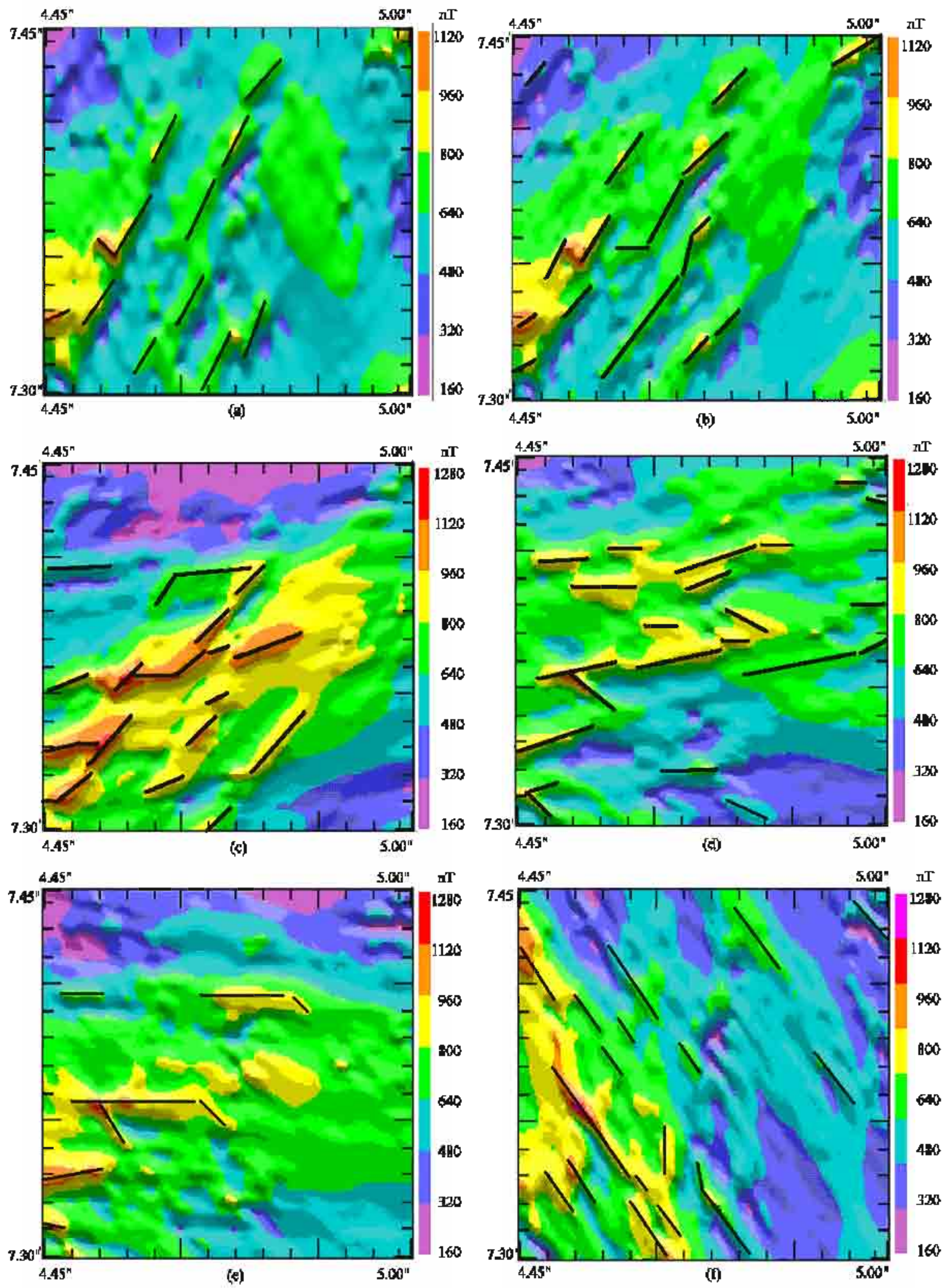

Fig. 4: Steerable filtered images (SFI) for θ in Eq. 7 equal to (a) 15°, (b) 30°, (c) 45°, (d) 70°, (θ) 90° and (f) 135°

Onyedim and Ocan (2001) observed that NE-SW lineaments correspond both in significance and direction to a major fracture set in the area. These fractures are parallel to and therefore control the alignment of straight stream segments and the orientation of itamerin two-mica granite located southeast of Ilesha town. Figure 4d and e which show the results for θ equal to 70° and 90°, respectively indicate that ENE and E-W fractures are also present particularly the ENE-WSW set. Elueze (1977) noted that some of the E-W trending fractures are of the strike-slip type. The shaded relief image in Fig. 4f shows the SFI for θ equal to 135°. The result is the observed enhancement of lineaments trending NNE-SSW, which occur mainly in the western half of the area. It is therefore likely that they are genetically related to and are complementary with the equally significant NNE-SSW fracture set. According to Oluyede (1988) and Udoh (1988), both represent important fracture systems which have been recognized in the Nigerian basement complex.

CONCLUSIONS

Subtle potential-field signatures of brittle faults and fractures necessitate detailed data processing, using a wide variety of anomaly-enhancement techniques and display parameters. This study has shown that steerable filters, a class of directional filtersc can be effective in the enhancement of lineaments on magnetic maps. Application to the aeromagnetic data of part of Ilesha area in southwestern Nigeria produced enhanced magnetic signatures of fractures which were not immediately obvious on the unfiltered maps. However, which methods will produce the most geologically meaningful results is often hard to know in advance. The final choice of processing and display options depends on which types and aspects of anomalies one aims to enhance, as well as on extensive experimentation.

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