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Magnetic Characterisation of Rocks Underlying FUTA Campus, South-Western Nigeria

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Abstract
The Federal University of Technology, Akure Campus is predominantly underlain by the Migmatite-gneiss-quartzite complex of the West African Basement Rocks, which forms part of the Pan-African mobile belt. Geo-magnetic characterisation of the underlying rocks was conducted in order to determine the rock boundaries and geologic features within the near surface and subsurface areas of the Campus. Both qualitative and quantitative interpretations of total magnetic intensity data obtained in the area yielded results in terms of different rock units, linear magnetic fabrics, subsurface features and depth to basement of the rocks. On the basis of magnetic response, four rocks units including Granite, Migmatite gneiss, Charnokite and Quartzite were delineated, with varying degree of fabrics' alterations. Depth-to-bedrock in the Campus varies from 0 to 98.5 m, while depth to fracture/fault in the area falls between 0.1 m and 149.6 m.
Key Words: Geo-magnetic characterisation, depth-to-bedrock, rock fabric, total magnetic intensity, magnetic response

1. Introduction

The magnetic geophysical method can be employed as a tool in differentiating rock types based on the magnetic mineral contents of the various rock types forming the Earth materials. Most geophysical methods can be used in delineating rock boundaries, contacts and internal structures of subsurface geology. In most cases, these geophysical methods are non-invasive, such as magnetic, gravity, electrical resistivity and electromagnetic methods.

The magnetic method has played prominent roles in mineral exploration, geological mapping, groundwater geophysics and environmental geophysics (Reynold, 1997). Magnetic surveying is used to investigate the subsurface geology of an area by detecting magnetic anomalies within the Earth's magnetic field, which are caused by the magnetic properties of the underlying rocks. Despite the fact that most rock-forming minerals are nonmagnetic, few rock types contain sufficient amounts of magnetic minerals which can impact magnetism to their host rock and thus produce detectable magnetic anomalies. Rock magnetism has both magnitude and direction, the latter being determined by the host rocks position relative to the past and present magnetic poles of the Earth.

Geological contacts or rock boundaries could be defined as the meeting point between two or more rock types depending on the geologic setting (Oyawoye, 1972). It is usually indicative of the beginning of a rock type and the end of another rock type within a given geologic environment in the subsurface.

The magnetic response of the rock types in the area is influenced by the mineral content whose magnetic susceptibility can vary considerably with age and location. Susceptibility varies not only between rocks and minerals, but also within rocks of the same type, thus the knowledge of susceptibility alone will not be sufficient to determine rock type, and alternately, the knowledge of rock type is often not sufficient to estimate the expected susceptibility. However, the wide range in susceptibilities implies that spatial variations in the observed magnetic field can readily be attributed to geological structure, which can be interpreted in terms of mineral content and alteration of rock fabrics.

This paper gives details of geologic mapping of The Federal University of Technology, Akure Campus through comprehensive ground magnetic survey in order to determine the rock boundaries and geologic features within the near surface and subsurface areas of the Campus.

1.1. Site Description

The Federal University of Technology, Akure is located in the North-western part of the ancient city of Akure, south-western Nigeria and has a land mass of about 6 km^2. It is situated within latitude 7 °07' N to 7° 08' N and longitude 5 °08' E to 5 °12' E (Figure 1). It has a relatively flat terrain with some rock outcrop located sparsely within the area. The area also falls within the rainforest zone which is characterized by continuous canopy of tall trees and shrubs, thus the vegetation has a positive influence on the climate through evapo-transpiration process. It lies within the humid tropical climate within annual rainfall ranging from 1250 to 1500 mm.

The study area is underline by crystalline rock of the Precambrian basement complex of the southern Nigeria (Rahaman, 1988). There are four major different rock units in the area as shown in Figure 1, comprising of migmatite-gneiss, quartzite, charnokite, and granite. The Migmatite-gneiss covers the largest part of the mapped area and occurs in the west, north-east, north central speeding to the south, southwest and south-eastern portion of the study area. The granitic rocks, which are members of the older granite suit, occupies of about 30% of the total study area. They occur as low lying outcrops in the west, east and the central portion of the map area. Charnokites occur in the eastern part of the Campus and some parts of the junior staff quarters around Industrial Design Department Studio extending to the south-gate of Campus. Quartzite occurs mostly in the north-central part of the Campus around the Sport Complex.

2. Materials and Methods

The magnetic survey conducted within the entire Campus involves total field intensity measurements with the aid of the GSM 19T Proton Precession (PPM) magnetometer. The proton magnetometer uses the principle of Earth's field nuclear magnetic resonance (EFNMR) to measure very small variation in the earth's magnetic field.

GARMIN 72 Global Positioning System (GPS) was used for recording the geographic location of data position. In order to reduce cultural noise in the observed data, a safe distance of 50 m and above were kept from buildings and other areas manmade structures.

The whole Campus was demarcated into blocks, while each block was covered with a base station established within and tied to a common base station for drift monitoring through the entire period of data collection. At each data point the total field intensity measurement was averaged over 3-samples per data point and 10-samples at the base station re-occupied at every hour.

Field observation of rock types was also carried out as the magnetic survey progressed. Each rock sample were carefully observed on the field, identified and located on the base map in order to update information on the rock types in the area and enhance geophysical interpretation of the acquired magnetic data.

Acquired field intensity data was corrected for drift which result from secular variation of magnetic field and the acquired data enhanced through digital filtering using moving average filter in order to remove high frequency noise in the magnetic data (Olayanju et al., 2015; Breiner, 1973).

To correct for secular variation, the repeated readings acquired at the base stations are used to generate a drift plot which is used to generate an equation used in the correction for secular variation in the other data collected at different stations.

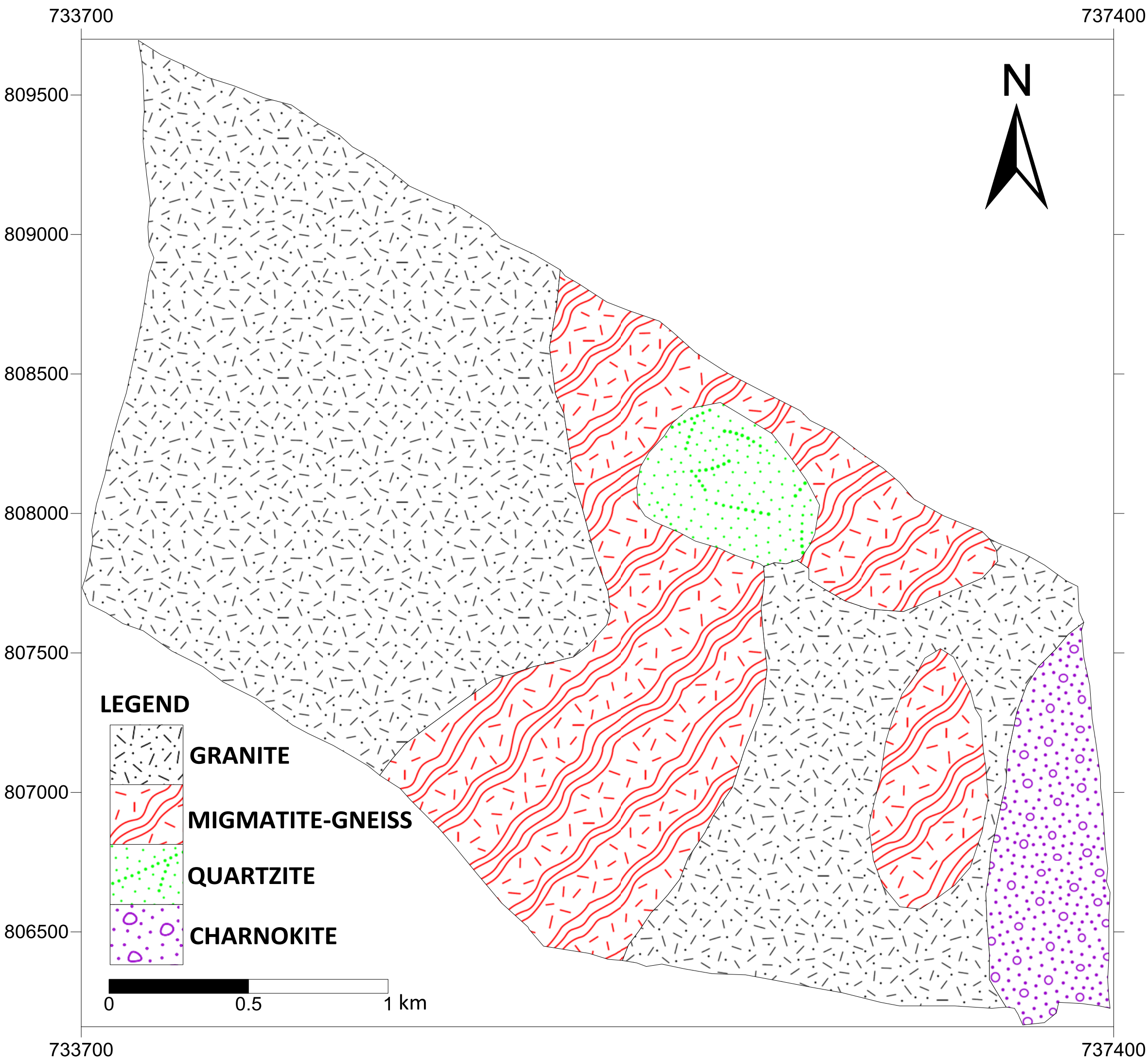

Figure 1: Local Geology map of the Study Area (After Kareem, 1995)

A general drift correction is of the form:

$$F_{dc} = F_{obs} - \frac{F_{base\ 2} - F_{base\ 1}}{t_{base\ 2} - t_{base\ 1}} (t_{obs} - t_{base\ 1}) \qquad (1)$$

where: F_{dc} = Corrected Field data; F_{obs} = observed field data at a particular station; $F_{base\ 1}$ = Average initial base station reading; $F_{base\ 2}$ =Average final base station reading; $t_{base\ 1}$ = Initial time at which first Base station was occupied; $t_{base\ 2}$ = final the base station was re-occupied; t_{obs} = the actual observation time at the particular field station.

Further processing of the ground magnetic data involved removal of variations in the Earth's main field with latitude, longitude and time by removing the International Geomagnetic Reference Field (IGRF) resulting in the anomaly separation. The IGRF values, comprising of the Earth main Total Field Intensity, Declination, inclination, and components of the Total field (H, X, Y and Z) were computed using an online geomagnetic calculator available on the United State National Geophysical Data Centre (NGDC/NOAA) website: (http://www.ngdc. noaa.gov/IAGA/vmod/home.html).

The interpretation of residual anomaly map generated involved both qualitative and quantitative interpretations which provide useful information on magnetic characteristics of different rock units, linear magnetic fabrics, subsurface features and depth to basement of the rocks. A quick estimate of depth-to-bedrock was carried out using the straight-slope and half-slope lengths and two dimensional (2D) Euler inversions of the residual anomaly profiles along sections drawn across the contoured magnetic field intensity map. The solutions from the Euler de-convolution aid in the structural interpretation for delineation of rock boundaries, linear features (dykes, faults or contacts) and depth- to- the basement in the study area.

Euler deconvolution is an interpretation technique for locating the sources of potential fields based on both their amplitudes and gradients and an estimate of the probable geometry of the causative body (Panisova et al., 2013; Reid et al., 1990). Euler program developed at University of Witwatersrand, South Africa (Durrheim and Cooper, 1998) was used for the 2D Euler estimate of the depth and locations of magnetic anomalous sources.

Details of application of Euler Deconvolution to geopotential fields have been documented by several authors (Oruc and Selim, 2011; Dewangan *et al*., 2007; Reid *et al*., 1990; Marson and Klingele, 1993; Thompson, 1982). Locations of peak-like structures were based on the Blakely (1996) method; using the highest sensitivity level to find all ridge peaks in the analytic signal map of the aeromagnetic data as described by Roest *et al.* (1992). Homogeneity equation derived by Thompson (1982) forms the basis of 3D Euler deconvolution and relates the geopotential field (magnetic or gravity) and its gradient components to the location of the source. Euler expression for a homogenous 3 dimensional geopotential field of degree n has the form:

$$f(tx, ty, tz) = t^n f(x, y, z) \qquad (2)$$

Potential fields which also satisfy the equation below known as Euler equation are referred to as harmonic functions:

$$x\frac{\partial f}{\partial x} + y\frac{\partial f}{\partial y} + z\frac{\partial f}{\partial z} = nf \qquad (3)$$

The usual Euler's equation is re-arranged in the form:

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{\partial z} = N(B - T) \qquad (4)$$

where (x_0, y_0, z_0) is the position of a source whose total magnetic field T is detected at (x, y, z). B is the regional value of the total field and N is the structural index equivalent to –n in the Euler's equation.

Equation 4 can be expressed for a 2D Euler problem as:

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} = N(B - T) \quad (5)$$

3. Results

Figure 2 shows the corrected and enhanced total field intensity map over the study area, while Figure 3 shows the superimposition of the residual anomaly map on the existing geologic map of the study area. Rock samples obtained from the field were also posted on the map in order to correlate the magnetic response with the rock units in the study area. The results of the Euler de-convolution of the residual field and 2D forward modelling of the field data for structural analysis are shown in Figures 4 – 10.

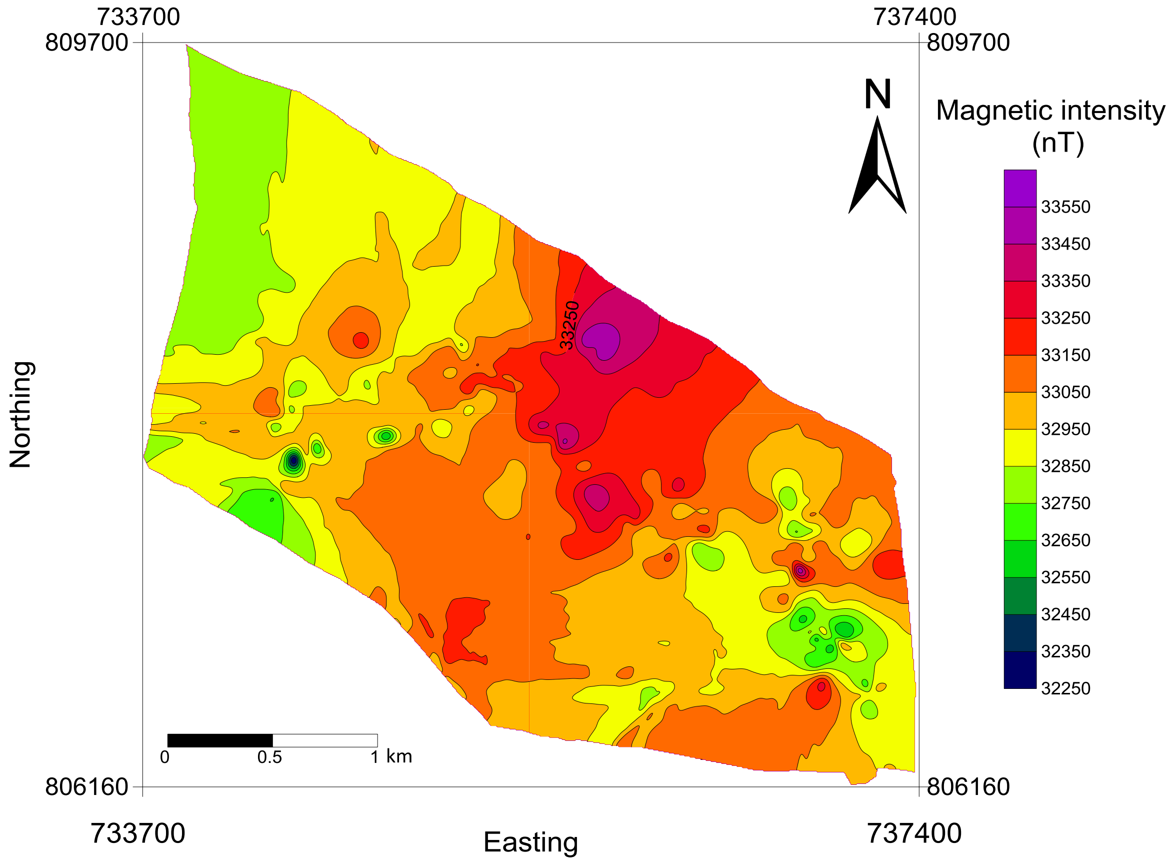

Figure 2: Total magnetic field intensity map over the study area.

From Figure 3, the magnetic response from various rock types can be correlated with the rock units in the area. Comparison of the produced geologic map of the area from the earlier work of Kareem (1995) and direct field observation provide opportunity to relate the magnetic textural imprints or alteration of rock fabrics in the area, which is reflection of variation in the rocks' susceptibilities.

4. Discussion

Magnetic structures

Characteristic magnetic anomalies from the residual anomaly map correlated with the field observation of the various rock units and existing geologic map of the study area revealed magnetic domains recognised to be coincided with the existing rock units in the area. Generally, strong magnetic anomalies are associated with rocks containing magnetite, pyrrhotite, chromite or ilmenite, while felsic rocks (such as granite or rhyollite) and most sedimentary rocks cause distinct magnetic lows (Ako et al., 2004). Magnetic anomaly pattern reflects relative low magnetic amplitude in the range of -800 to 500 nT as shown in Figure 3 and Table 1.

Generally, the rocks underlain the area have great imprints of several faulting/fracturing occurring as linear features. Identification of magnetic lineaments (fractures/faults/Contact) are based on the results of Euler inversion of the residual magnetic field intensity and 2D modelling across seven magnetic profiles generated from the residual anomaly intensity over the area.

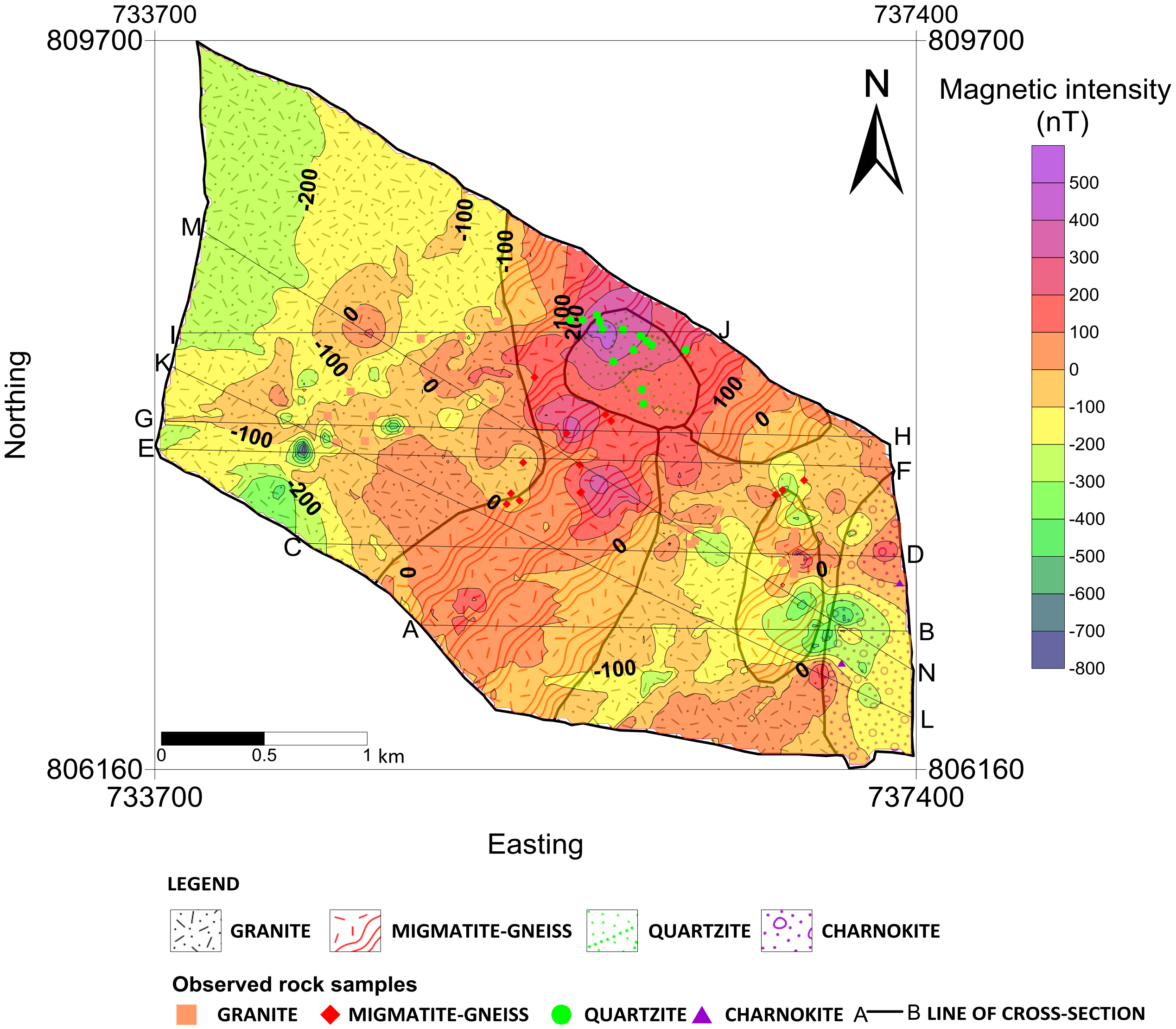

Figure 3: Diagram showing the superposition of residual magnetic intensity field on the geologic map of the area.

Table 1: Characteristic magnetic anomaly of rocks in the study area.

S/N	*Residual anomaly amplitude	Rock type
1	< -200 nT	Charnokite
2	-200 – 0 nT	Granite
3.	0 – 100 nT	Migmatite-gniess
4.	100 – 500 nT	Quartzite

* anomaly amplitude is relative and negative values do not translate to negative magnetic susceptibility

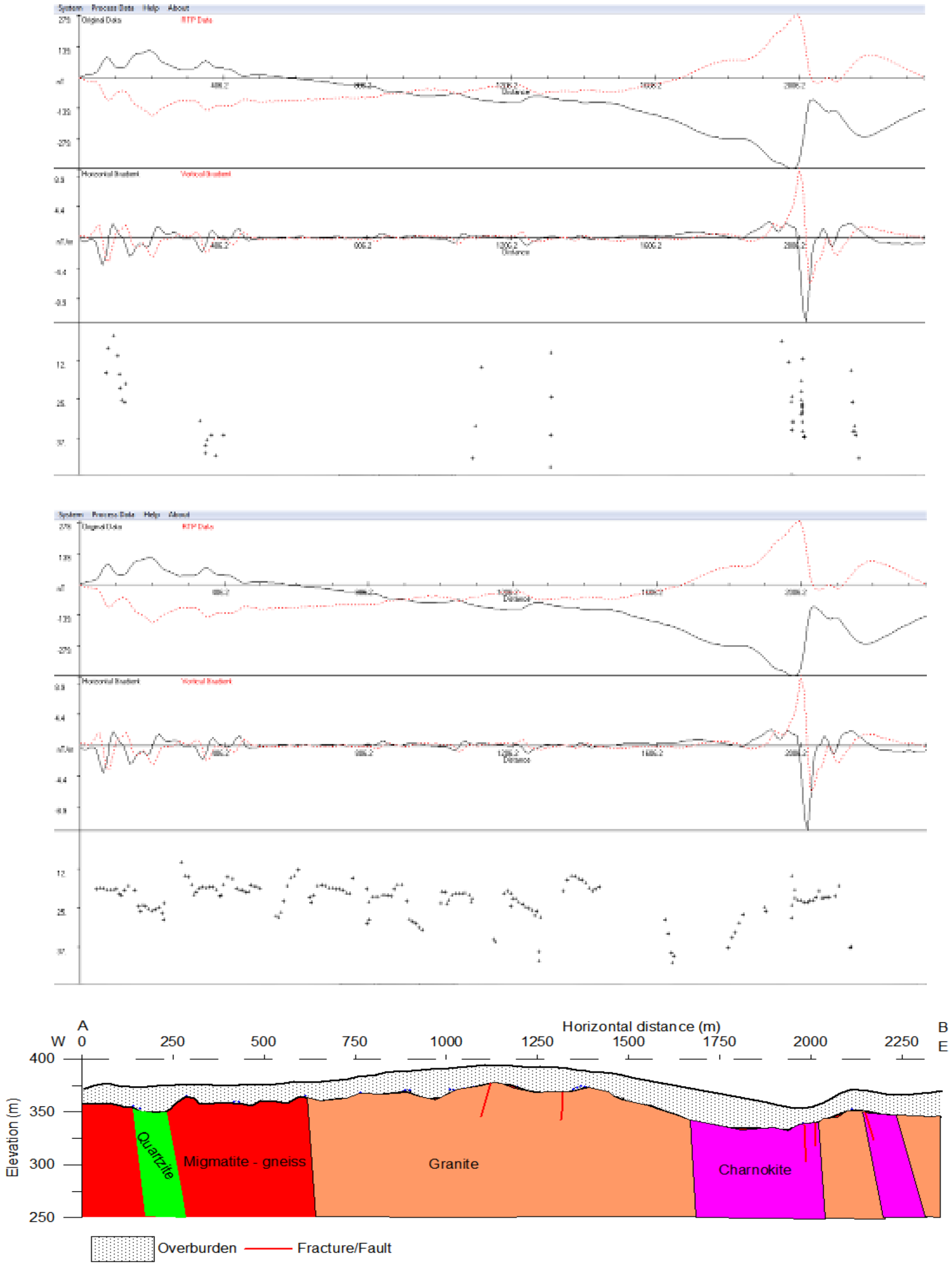

Figure 4: 2D Euler deconvolution inversion of magnetic intensity; (a) Fault/Contact model, (b) Contact/dyke model, and (c) 2D forward modeling showing subsurface geologic section along cross section AB.

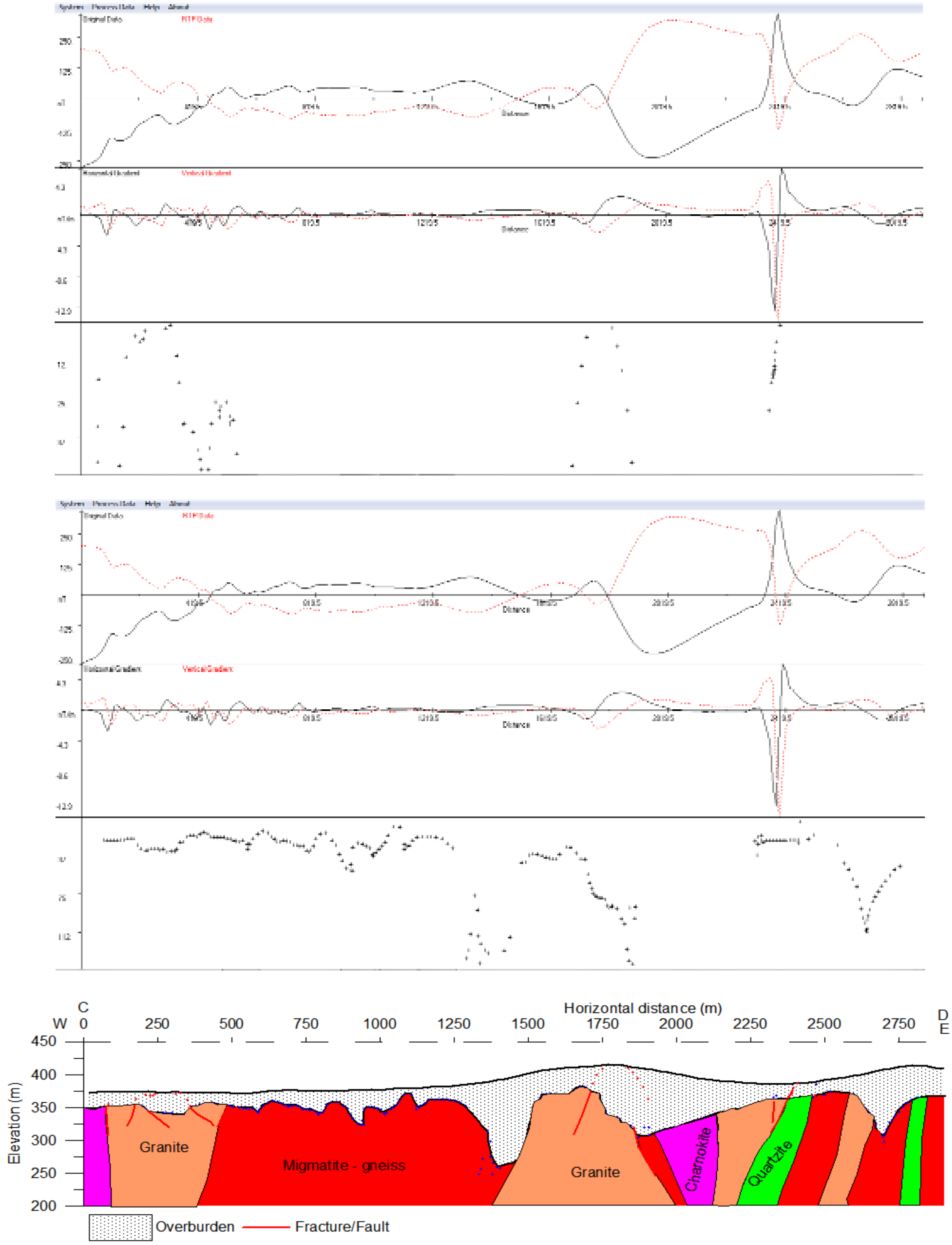

Figure 5: 2D Euler deconvolution inversion of magnetic intensity; (a) Fault/Contact model, (b) Contact/dyke model, and (c) 2D forward modeling showing subsurface geologic section along cross-section CD.

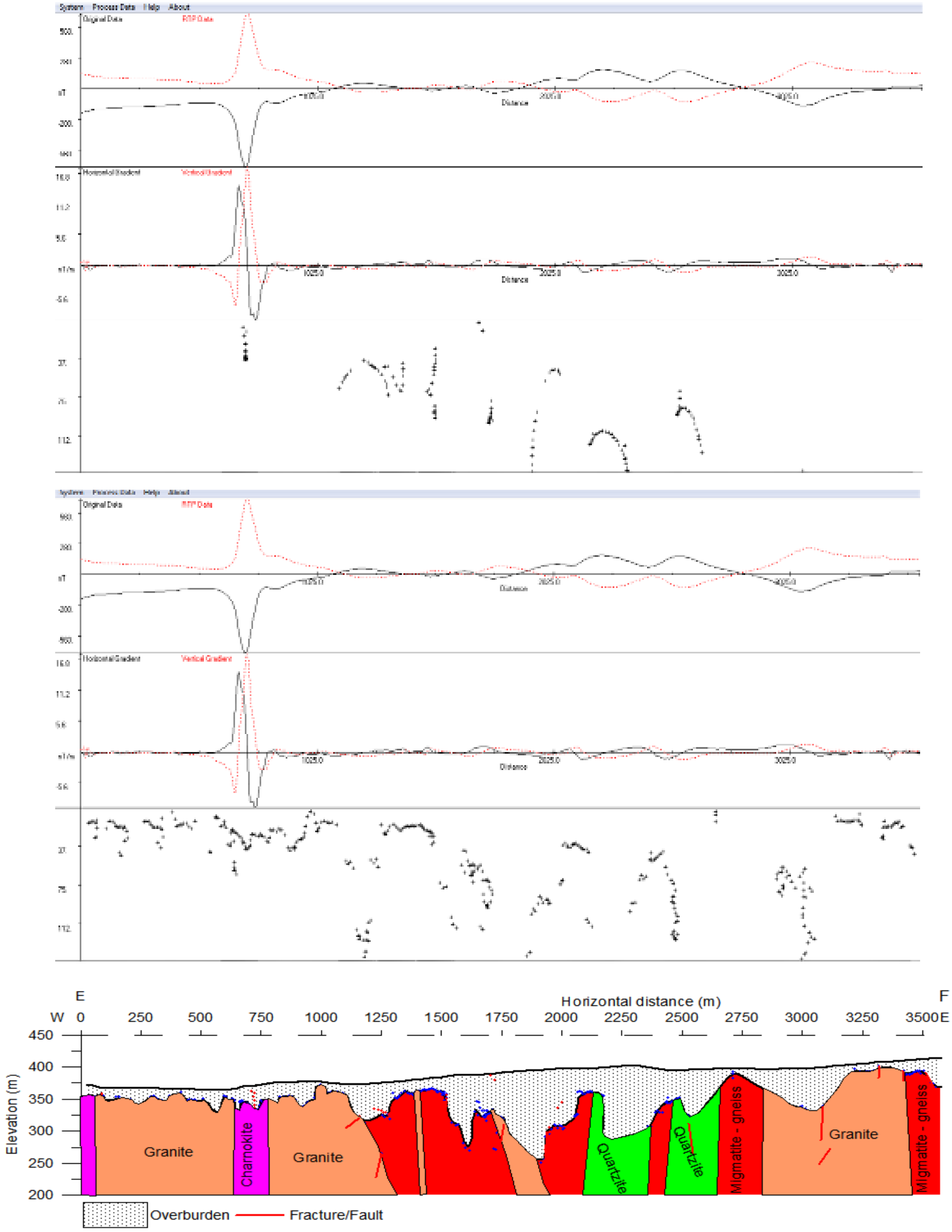

Figure 6: 2D Euler deconvolution inversion of magnetic intensity; (a) Fault/Contact model, (b) Contact/dyke model, and (c) 2D forward modeling showing subsurface geologic section along cross-section EF.

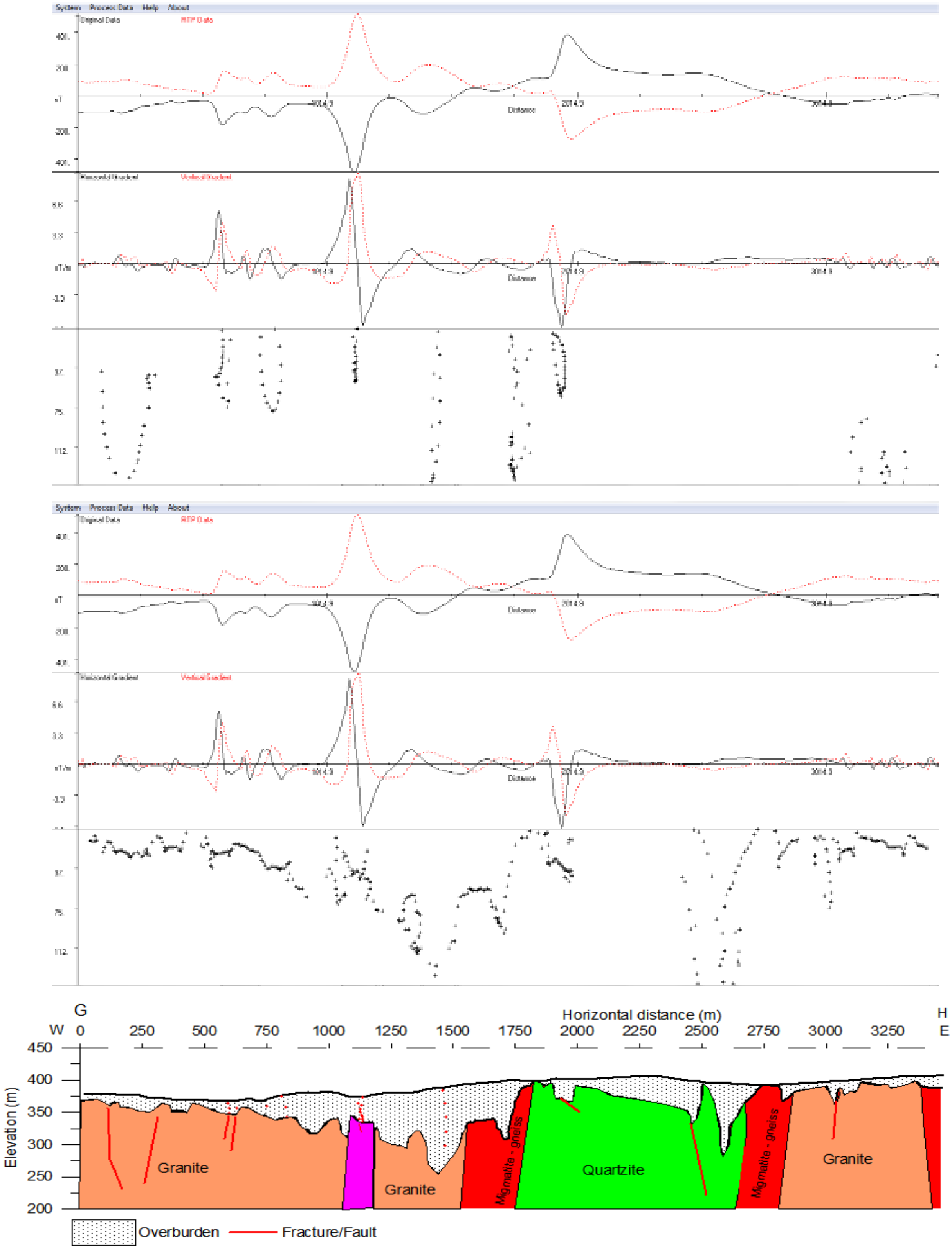

Figure 7: 2D Euler deconvolution inversion of magnetic intensity; (a) Fault/Contact model, (b) Contact/dyke model, and (c) 2D forward modeling showing subsurface geologic section along cross-section GH.

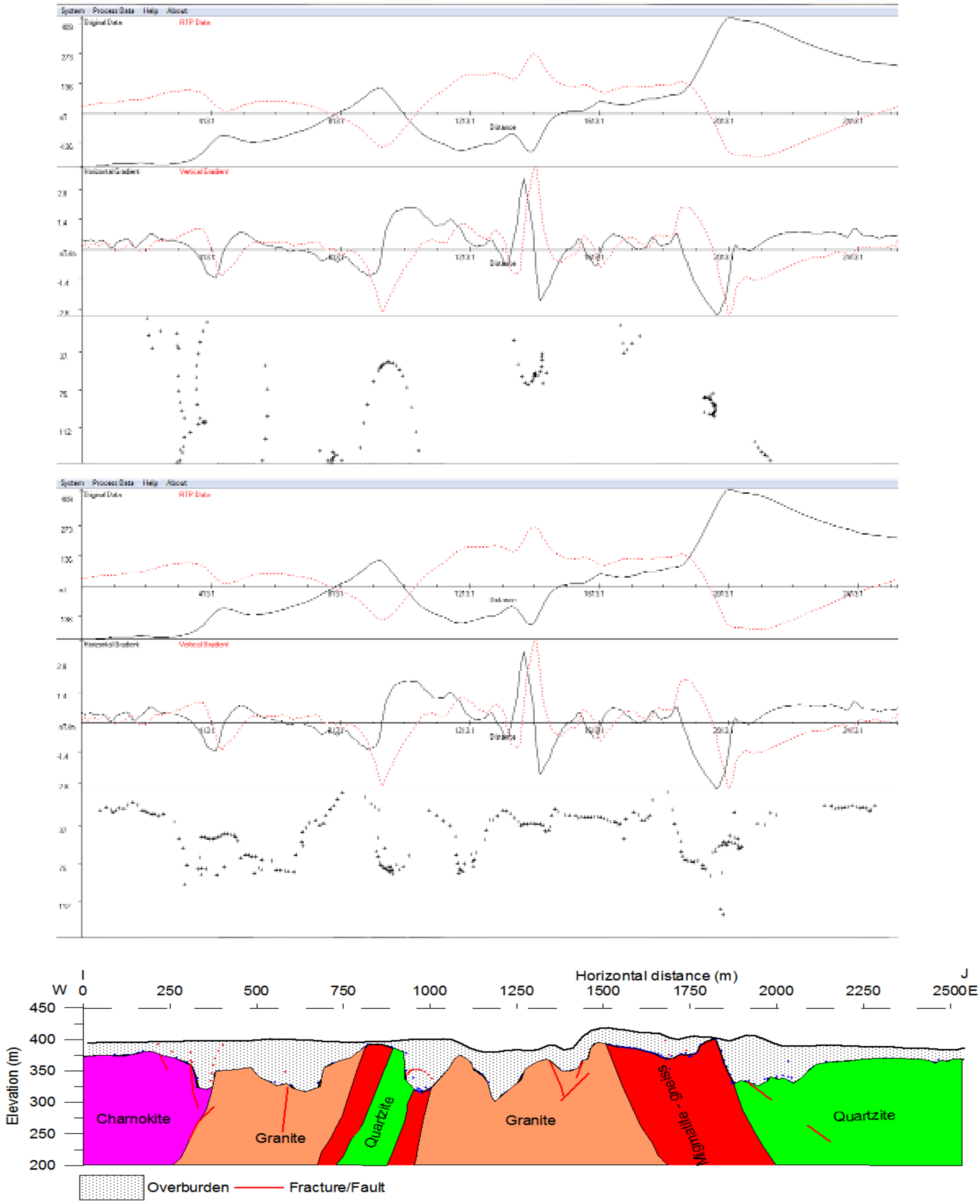

Figure 8: 2D Euler deconvolution inversion of magnetic intensity; (a) Fault/Contact model, (b) Contact/dyke model, and (c) 2D forward modeling showing subsurface geologic section along cross-section IJ.

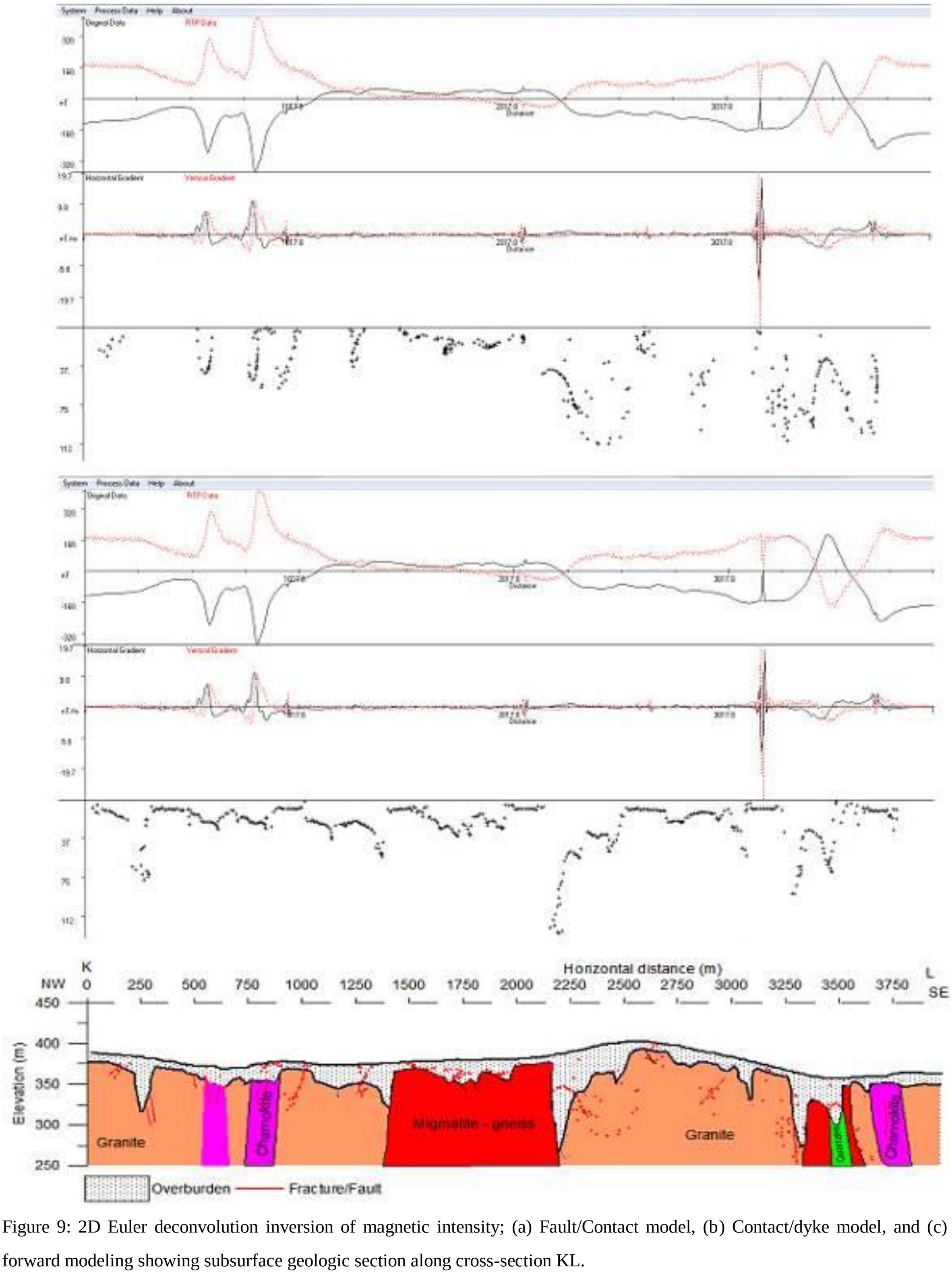

Figure 9: 2D Euler deconvolution inversion of magnetic intensity; (a) Fault/Contact model, (b) Contact/dyke model, and (c) 2D forward modeling showing subsurface geologic section along cross-section KL.

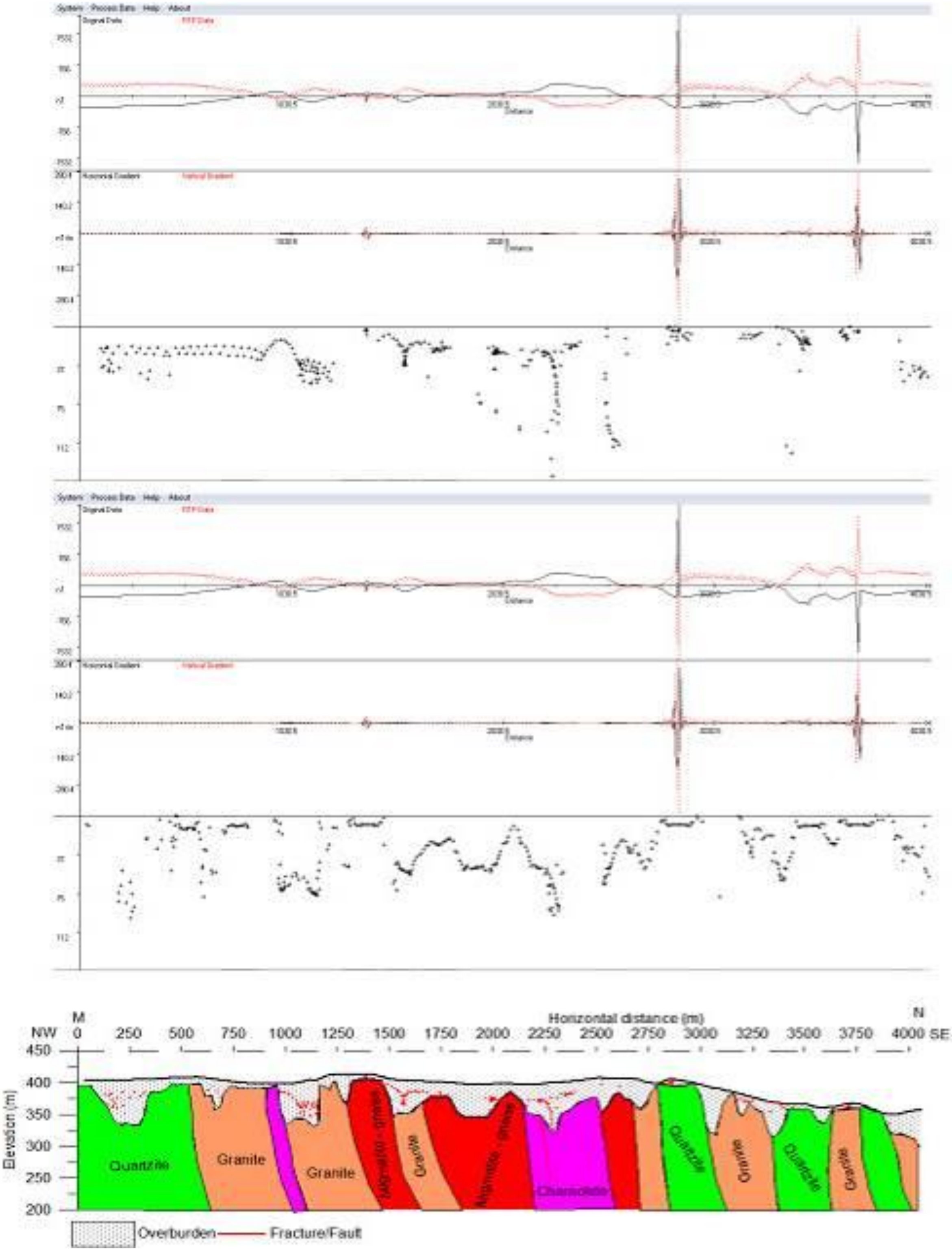

Figure 10: 2D Euler deconvolution inversion of magnetic intensity; (a) Fault/Contact model, (b) Contact/dyke model, and (c) 2D forward modeling showing subsurface geologic section along cross-section MN.

Five magnetic profiles were made along W-E directions, while 2 profiles were along NW-SE directions across major residual anomalies recognized over the study area.

For most structural interpretation, anomaly sources can be adequately represented by dyke-like model (SI of 2), while structural index of 1 was used for contact/fault models. Average main earth magnetic field intensity 33,069 nT, inclination -11.17 and declination -2.21 obtained from the IGRF values over the area were used as input to the Euler inversion software for the depth and source location determination.

W-E Profiles

Anomaly amplitude along these profiles varies from -713 – 439 nT, while depth to the bedrock along these profiles varies between m and m. Along these profiles series of Euler solution for structural index of 1 show the position and depth to the magnetic lineaments recognized as basement fractures and faults, while the location and depth to bedrock of the dyke model (SI of 2) coincide with the top of the basement rock along the profiles. Some of the Euler solution for structural index of 2 coincides with rock contacts and some identified faults/fractures are found at the rock contacts. Depth to the lineaments (fracture/fault) along these profiles varies from 0.8 – 149.6 m, while depth-to-bedrock ranges between 0.4 m and 50.1 m.

NW-SE Profiles

Along the NW-SE profiles, the anomaly amplitude ranges from -425 – 311 nT, while depth-to-bedrock was estimated to be between 0 m and 98.5 m. Depth to the position of lineaments (fracture/fault) vary from 0.1 – 112.9 m. In a similar pattern to the W-E profiles, some recognized faults/fractures are located at the rock contacts.

Modified Geological Map

Based on the recognized magnetic patterns and modelled 2D subsurface magnetic structures, locations of the contacts between different rock units, linear magnetic fabrics, and magnetic lineaments identified as fractures/faults were identified. Quartzite and migmatite-gneiss show relatively high magnetic amplitudes in comparison with low amplitudes observed over granite and charnokite. High amplitudes of magnetic anomalies over quartzite and migmatite-gniess can be attributed to their metamorphism (Neawsuparp et al., 2005; Ako *et al*., 2004). On the basis of the magnetic characteristics of the various rock units as shown in Table 1 and the delineated geologic sections from the Euler inversion of the magnetic data, a modified geologic map of FUTA was produced as presented in Figure 11.

5. Conclusion

Position and depth to basement rocks and locations of contacts, fractures/faults within the Federal University of Technology, Akure Campus have been determined from the Total Magnetic Intensity (TMI) over the area.

From the results of magnetic survey, modified geological map was generated on the basis of the observed magnetic textural imprints of the various rock types, which is reflection of variation in the rocks' susceptibilities. Recognized rock types within the Campus are Charnokite, Granite, Migmatite and Quartzite; each of the rock types gives different response to magnetic measurement. The residual magnetic value of the rocks ranges from ranges for -800 to 500 nT, with Charnokite having lowest magnetic response (consequently lowest magnetic susceptibility), while the high magnetic anomalies amplitudes observed over quartzite and migmatite-gniess can be attributed to their level of metamorphism.

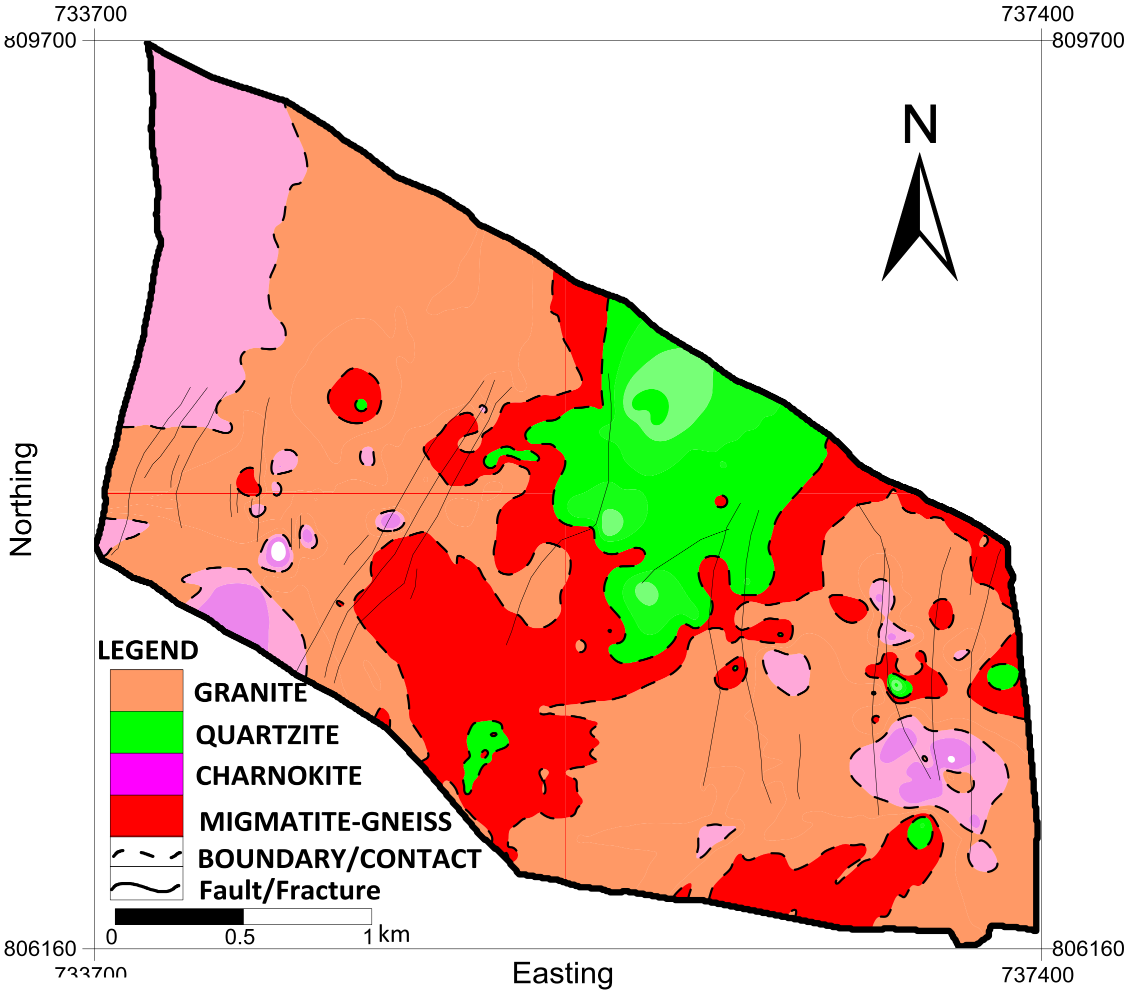

Figure 5: Modified geologic map of FUTA Campus.

On the basis of magnetic interpretation results, the basement rocks delineated show intense weathering of the basement rock within the Campus as well as high degree of fracturing and faulting as observed on the magnetic structural sections. The rocks in this area are competent for most structural infrastructures; however there is a need to carry detailed geophysical survey in most areas in order to avoid locating structures on some of the linear features which are likely to be fractures or faults. In addition, position of most deep fractures in the area will be of hydro-geologic significance to groundwater development of the Campus.

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