
Investigating Possible Fault Lines Responsible For the September 2016 Earth Tremor at Kwoi,
Nigeria, Using Aeromagnetic Data

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ABSTRACT

This research was aimed at investigating possible fault lines responsible for the September 2016 earth tremor at Kwoi, Nigeria using aeromagnetic data. Four aeromagnetic maps were acquired from the Nigerian Geological Survey Agency (NGSA), Abuja. These sheets include; sheets 166 (Anfu), 167 (Kachia), 187 (Kagarko) and 188 (Jemaa). The sheets then put together extend from 9° 00'N - 10° 00'N and from 7° 30' E - 8° 30' E covering the study area and its environs. Most of the anomalies trend NE - SW directions. The regional magnetic field data was separated from the residual magnetic data using the polynomial fitting method. The residual magnetic field image map revealed some subtle lineaments within the study area including region around epicenters. The upward continued data of 150m gives a clearer view of the magnetic anomalies as the noise arising from the high frequency anomalies is suppressed. The shaded relief map of the upward continue data revealed some lineation close to the epicenters. Some lineaments observed on the Analytic signal map align with major fault/fracture on the geologic map especially south of Kwoi. Some Werner solutions generated intercept with some observed lineaments in the study area and no solution was generated on any of the epicenters. Euler solutions were generated around two of the epicenters. The depth range of the Euler solutions around the two epicenters is 1.2 km - 3.0 km. Cluster of Euler solutions around the epicenters trend along NW-SE and EW aligning with trend of the lineament on the Analytic signal and first vertical derivative maps.

INTRODUCTION

An earthquake is a sudden release of energy caused by the sudden breaking and movement of large sections (tectonic plates) of the earth's interior. The edges of the tectonic plates are marked by faults (or fractures). Most earthquakes occur along the fault lines when the plates slide past each other or collide against each other. A natural disaster of geological nature such as earthquake, for instance, is a phenomenon that defies human understanding and is well known for its devastating impact on human life, economy and environment. The first widely reported occurrence of an Earth tremor in Nigeria was in 1933. Other events were reported in 1939, 1964, 1984, 1990, 1994, 1997, 2000 and 2006 (Akpan and Yakubu, 2010).

Aeromagnetic survey is a powerful tool in delineating regional geology (lithology and structure) of buried basement terrain. Basement rocks generally have strong magnetic susceptibilities compared to values for sedimentary rocks. Variations of the magnetic intensities over basement complexes are therefore considered to originate in the sedimentary structure,

intrusive and extrusive volcanic bodies either within the basin or basement itself, or occasionally in variation of susceptibilities in materials within the basement (Klitgord and Behrendt, 1980). A variety of methods have been used for these purpose, the earliest methods include those of Peters (1949) and Vacquier et al., (1951). In recent times, however, emphasis has shifted to more automated techniques such as those described by Spector and Grant, (1970), Hartman et al., (1971) and Phillips (1978).

Location and Geology of the Study Area

The study area is located in the southern part of Kaduna State within the basement complex rocks of north central Nigeria. It lies between latitude 9° 00' to 10° 00' North and between longitude 7° 30' to 8° 30' East (Figure 1.1). Some earlier workers in the area concentrated on the general geology of the area. Nahikhare (1971) and Okezie (1970) all identified graninites, migmatites and gneisses as the dominant rocks in the area.

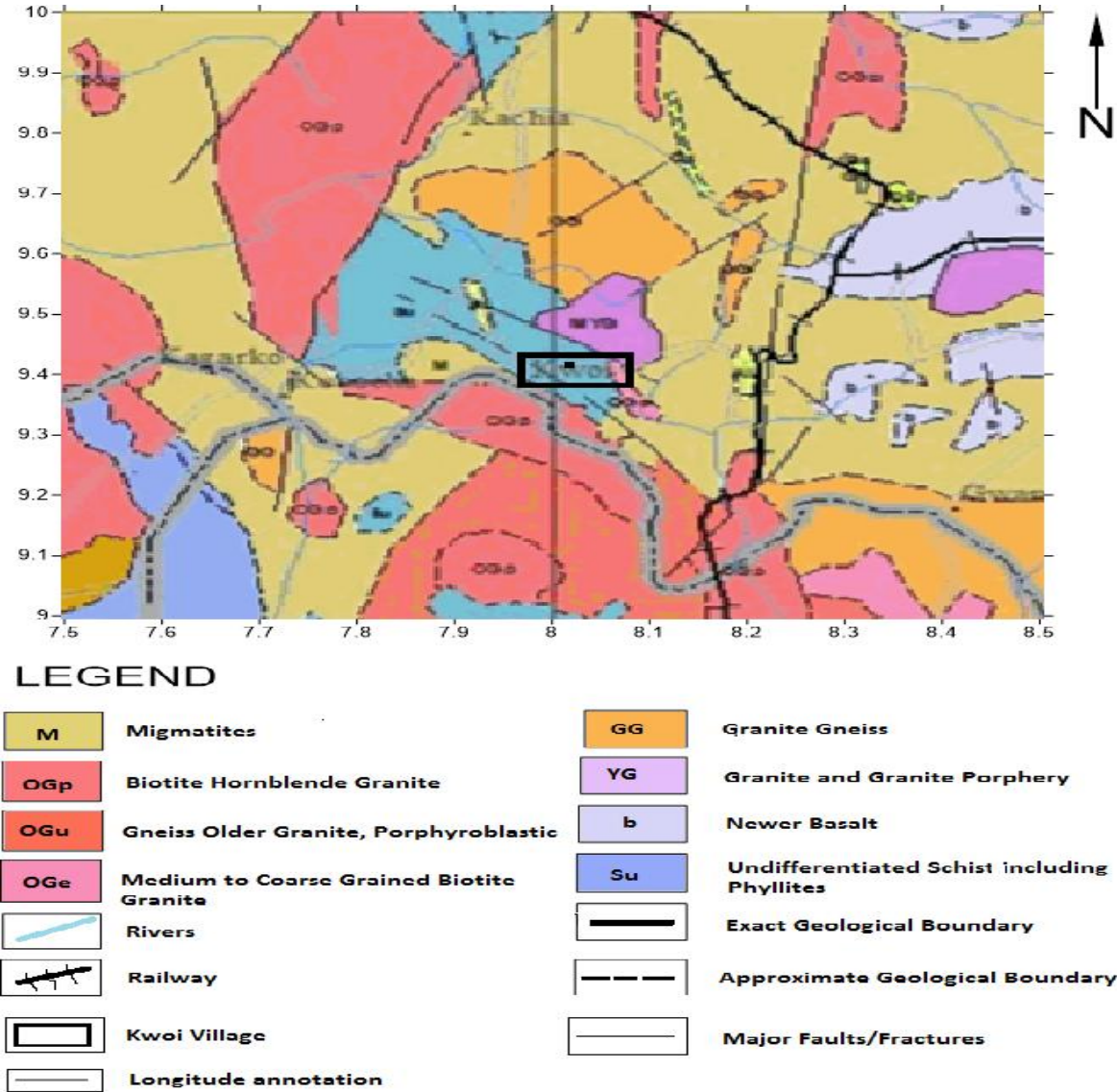


Figure 1.1: Geological Map of the Study Area (After NGS, 2006)

MATERIALS AND METHOD

Data Acquisition

Four aeromagnetic maps were acquired from the Nigerian Geological Survey Agency (NGSA), Abuja. These sheets include; sheets 166 (Anfu), 167 (Kachia), 187 (Kagarko) and 188 (Jemaa). The aeromagnetic data were obtained as part of a nationwide aeromagnetic survey sponsored by the Geological Survey of Nigeria. The data were acquired at a flight altitude of 80m along a series of NE – SW flight lines with a spacing of 500m. The sheets then put together extend from 9° 00’ 00” N - 10° 00’ 00” N and from 7° 30’ 00” E - 8° 30’ 00” E covering the study area and its environs.

Table 2.1: Sequence of the events (After CGG Toro 2016)

S/n	Latitude (degrees)	Longitude (degrees)	Magnitude ()	Date	Time
1	9.62	7.94	2.9	11/09/2016	12:28:13
2	9.56	7.82	2.8	12/09/2016	03:10:45
3	9.48	8.03	3.2	12/09/2016	03:11:13

Aeromagnetic Survey Method

An aeromagnetic survey is a common type of geophysical survey carried out using a magnetometer aboard or towed behind an aircraft. The principle is similar to a magnetic survey carried out with a hand-held magnetometer, but allows much larger areas of the Earth's surface to be covered quickly for regional reconnaissance. The aircraft typically flies in a grid-like pattern with height and line spacing determining the resolution of the data.

DATA ANALYSIS AND RESULTS

Total Magnetic Intensity

The total magnetic field intensity values ranges from 32942.5 to 33086.9 nT. Most of the anomalies trend NW – SE and NE – SW directions (see fig. 3.1a). Kwoi village and two of the epicenters lie on the same geologic unit (i.e. undifferentiated Schist including Phyllites), but the third epicenter – very close to Kwoi village – lies on the Granite Porphyry.

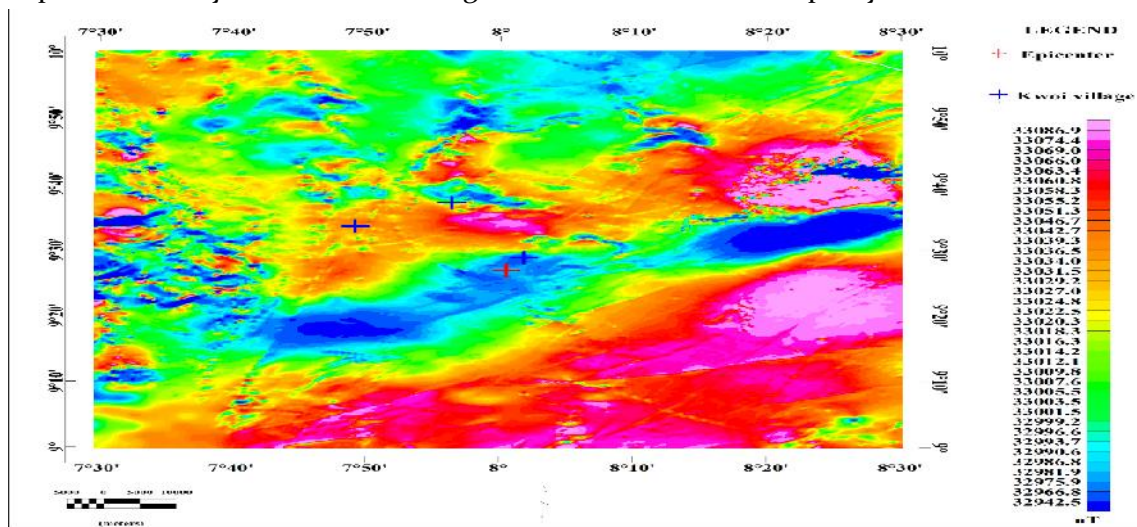


Figure 3.1: Total Magnetic Intensity Map of the study area.

Regional and Residual Separation of Magnetic Anomalies

Magnetic data interpretation usually commence with some procedure that separates the smooth, presumable deep seated regional effects from the observed field so as to obtain the residual effects, which are the anomalies of geological interest. The regional magnetic effects correspond to low frequencies of the observed field, while the residual effects is the difference between the observed field and regional field, and correspond to high frequencies of the observed field. The anomaly separation procedure may consist of removal of smooth regional fields from the observed or measured field, leaving the irregular residual field.

The regional magnetic field data was separated from the residual magnetic data using the polynomial fitting method with regression coefficient $Z(X,Y) = 33293.6335167 - 0.0003698Y + 0.0002985X$. Residual magnetic field data was obtained as the deviations of the fitted plane surface from the total magnetic intensity using SURFER 13 software and the regional magnetic field contour map is shown in Figure 3.2. The residual magnetic field image map revealed some subtle lineaments within the study area including region around epicenters as shown in figure 3.3.

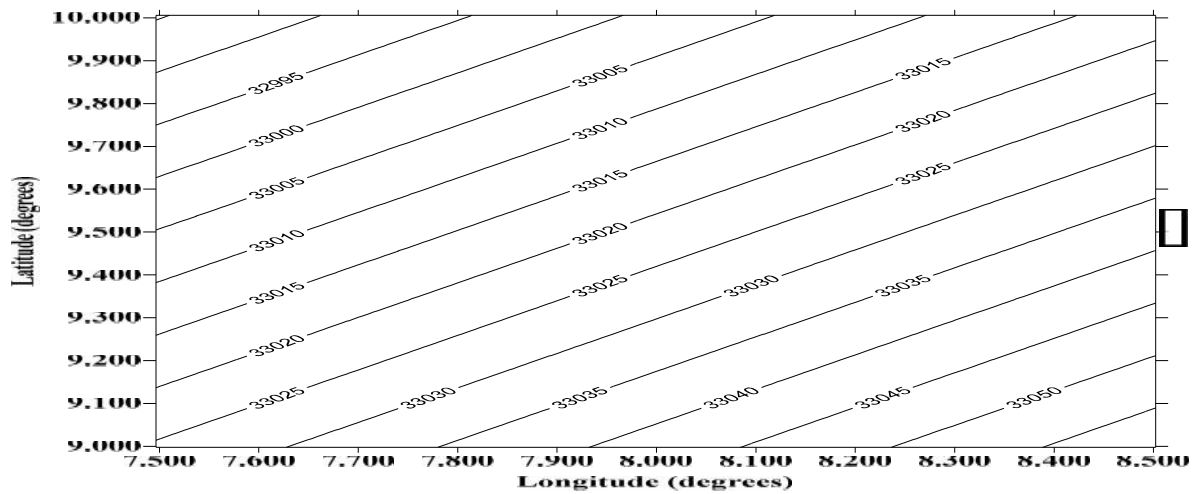


Figure 3.2: Regional map of the study area.

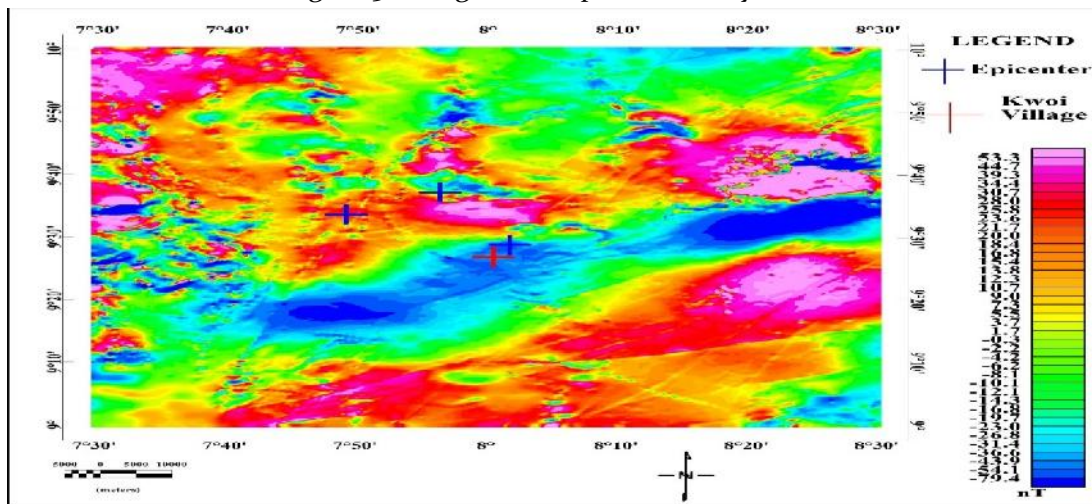


Figure 3.3: Residual field map of the study area

Upward Continuation

The Oasis montaj software is used to upward continue the residual field to a height of 150 m which is about one third the size of the inter-profile spacing used in acquiring the data. Since our interest is on relatively shallow structures which might be more affected by the noise resulting from the near surface cultural features, upward continuing the field will give us a clearer view of our anomalies of interest.

The upward continued map (figure 3.4) gives a clearer view of the magnetic anomalies as the noise arising from the high frequency anomalies is suppressed, thus, it is useful as a low-wave number pass filter. As such the 150 m upward continued data appears to provide an excellent view of the study area undistorted by the local, high amplitude, high gradient anomalies of the magnetic sources in the shallow source magnetic anomalies in the study area. It is apparent that the attenuation of the shallow source anomalies in the upward continuation process permits a clearer or enhanced view of the relatively deeper anomaly sources (Ravart, 1996). The upward continuation of 150 m was found to be suitable because apart from suppressing the noise level, it also preserve some anomaly of interest i.e. lineaments. The shaded relief map of the upward continue data revealed some lineaments close to the epicenters (see figure 3.5)

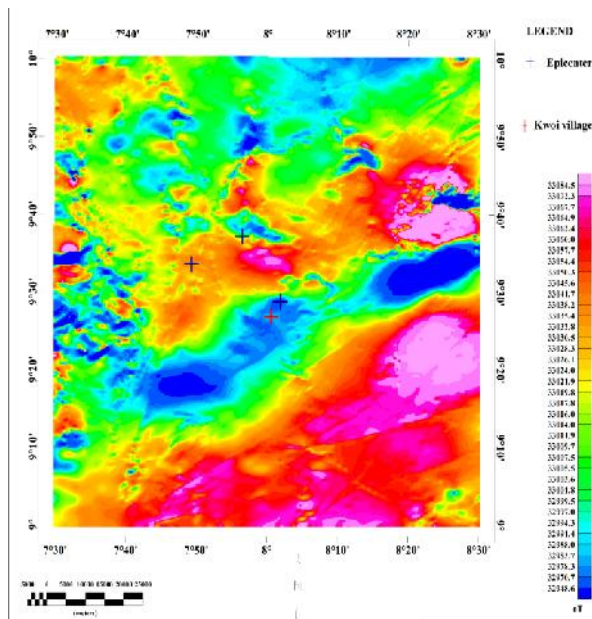
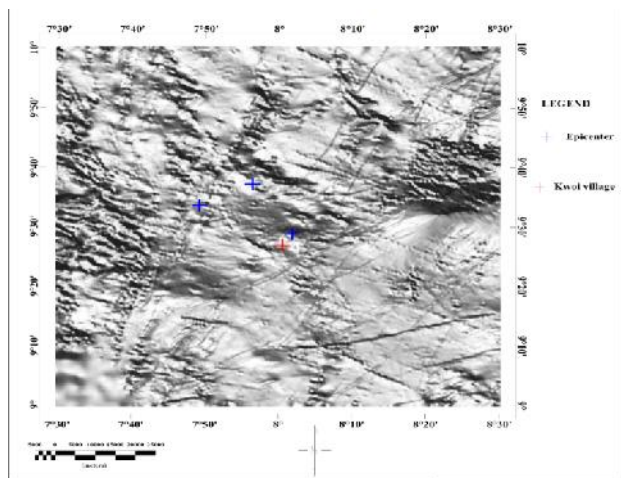


Figure 3.4: Residual field upward continued to 150 m Figure 3.5: Shaded relief map of the upward continued data.

First Vertical Derivative (FVD)

Applying the first vertical derivative is an important step in the interpretation of aeromagnetic data, particularly in studies dealing with narrow and shallow anomalies. This is done because it reduces the effect of long-wavelength regional anomalies (which are usually deeper) and enhances the higher frequency shallow anomalies according to (Grauch et al., 2009; Milligan and Gunn, 1997). This vertical derivative

map is much more responsive to local influences than to broad or regional effects and therefore tends to give sharper picture than the map of the total field intensity. However the smaller anomalies are more readily apparent in area of strong regional disturbances. In fact, the first vertical derivative (FVD) is used to delineate high frequency features more clearly where they are

shadowed by large amplitude, low frequency anomalies. The first vertical derivative grid map of the study area exposed more subtle lineaments (see Fig 3.6 below) as compared to that of upward continued grid map in Figure 3.5.

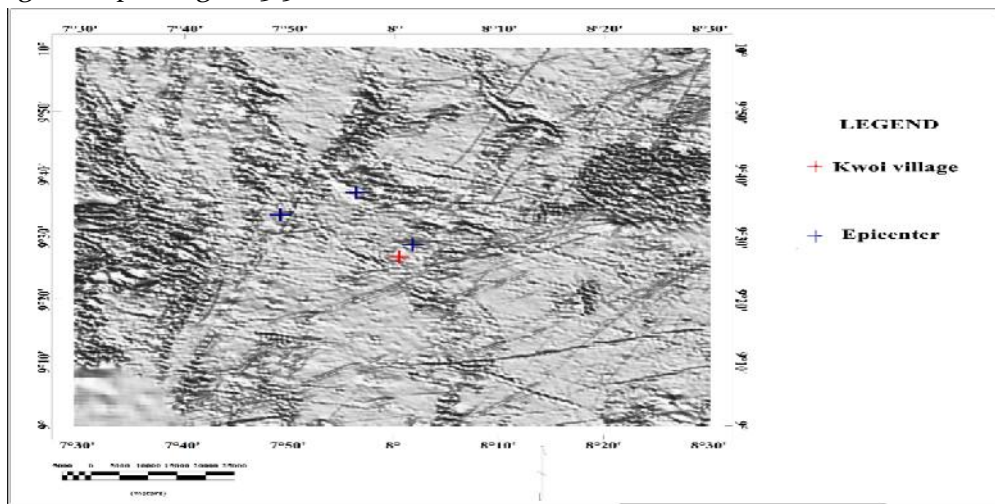


Figure 3.6: First vertical derivative map showing the study area and the epicenters

Analytical signal technique

Analytical signal of the upward continued data has much lower sensitivity to the inclination of the geomagnetic field than the original Total Magnetic Intensity data, and provides a means to analyze low latitude magnetic fields without the concerns of the RTP operator. Analytical signal is a popular gradient enhancement, which is related to magnetic fields by the derivatives.

The analytic signal of the residual field of the aeromagnetic data was computed and the map was plotted (see fig. 3.7a) using the OASIS MONTAJ software. Some of the linear features in the analytic signal map align with major fault/fractures on the Geologic map especially around Kwoi (see Fig. 3.7 b below).

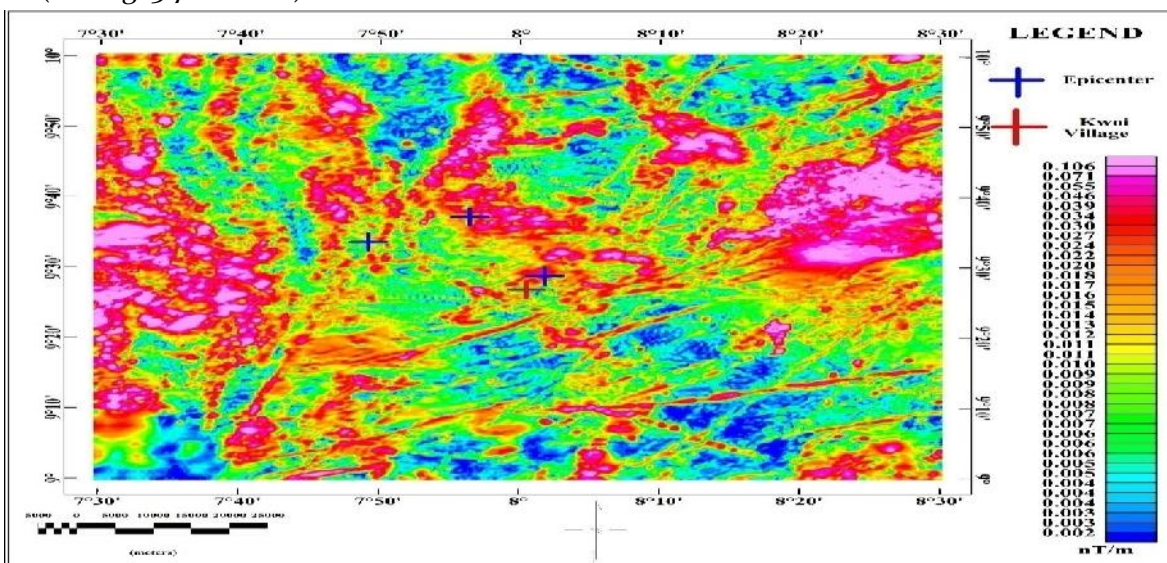


Figure 3.7a: Analytical signal map of the residual magnetic intensity

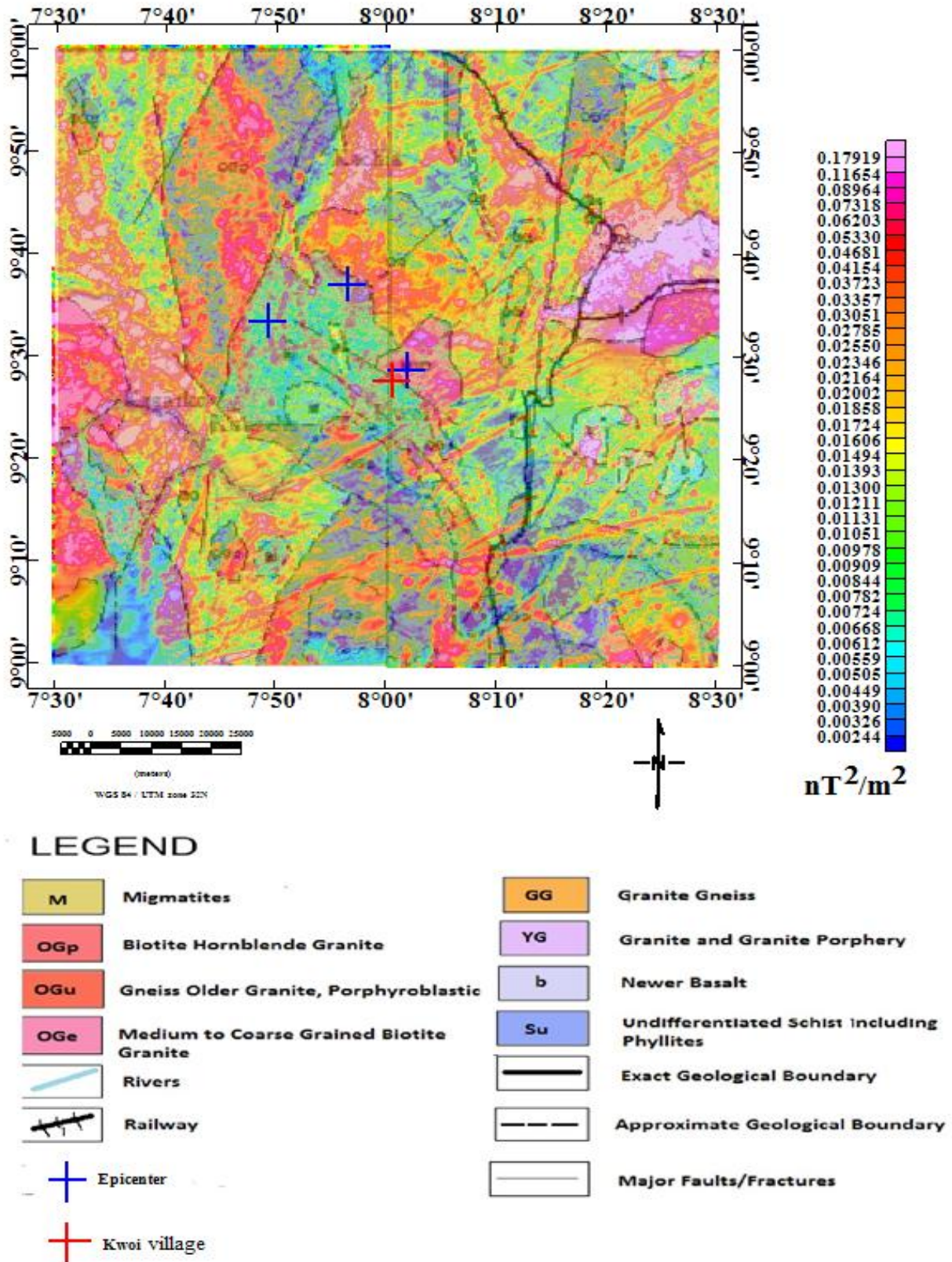


Figure 3.7b: Overlay of Analytic signal and Geologic maps

Werner Deconvolution

The Werner deconvolution function, which uses the horizontal and vertical derivatives in calculating the depth to basement of the magnetic anomaly was employed. The anomaly profiles selected were perpendicular to the epicenters and the Kwoi village. Solutions derived from the total field profile are designated dyke solutions and solutions derived from the horizontal gradient are designated contact solutions. Four profiles (EP1a-EP1b, EP2a-EP2b, EP3a-EP3b, KV a-KVb) were respectively extracted from the upward continued map of the study area to estimate the depth to magnetic bodies, and the location of the causative body such as (faults) using the Werner deconvolution technique when the sources are assumed to be dyke and contact. The profiles were taken perpendicular to the epicenters and the Kwoi Village in order to obtain the best estimate of parameter of some features along the selected profile. This selected profiles are represented in figure 3.8 below.

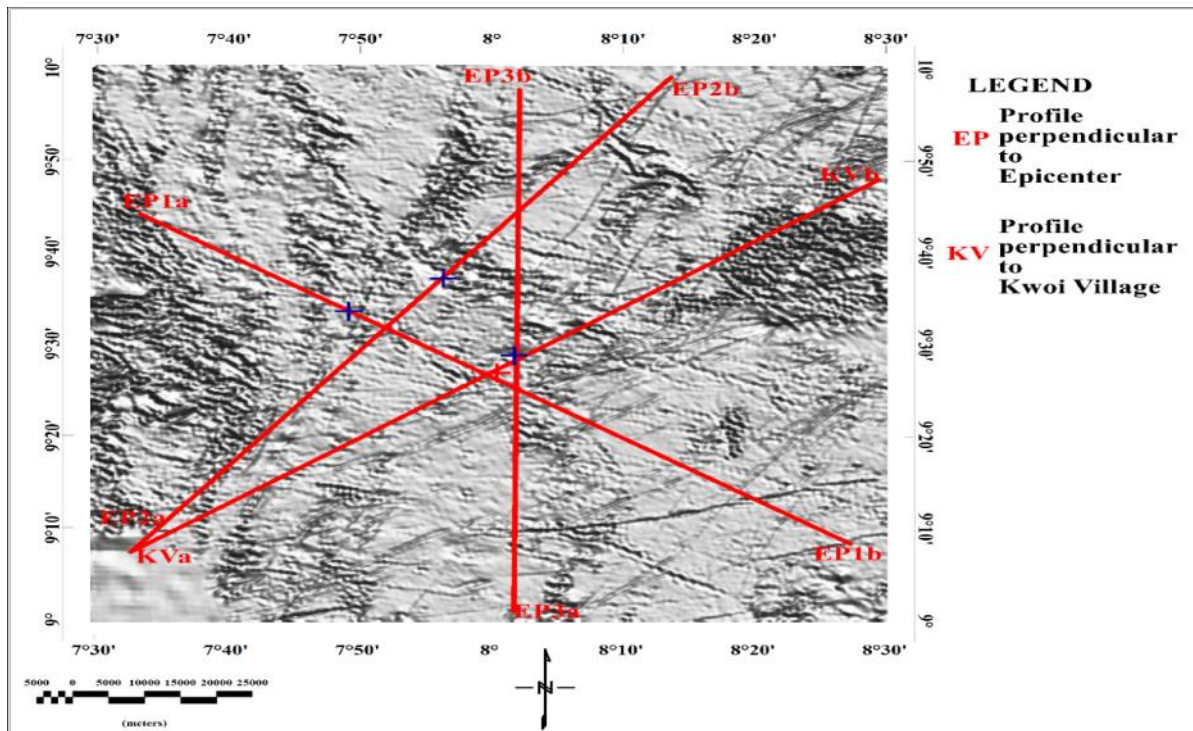


Figure 3.8: Shaded relief map showing the four selected profiles across the epicenters and the Kwoi Village.

Considerable skill appears to be required to use the results in a meaningful way. The Werner deconvolution of the four profiles taking across the epicenters and the Kwoi Village was computed. The computed depth estimates associated with magnetic basements dykes/faults/contacts of the four magnetic profiles using the Werner deconvolution technique was obtained and are shown in the figures below (i.e. Fig. 3.9, 3.10, 3.11 and 3.12).

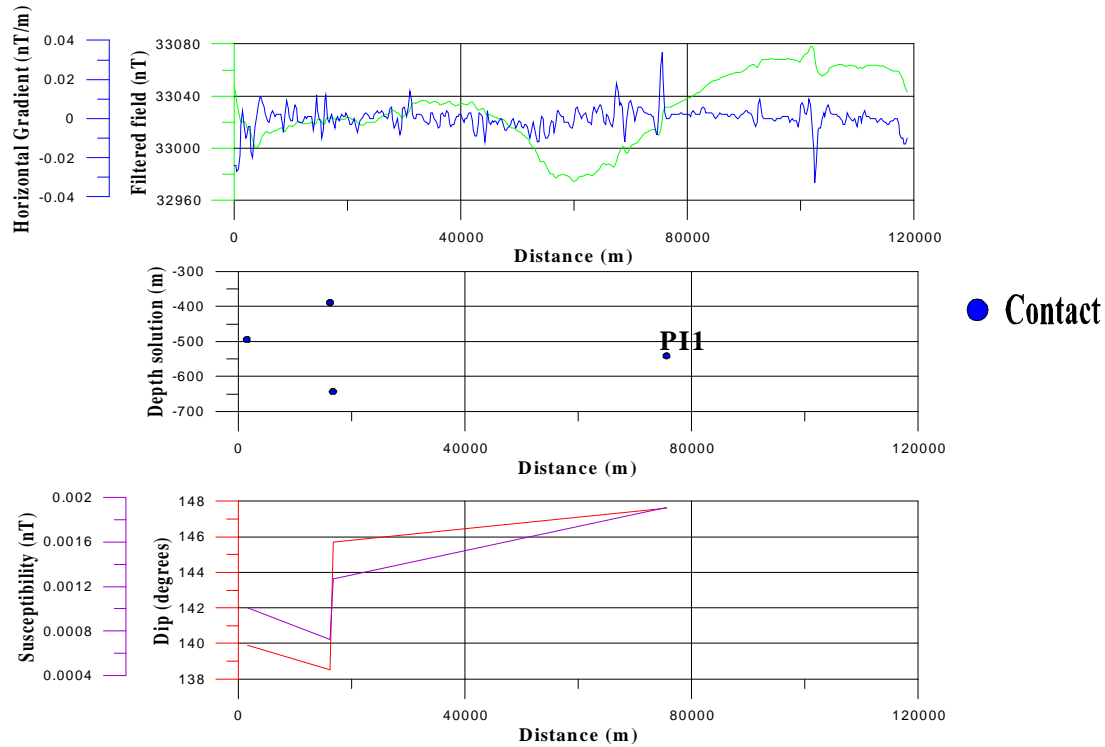


Figure 3.9: Werner depth solution for profile EP1a-EP1b with point “PI1” indicating point where Werner solutions intersects linear features.

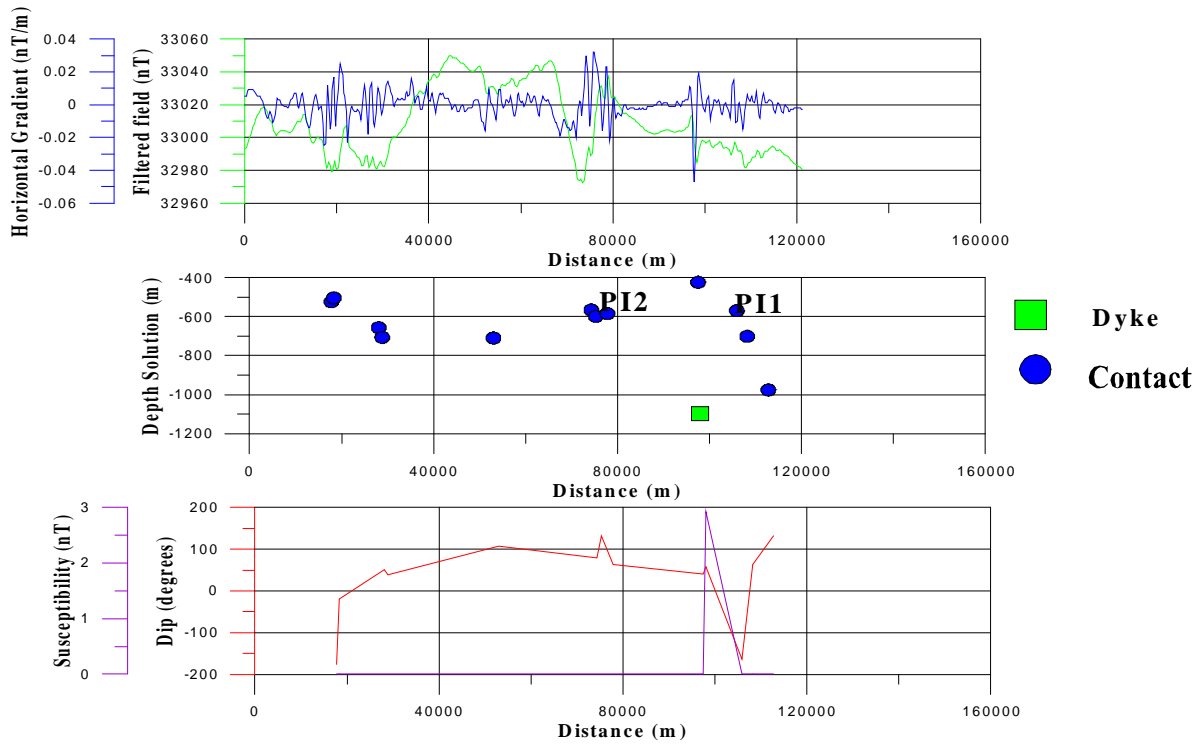


Figure 3.10: Werner depth solution for profile EP2a-EP2b with point PI1 and PI2 indicating points where Werner solutions intersects linear features.

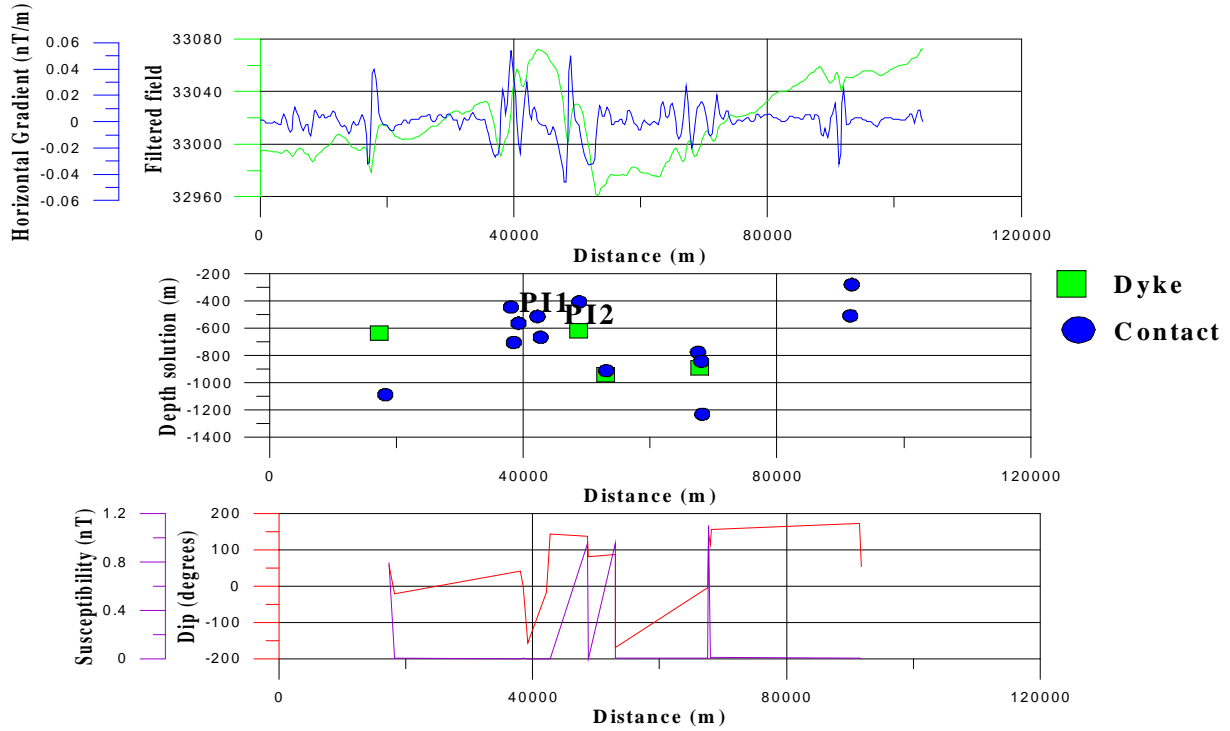


Figure 3.11: Werner depth solution for profile EP3a-EP3b with point “PI₁ and PI₂” indicating points where Werner solutions intersects linear features.

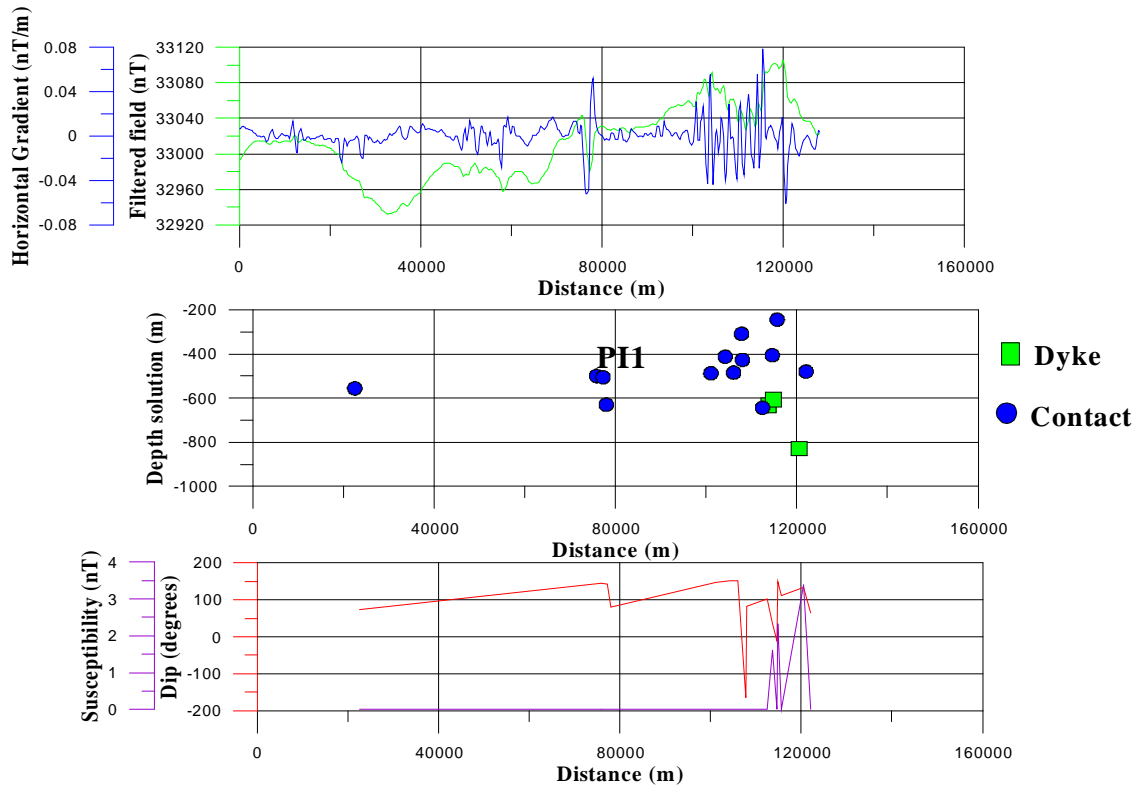


Figure 3.12: Map showing the contact and dyke solutions for profile KVa-KVb with point “PI₁” indicating point where Werner solutions intersects linear features.

Euler deconvolution technique

Euler deconvolution method was applied to the upward continued data. This technique provides automatic estimates of source location and depth. Therefore, Euler deconvolution is both a boundary finder and depth estimation method. Euler deconvolution is commonly employed in magnetic interpretation because it requires only a little prior knowledge about the magnetic source geometry, and more importantly, it requires no information about the magnetization vector (Thompson, 1982; Reid et al., 1990).

3D Euler deconvolution was performed on the residual aeromagnetic data, this was done to locate depths to the geological structures on the gridded map. The best clustering solution was achieved using a 9% depth tolerance. The tolerance level generated fewer solutions implying the most reliable solution.

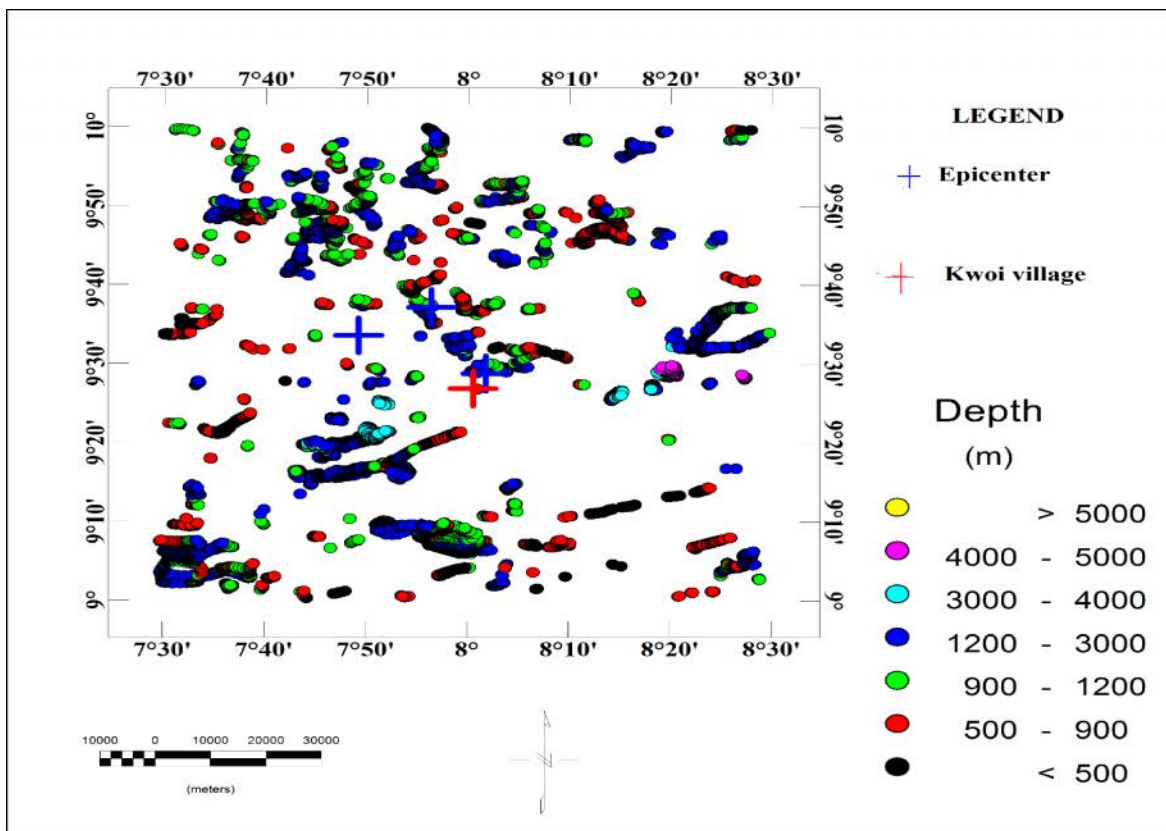


Figure 3.13: Map showing Euler depth solution of the residual map of the study area

DISCUSSION

For the purpose of this study, several qualitative and quantitative interpretation methods were applied with the goal of achieving the research objective of enhancing the signature of the subtle lineaments in Kwoi and the epicenters. Qualitative interpretation of the residual field data was carried out by enhancing the lineaments on the study area using first vertical derivative and analytic signal while quantitative interpretation is carried out by Werner and Euler deconvolution techniques.

The Total Magnetic Intensity (TMI) data of the study area was subjected to Regional-Residual separation. Then, residual of the TMI data was upward continued to suppress the noise level of the data. The upward continuation of 150 m was found to be suitable because apart from suppressing the noise level, it also preserve the observed anomaly of interest i.e. lineaments. Qualitative interpretation of the filtered data was carried out by enhancing the lineaments on the study area using first vertical derivative and analytic signal, while quantitative interpretation technique such as Werner and Euler deconvolution techniques also undertaken. The depth estimate of the geologic structures such as faults was obtained using the Euler deconvolution techniques.

There is no obvious indication of lineament around the epicenters and Kwoi village on the TMI map (see figure 3.1). Some lineaments were obvious on the residual TMI map (see figure 3.3). The first vertical derivative map revealed some lineation close to the epicenter but region around Kwoi village appear unaffected by lineament (see figure 3.6). The analytic signal plot also shows some lineament around the epicenters (see figure 3.7a). Some lineaments observed on the Analytic signal map align with major fault/fracture on the Geologic map especially south of Kwoi (see figure 3.7b).

Some Werner solutions generated intercept with some observed lineaments in the study area (see figure 3.9 – 3.12) and no solution was generated on any of the epicenters. The depth of the contacts and dykes varies on each profiles: Profiles contact's depth range are 0.2 – 1.2 km, and for the dyke's depth range are 0.6 - 1.1 km. Euler solutions were generated around two of the epicenters. The depth range of the Euler solutions around the two epicenters is 1.2 – 3 km as shown in figure 3.13. Cluster of Euler solutions around the epicenters trend along NW-SE and EW aligning with trend of the lineament on the Analytic signal and first vertical derivative maps.

CONCLUSION

From the interpretation of aeromagnetic data, the subtle lineaments (which are indications of fault lines) were exposed on residual TMI map due to regional-residual separation. The result of both qualitative and quantitative interpretations revealed that the presence of lineaments (which align with major fault/fracture on the geologic map) around the epicenters but outside the region of Kwoi village. This implies that Kwoi village is stable thereby making the devastation of the tremor to be massive as the shock may not be absorbed properly.

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