

# IFEWARA MYLONITE: Identifying the Neo-Tectonic Overprint Using Integrated Geophysical Methods

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## ABSTRACT

Integrated surface electrical resistivity and ground magnetic survey was carried out across the Ifewara Mylonite zone of Southwestern Nigeria. The previous remote sensing images and Proton Precision Magnetometer (PPM) data from previous observations along four traverses were used together to map the prominent fault/shear zone in the Precambrian Basement Complex. The aim of the research work was to delineate the shear zone as indicated by Mylonite. Dipole–Dipole DC resistivity profiling data were acquired at 10 m interval along four traverses established in approximately East-West direction across the location of suspected shear zone. Magnetic data were also acquired at 5 m interval along the traverses. Topographic corrections were made on the resistivity data, which were subsequently inverted using a Finite Difference (FD) and Finite Element (FE) approach. Numerical Modelling (NM) was also carried out to confirm the existence of the Mylonite. 2D subsurface resistivity structure of the Mylonite was obtained from the inversion of the numerically modelled data. The inverted resistivity sections obtained depicted three subsurface geologic strata comprising of top soil/overburden, weathered basement and the fresh bedrock. The magnetic highs observed along the four traverses correspond to a rock type of little or no magnetic properties (quartzite) and/or rock with a possible remnant magnetisation. The magnetic lows observed are presumably characterised by rocks in mafic mineral or quartzite with magnetic impregnation. High unit of basement rock located within distinct low resistivity region and interpreted as a shear zone—represents the location of Mylonite in Ifewara.

An overprint of Mylonite is indicative of a possible fault or shear zone presence. Anomalies noted in the generated magnetic profiles correlated with the shear zones indicated in dipole-dipole resistivity profiles. Furthermore, outcome of the NM results showed Shear zone or faults, covered by thin overburden thickness, producing good responses—this depicts high-resolution resistivity images. As the thickness of the overburden increases, the resolution of the resistivity images obtained dropped. The width of the shear zone or fault play some major roles in controlling image resolution. Validity of results obtained heightened by employing a Synthetic Modelling (SM) tool.

**KEYWORDS:** Mylonite; Shear zone; Fault; Neo-Tectonic; Basement complex; Precambrian

## INTRODUCTION

Poor understanding from previous studies of the origin, structure and nature of a major Ifewara fault persists. The Okemesi fold belt within Ifewara, harbours the major fault zone; the fold belt represents one of the most distinct manifestations of the Late-Precambrian deformation in Nigeria. An elongated deformed belt trends NNE-SSW, covering an area of approximately 2000 km<sup>2</sup>. Hubbard [1] reports that migmatite, gneisses and a meta-

supracrustal sequence are the major rocks found around the shear zone. Amphibolite schist, quartz-schist and associated pegmatite and gneisses are underlying rock types situated to the west of the shear zone. Quartzites and quartz-schist (Effon Pammitte Formation) in association with quartzo-feldspathic gneisses are rock types located to the east of the shear zone. Odeyemi [2] reports that aerial photography and Landsat and Side-Looking Airborne Radar (SLAR) images reveal this shear zone.

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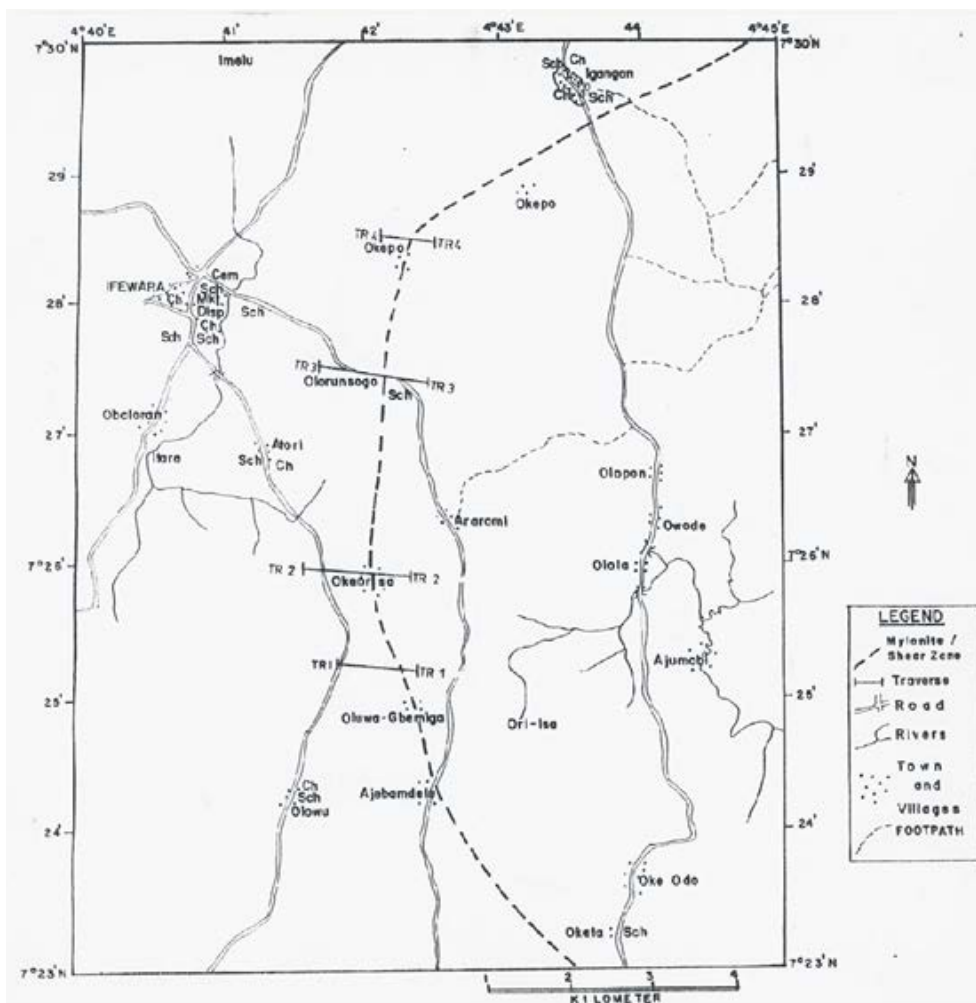


Figure 1: Map of the Study Area Showing Mylonite/Shear Zone and the Geophysical Traverses (Federal Survey of Nigeria, 1966).

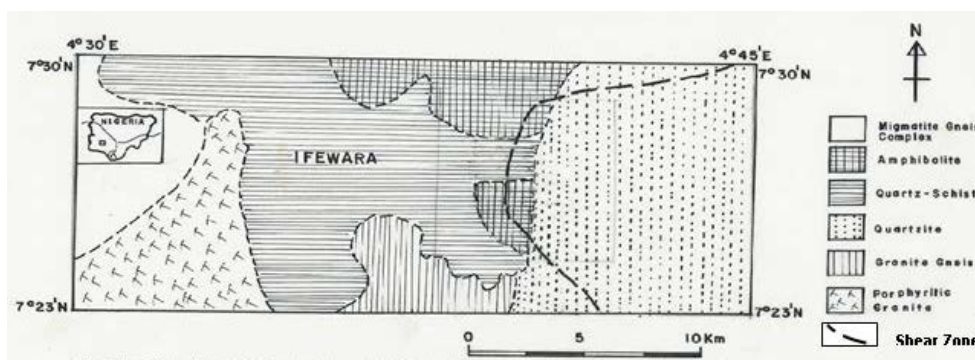


Figure 2: Regional Geologic map of part Ife-Ilesha Schist belt showing the study area (Modified after Odeyemi,1993)

**Location of study area**

The study area is located within 7°30N, 4°40'E; 7°23N, 4°40'E; 7°30N, 4°45'E; 7°23N, 4°45'E and is presented (Figure 1). A network of meandering roads links the Ifewara region to the rest of Nigeria. Undulating permanent footpaths and temporary lateritic roads connects Ifewara to surrounding villages and hamlets [3].

**Research aim**

The research aim is to delineate the shear zone unravelled by Mylonite settlement. Outcome of research should provide information on the competencies of dipole-dipole DC. Electrical Resistivity and Magnetic methods in the imaging of the Ifewara Mylonite. Furthermore, the work will serve as a search for, and

proof of the existence of the shear zone as indicated by Mylonite. Above all, to show how incorporating a priori information in NM would aid and facilitate locating a sheared zone within a basement complex rock with good precision and accuracy.

**Geology of the study area**

Turner and Oluyide have identified the Ife-Ilesha schist belt of South Western Nigeria as constituting the upper Proterozoic schist belt in the Nigerian Basement Complex. Work by Rahaman (1988) describes the Ife-Ilesha belt as consisting of two contrasting lithological rock associations separated by a major Ifewara fault presented in Figure 2. The survey area is a schist belt of southwestern Nigeria that comprises of abundant of mafic rocks and a large mafic to ultramafic body that could represent remnants

of an oceanic assemblage. The rock formations found in the survey area are an integral part of the basement complex rock of Nigeria.

As earlier mentioned under the first subsection of the first section, the study area is underlain by Amphibolite, Amphibolite schists, Quartzschist, Quartzite and Granite basement rocks overlain by a relatively thick covering of weathered materials made up of lateritic clay, clayey-sand and weathered activities and brecciation of the sheared zone. Ajibade et al [4] confirmed varied metamorphic mineral assemblages within Ifewara, ranging from green schist to amphibolite facies. There are two structural types characterising the rock within the study region:

- North-south upright folding with low-plunging stretching lineation that suggest transpressive regime
- Recumbent foliation, which probably suggest that this structure formed under an extensional setting of post-collisional gravitational collapse coeval with magma emplacement.

## Methodology

### Data description, acquisition and processing

Electrical Resistivity and Magnetic Methods are employed in this geophysical prospecting. Electrical Methods in prospecting involve the detection of subsurface effects produced by electric current flow in the ground. Using electrical methods, one may measure potentials, currents, and electromagnetic fields that occur naturally or are introduced artificially in the earth. The array of choice employed, under the Electrical Resistivity method, was Dipole - dipole configuration.

The data for this research work are obtained along four geophysical traverses in an East-West orientation as shown in Figure 1. The traverses are oriented in a direction, perpendicular to an inferred axis of the fault planes. It is worth noting that, the Mylonite deposit is assumedly located at the geologic contact owing to shearing activities.

The location of the fault is consequent upon the result of recent research work [2]. The location of the fault was determined based on the images obtained from the study of the structure of the Okemesi fold belt, where the Ifewara shear zone was observed as shown on landsat and SLAR images and even aerial photographs.

### Dipole-dipole array

With Dipole-dipole array adoption, ABEM, Sweden SAS 300C, 2 pairs of current and potential electrodes, red and black coloured insulated cables and crocodile clips were coupled to generate apparent resistivity data—10 m inter-electrode spacing was used. Data were acquired along four traverses laterally. The  $n$  value, simply a multiple of the inter-electrode spacing,  $a$ , varied from 1 to 5. Total length of traverse 2 and 3 was 500 m each while traverse 3 has 400 m long and traverse 4 has 200 m.

Coordinate information of the study area was acquired by employing the Global Positioning System (GPS) for the purpose of topography correction, elevations reading of each station position

The electrical current was introduced into the ground via current dipole,  $C_1$  and  $C_2$  while the ground voltage along the traverse was determined via potential dipole,  $\Pi_1$  and  $\Pi_2$  all dipoles are of equal length

- Increase in distance between the dipoles leads to increase in depth of investigation.

It is well established that dipole-dipole array has greater depth of penetration compared to other resistivity methods [5]. In order to ascertain the quality and the consistency of the field data, four resistivity measurements were taken at each measurement point and then compared with each other.

### Finite: Difference (FD) and finite-element (FE) methods in 2D forward modelling program

A forward modelling subroutine is an integral part of any inversion program; since it is necessary to compute the theoretical apparent resistivity values; for the model produced by the inversion routine to see whether it agrees with the values.

The apparent resistivity values for a specified model could be calculated by:

- Boundary Element Methods (BEM)
- Analytical Method (AM)
- Finite Measured - Difference (FMD) and Finite-Element Methods (FEM).

The method adopted in this work can subdivide the subsurface into thousands of cells with different resistivity values.

EM 2D Model software was employed to divide the modelled subsurface into a large number of rectangular cells. The FD method well described and developed, has been modified to correct its inherent minor inconsistencies.

The FE method uses the standard first-order triangular element. FE was used for the model program. Marquardt response calculation FM in the inversion approach was used for inversion procedure, with recalculation of the Jacobian matrix of each model after consecutive calculation.

## RESULTS AND DISCUSSION

### Processing and field data correction for the magnetic data

Prior to interpretation, the repeated magnetic readings at each station along the four traverses were averaged. The time taken were converted to seconds by multiplying the observed time in hour (h) by 3600 s and that of minutes (mm) by 60 s.

The anomaly in the geomagnetic field was obtained by subtracting the regional geomagnetic field [6] for Ifewara area from the observed geomagnetic field so as to produce the residual geomagnetic field.

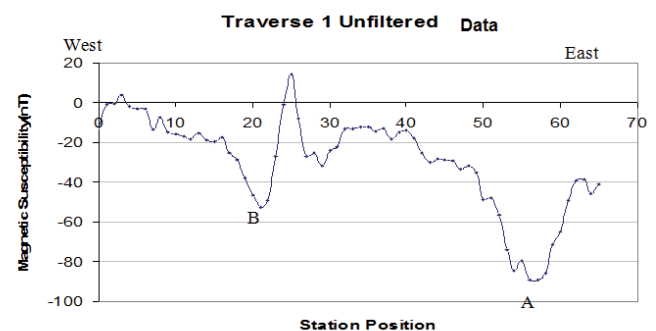


Figure 3a: Corrected and Unfiltered Magnetic Field Data of Traverse 1. A=Low Magnetic susceptibility; B=Low Magnetic susceptibility

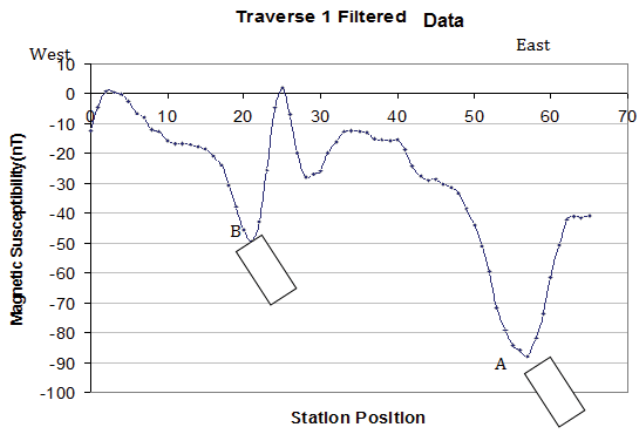


Figure 3b: Corrected and Filtered Magnetic Field Data of Traverse 1. A=Low Magnetic susceptibility; B=Low Magnetic susceptibility

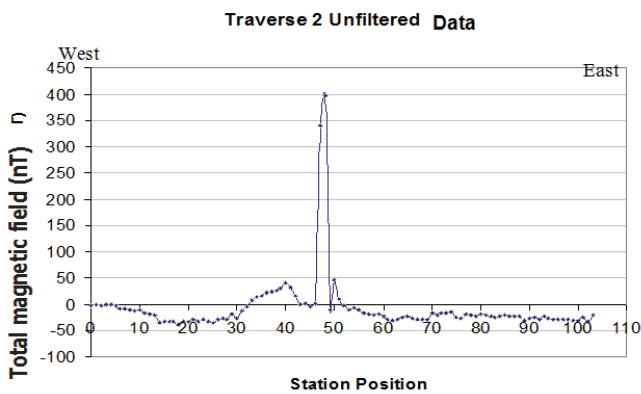


Figure 4a: Corrected and Unfiltered Magnetic Field Data of Traverse 2.

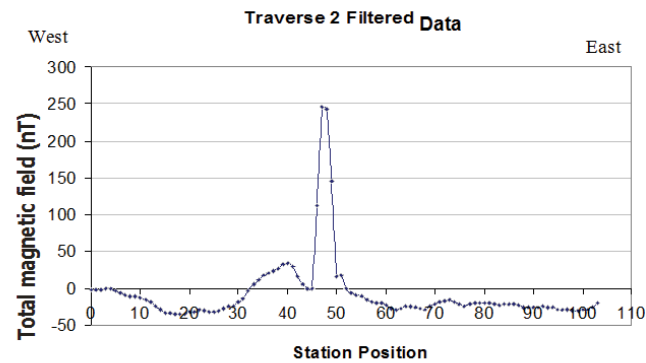


Figure 4b: Corrected and Filtered Magnetic Field Data of Traverse 2.

In order to correct for offset in the geomagnetic field data, a magnetic local base station was established in an area away from a station 1 of each traverses. These base stations were quick and easy to relocate and re-occupy at beginning and end of data acquisition along each traverse. The exact time of occupation of each station was recorded. Three readings of the total field strength were recorded and averaged for each station.

A three point moving average linear filtering, proposed by Breiner (1999) was applied to the data. This was done so as to improve the signal to noise ratio (S/N) of the geomagnetic field data. A Formula Translation (FORTRAN) program incorporating all the geomagnetic data corrections and filtering process was written for the purpose of this work. (Figures 3-6)

### Quantitative interpretation of the magnetic data

The field magnetic data were interpreted using Euler Deconvolution

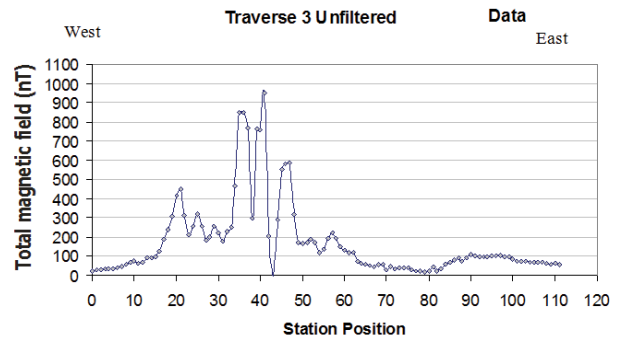


Figure 5a: Corrected and Unfiltered Magnetic Field Data of Traverse 3.

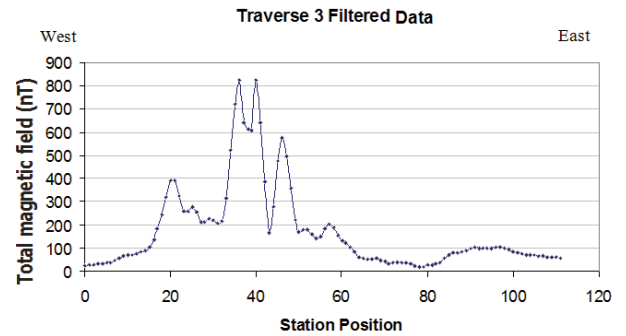


Figure 5b: Corrected and Filtered Magnetic Field Data of Traverse 3.

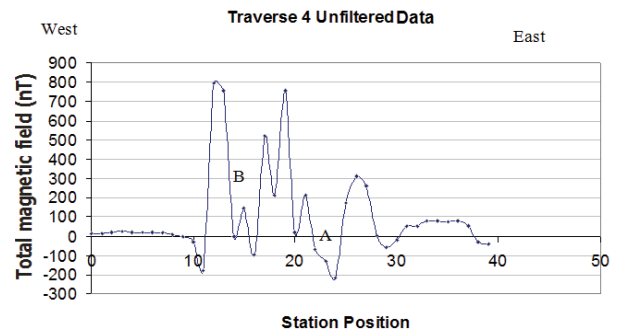


Figure 6a: Corrected and Unfiltered Magnetic Field Data of Traverse 4.

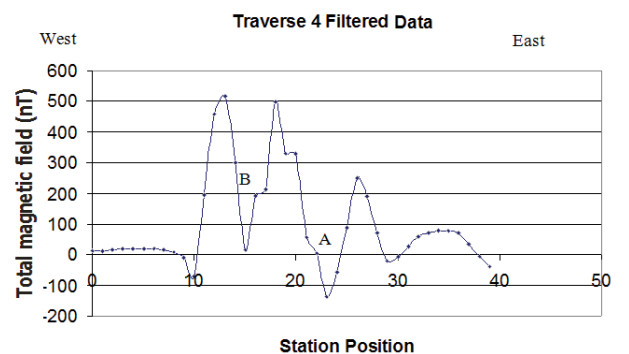
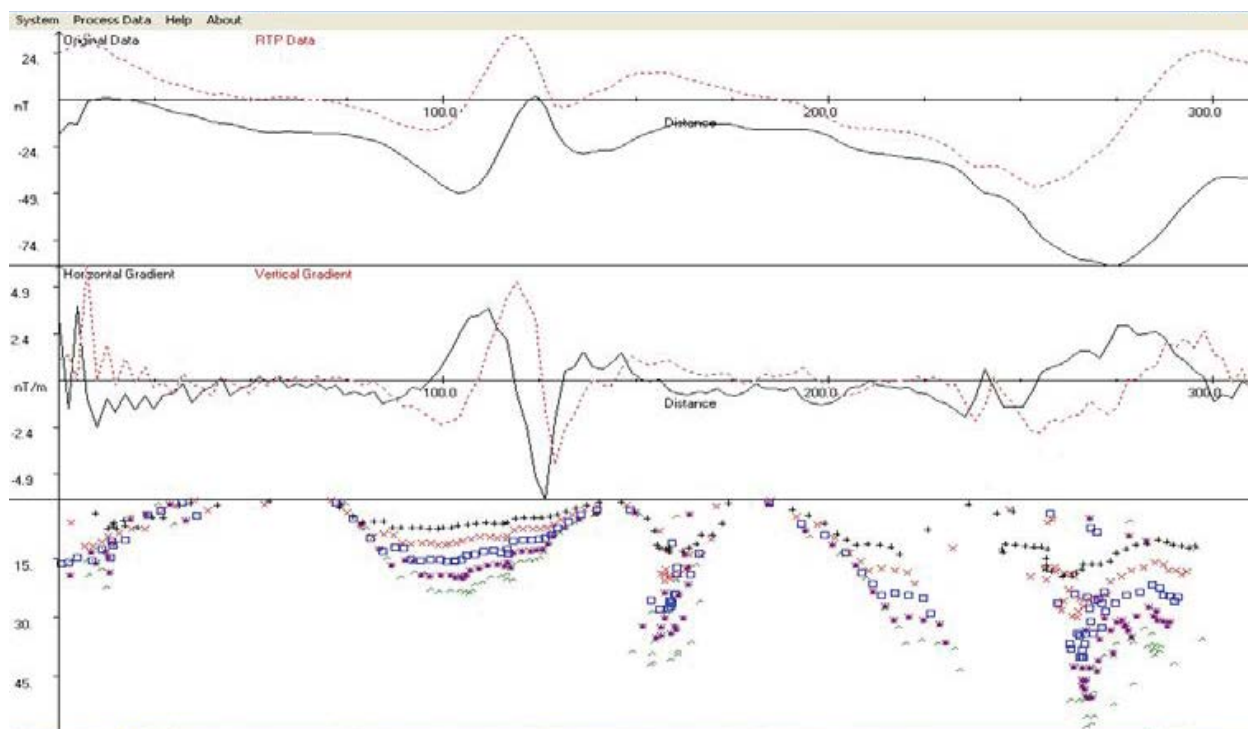
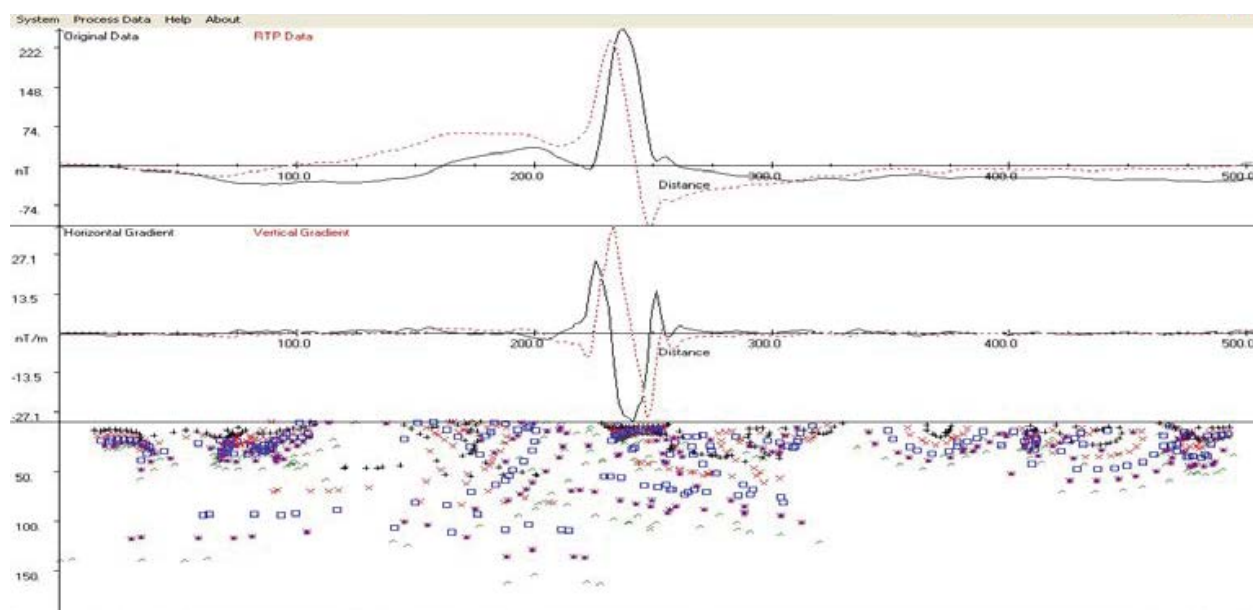


Figure 6b: Corrected and Filtered Magnetic Field Data of Traverse 4.

in order to obtain the depth to the basement and delineating any existing structural feature. The Euler solutions obtained along traverses one, two, three, and four are shown in Figures 7-10 respectively and the curve reveal a distinct clustering of the Euler solutions. A prevalent shallow basement is revealed within the shear zone region. The results of the Euler's solution along the four traverses depict similar pattern and trend. The basement topography is well delineated at a depth of about 10 m along traverse one, about 25 m along traverse two, about 12 m along



**Figure 7:** Euler Solution obtained along Traverse1 using structural index of 1 and 2, the upper panel shows the original magnetic data and the reduced pole data, the middle panel shows both the completed horizontal and vertical graded, while the lower panel shows the Euler solution.



**Figure 8:** Euler Solution obtained along Traverse2 using structural index of 1 and 2, the upper panel shows the original magnetic data and the reduced pole data, the middle panel shows both the completed horizontal and vertical graded, while the lower panel shows the Euler solution.

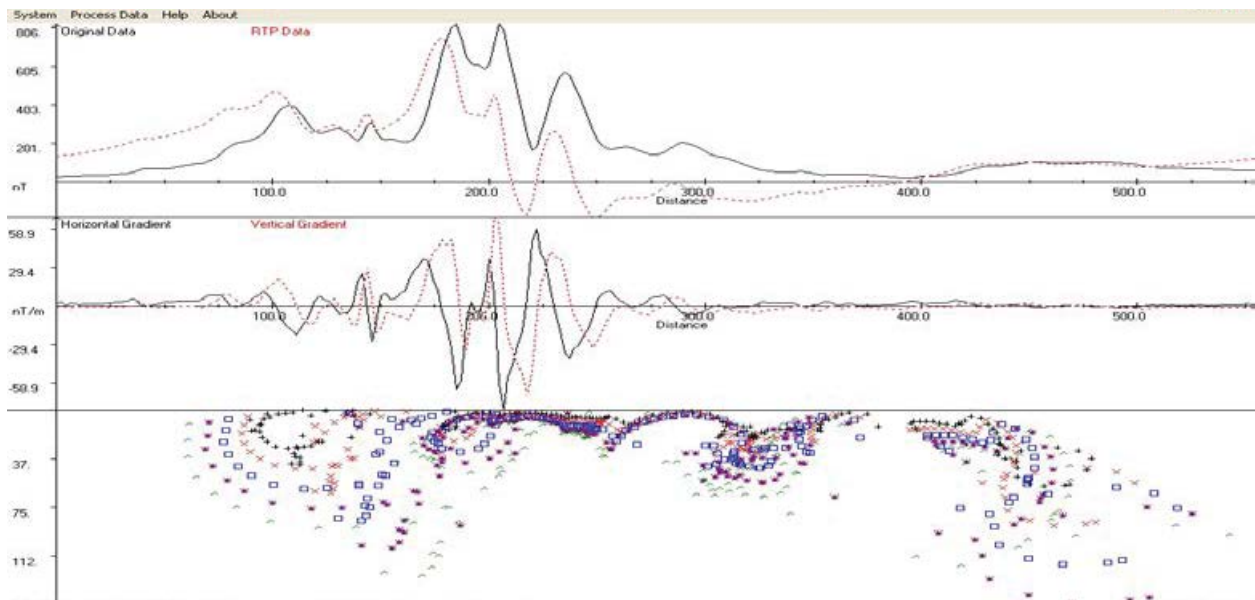
traverse three and about 7 m along traverse four. Using a structural index  $\eta=1$  and 2. The horizontal and vertical gradient maxima and minima indicate the boundaries and width of the Mylonite at 15 m on all the traverses. Resistivity inversion estimated the depth of basement to be in good agreement with the depths derived from the Euler solution, depth solution is generally with relative error less than 6% were accepted.

From the above Euler Solution, the correlation of the location of these structural features to the local geology, confirms that linear features are not artefacts of the Euler deconvolution techniques; the magnetic source at the centre of the structure has depth of 6 m to 25 m, corresponding to the Precambrian basement.

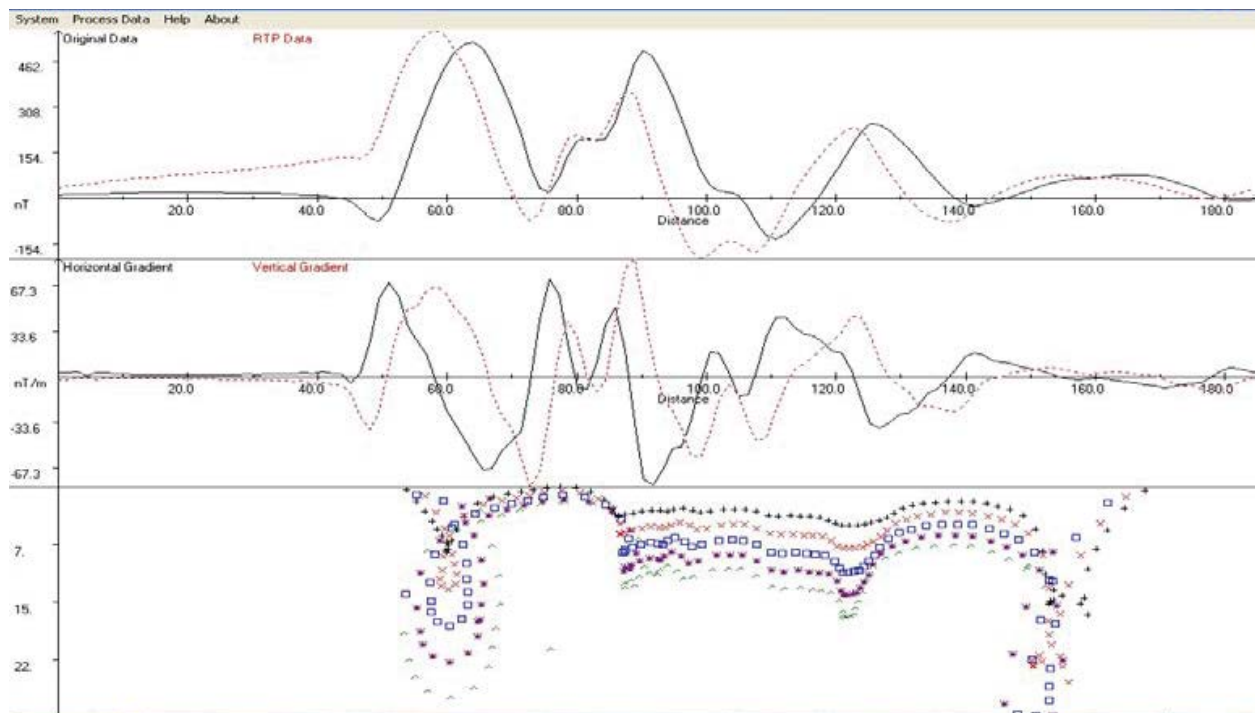
The Euler solution is in agreement with the estimates obtained from 2D inversion data. The Euler's solutions cluster around the edge of Mylonite, this is a clear indication of the utility of using the Euler's technique to delimit the boundary of features.

The magnetic anomaly along traverse 1 and 4 indicate in both filtered and unfiltered of the magnetic field data that the Mylonite is actually dipping towards Eastern direction; while the resolution of dip along Traverses 2 and 3 is not diagnostic. It is worth noting that topographic effects are accounted for in the field data.

Five different mylonitic zone models are considered in this study. In model 1, the width of the mylonite is 5 m, 10 m for model 2, 15 m for model 3, 20 m for model 4 and 30 m for model 5 (Figure



**Figure 9:** Euler Solution obtained along Traverse3 using structural index of 1 and 2, the upper panel shows the original magnetic data and the reduced pole data, the middle panel shows both the completed horizontal and vertical graded, while the lower panel shows the Euler solution.



**Figure 10:** Euler Solution obtained along Traverse4 using structural index of 1 and 2, the upper panel shows the original magnetic data and the reduced pole data, the middle panel shows both the completed horizontal and vertical graded, while the lower panel shows the Euler solution.

11a-11e). In these models, a resistivity value of 150 ohm-m was assigned to the mylonitic zone, 250 ohm-m was chosen to represent the resistivity of the top layer overburden.

According to Olayinka and Weller [7], the assigned resistivity of the overburden should be the weighted average of the various geoelectrical units that make up the overburden in a crystalline basement terrain which is lumped together and shown having single resistivity in the models. A resistivity of 1000  $\Omega$ m was assigned to the bedrock (host rock). 2% Gaussian noise representing instrumental noise was added to the synthetic data so as to simulate field conditions. For each model, the numerical Modeling and inversion was carried out for five cases of overburden thickness that is 5 m case, 10 m case, 15 m case, 20 m case and 30 m case. These overburden thickness representing a typical Scenario in basement complex of Ifewara.

The effect of increasing the overburden thickness and width of the mylonite on the resulting resistivity images derived from the inversions that were studied.

### Interpretation of the inverted resistivity data

**Dipole-dipole field data:** Figures 13-16 show the observed inverted apparent resistivity data plotted as convectional pseudo-depth. These data have been inverted to produce the image of Figures 13-16, these 2 D models show low resistivity mylonite/shear zone and high resistivity bedrock. The topography of the bedrock is inconsistent along four lines with overburden thickness varying between 5 m and 30 m.

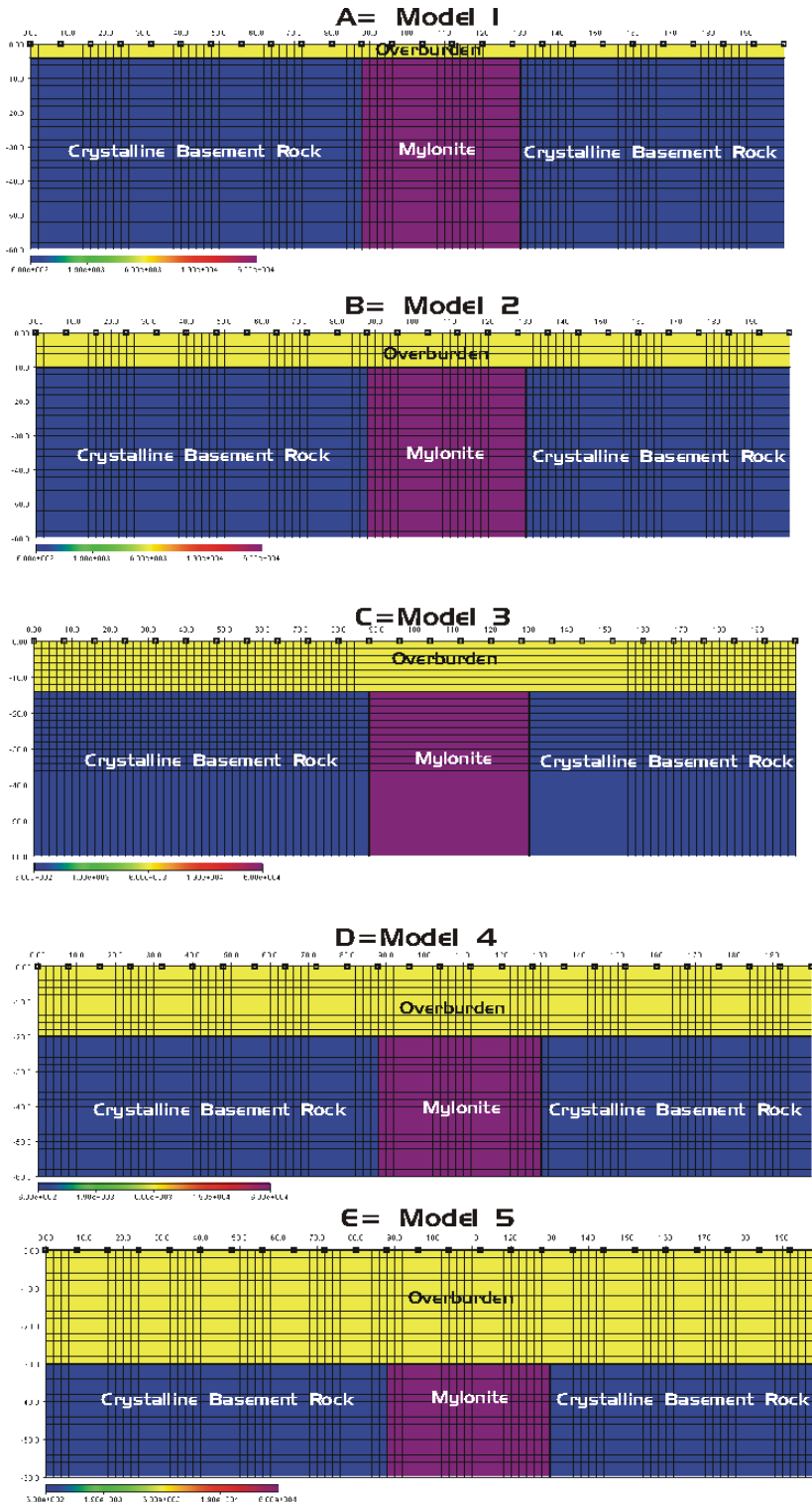
The geo-electrical models along traverses 1-4 are presented as Figures 13-16. The final geo-electrical models shown in Figures 12a-12e

were obtained at various stages of the numerical modelling. In these models, areas having resistivity values ranging between 3167 Ωm and 26988 Ωm (high resistivity) were interpreted as crystalline bedrock. The areas having low resistivity values ranging between 117 Ωm and 550 Ωm were interpreted as Mylonitic zones indicated by the field data in Figures 13-16. From the pseudo-sections in Figures 13-16 of these profiles, a broad low resistivity anomaly is detected between stations 21-25 along traverse 1.

This low resistivity value of about 48 ohm-m was observed along Traverse 1. This thus depicts shear zone/Mylonite. Stations 29

to 31 along traverse 2 depict a major low resistivity of Mylonite which is banded by high resistivity of possible Basement rock as shown in Figure 16. Stations 31-33 along Traverse 3 equally depict a major low resistivity attributed to shear zone/Mylonitic zone while Traverse 4 shows a shallow buried Mylonite as indicated by low resistivity in Stations 11-12 along this traverse, here the Mylonite occurs very close to the surface (Figure 16). Areas of moderately low resistivity were interpreted as weathered bedrock.

In addition, the observed low resistivity zone within the basement complex of the study area indicates that basement rock is actually



Resistivity of the Mylonite = 150ohm-m.

Resistivity of the basement rock = 1000ohm- m.

Resistivity of the overburden = 250ohm-m.

**Figure 11a-e:** Synthetic 2D Resistivity Model for 100m wide Mylonitic zones of varying Depth, The thickness of the Mylonite was fixed, while the Overburden Thickness varies from 5m for model 1, 10m for Model 2, 15m for Model 3, 20m for Model 4 and 30m for Model 5.

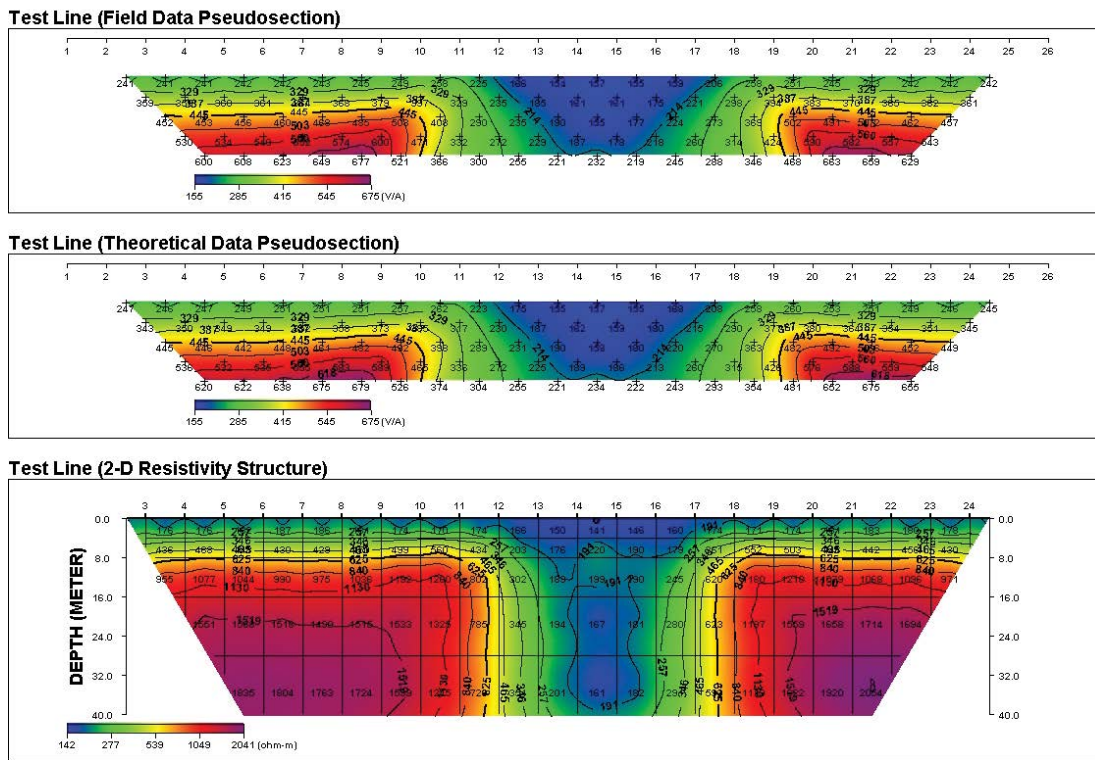


Figure 12a: Inverted Resistivity of 100m wide Mylonite obtained using the synthetic resistivity model 1 showing in Figure 11a.

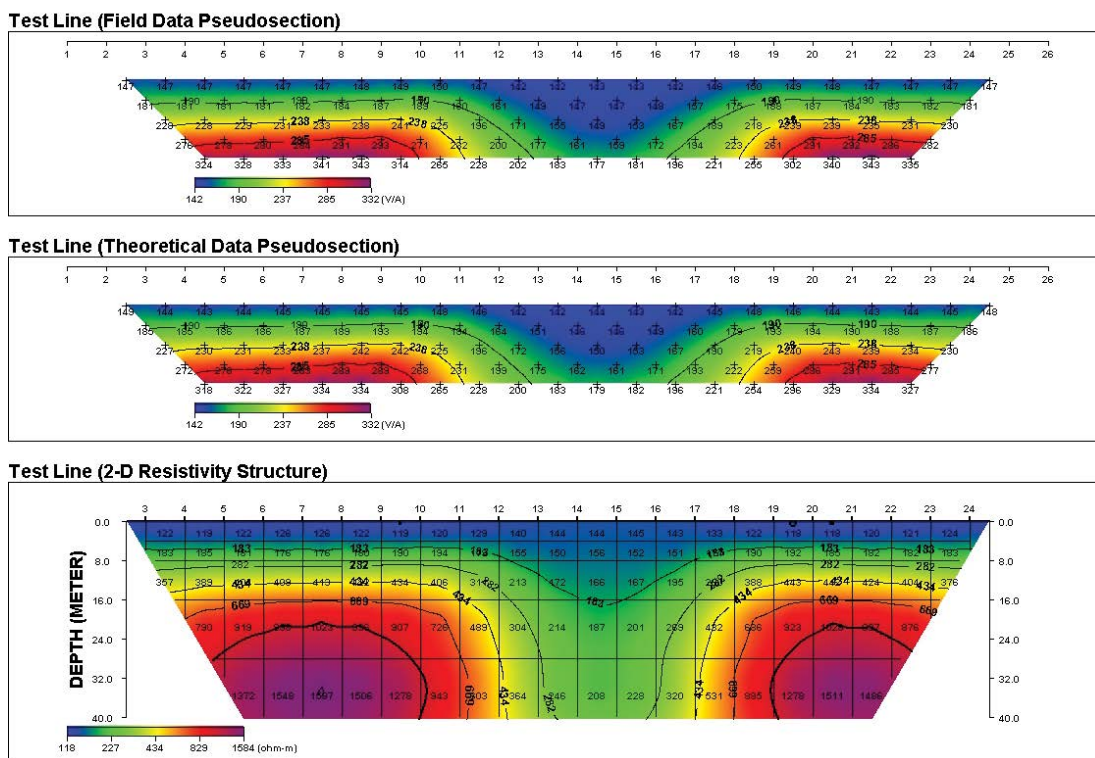


Figure 12b: Inverted Resistivity of 100m wide Mylonite obtained using the synthetic resistivity model 2 showing in Figure 11b.

sheared. Thus, the four sections (Figures 13-16), the low resistivity are interpreted as mylonitic zone.

A comparison of the synthetic inverted resistivity images in Figure 12, with the inverted field resistivity images in Figures 13-16, show that the images of the subsurface profiles 1, 2, 3 and profile 4 were well reconstructed and the resistivity values recovered, approximates the actual situation. Based on the pseudo-section

between stations 25-26 along traverse 1 and stations 28-32 along traverse 2, stations 30-33 along traverse 3 and stations 11-12 along Traverse 4; the inverted field result corroborates the result from the synthetic simulation which actually depicts the suspected Mylonite as a depression round the centre of the models.

Shear zone models of limited depth extent were studied to evaluate the limit of the resolution of the depth extent of the Mylonitic zone



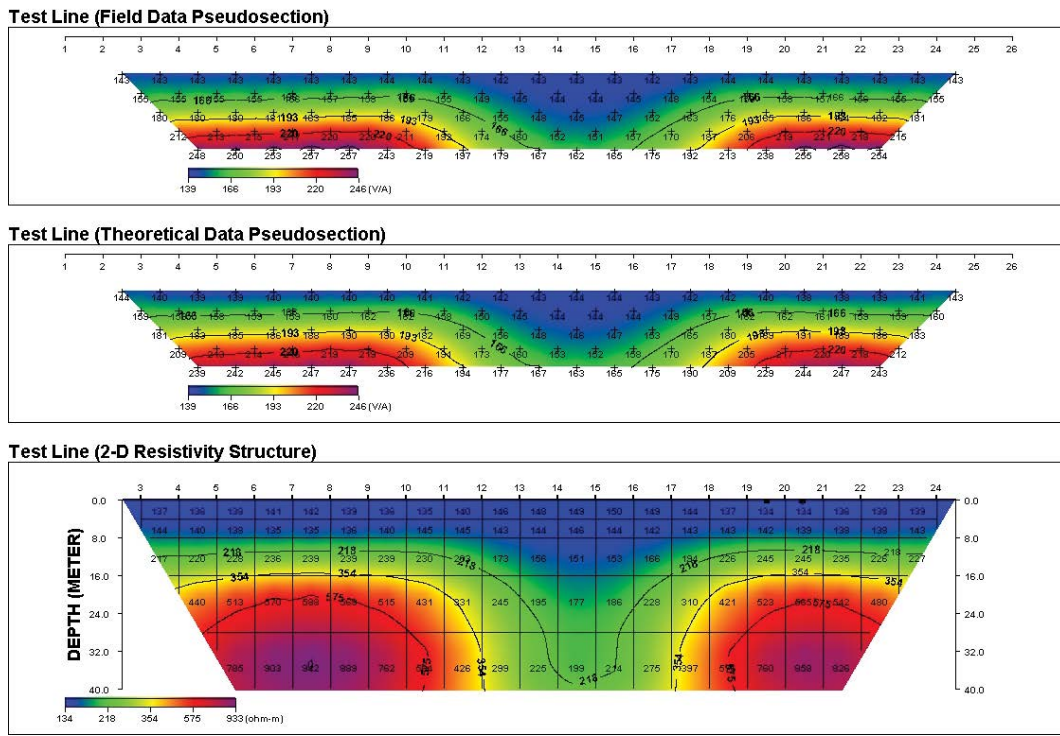


Figure12c: Inverted Resistivity of 100m wide Mylonite obtained using the synthetic resistivity model 3 showing in Figure 11c.

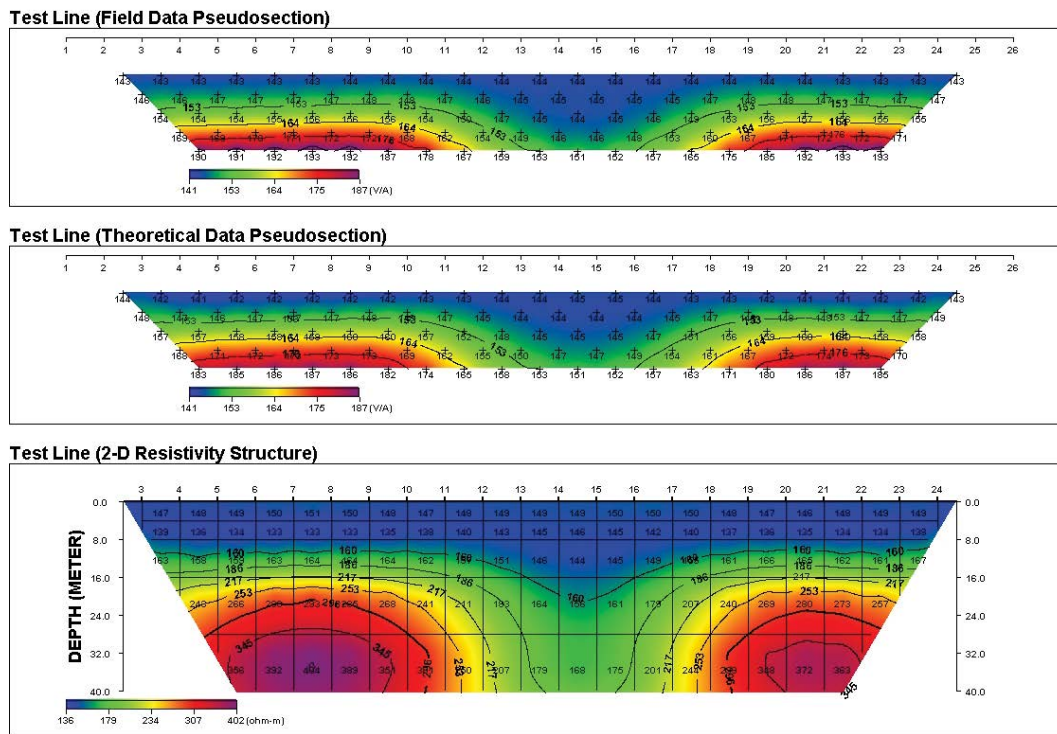


Figure12d: Inverted Resistivity of 100m wide Mylonite obtained using the synthetic resistivity model 4 showing in Figure 11d.

images shown in Figures 12a-12e and confirm whether the inverted dipole – dipole data shown were actually detecting the Mylonite or the shear zone. For these particular model, the Mylonite thickness were fixed for the five models while the overburden thickness were varied from 5 m, 10 m, 15 m, 20 and 30 m respectively (Figure 11). The computed pseudo-sections for the above models show a convincing evidence of the existence of the Mylonitic zone as depicted in Figure 12a-12e inform of a depression which thus attributed to fault zone.

The presence of Mylonite zone might possibly be the cause of the local deepening of the bedrock topography. From the interpretation, it was discovered that increase in shearing effect led to increase in the depth extent of Mylonite. The result of these synthetic examples shows that it is really not possible to see the bottom of the Mylonite from inverted images but rather its top is well resolved compared its base. The resolution, vis-à-vis the amplitude of the observed local anomaly seen at the location of Mylonite is controlled by the overburden thickness.

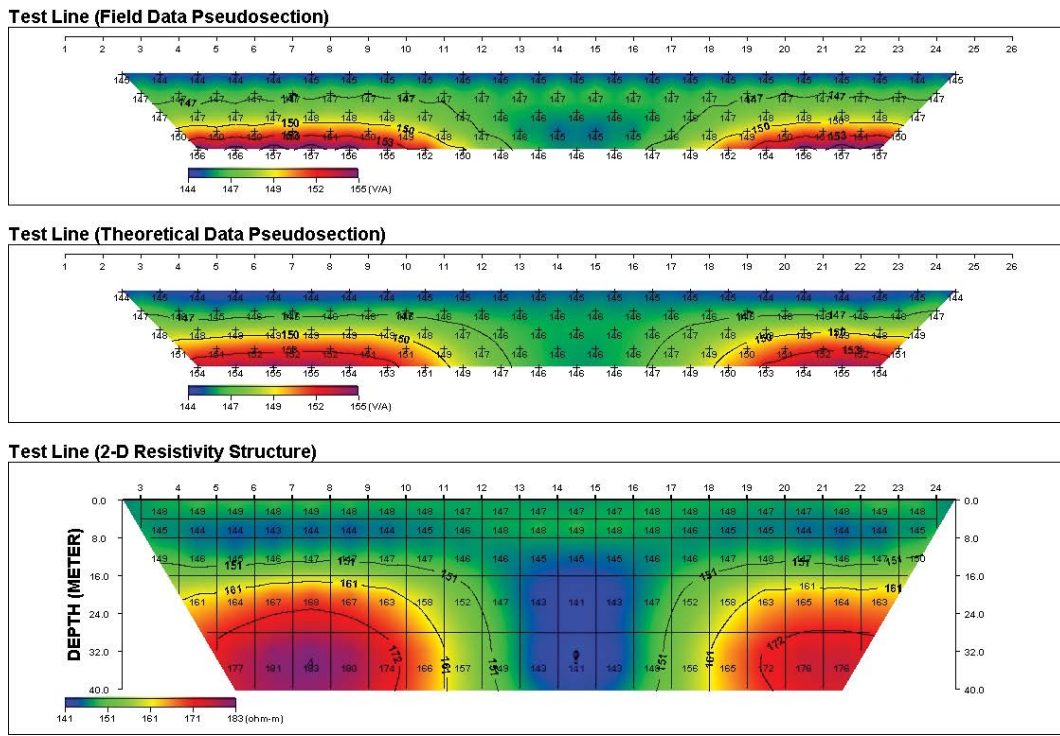


Figure 12: Inverted Resistivity of 100m wide Mylonite obtained using the synthetic resistivity model 5 showing in Figure 11e.

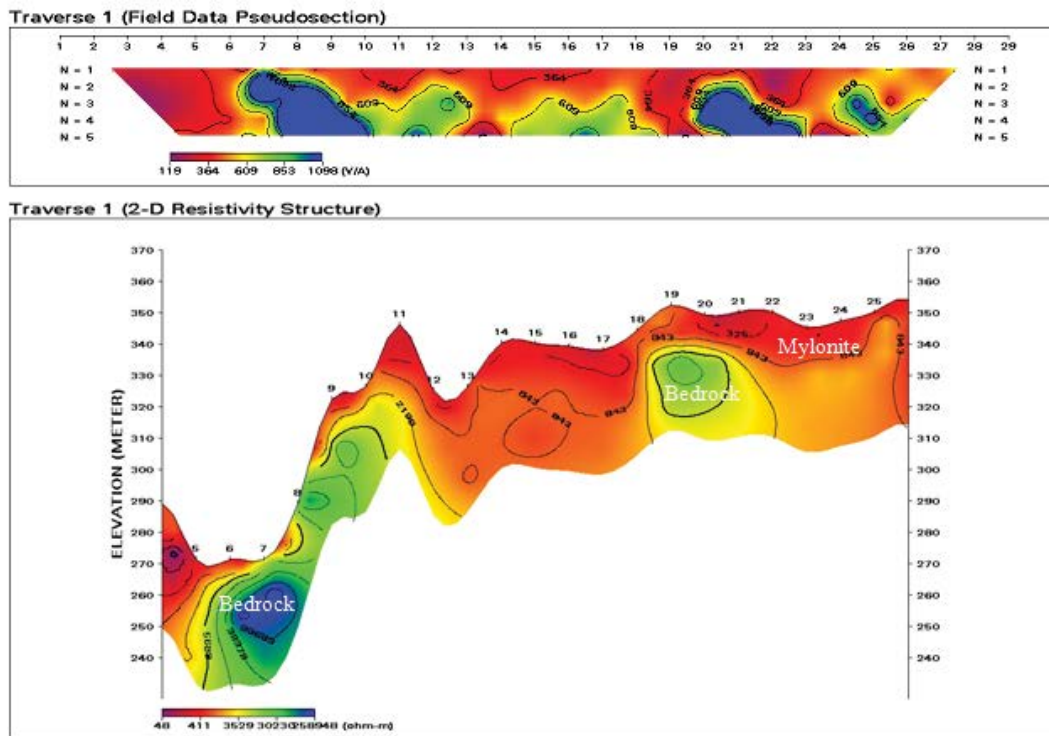


Figure 13: Diagram showing pseudosection of the field data (upper panel and inverted earth model (lower panel) of resistivity structure along traverse 1.

In general, a prominent low resistivity zone corresponding to the location of the Mylonitic zone is delineated at the centre of all the synthetic models. It is evident that overburden thickness and the Mylonitic zone played prominent roles in the overall model responses that were obtained. Additionally, the presence of basement terrain areas having thick overburden and low resistivity zone associated with basement overprint is a direct indicator of the existence of possible Mylonite.

### CONCLUSION

Two surface geophysical methods, the direct current resistivity and magnetic surveys are employed to map the Mylonite/shear zone, attributed to low angle fault trending NNE- SSW in the Ifewara area. The results obtained from both synthetic and field data were correlated to locate the Mylonitic zone. A prominent anomaly was detected with these two methods. The location of the shear

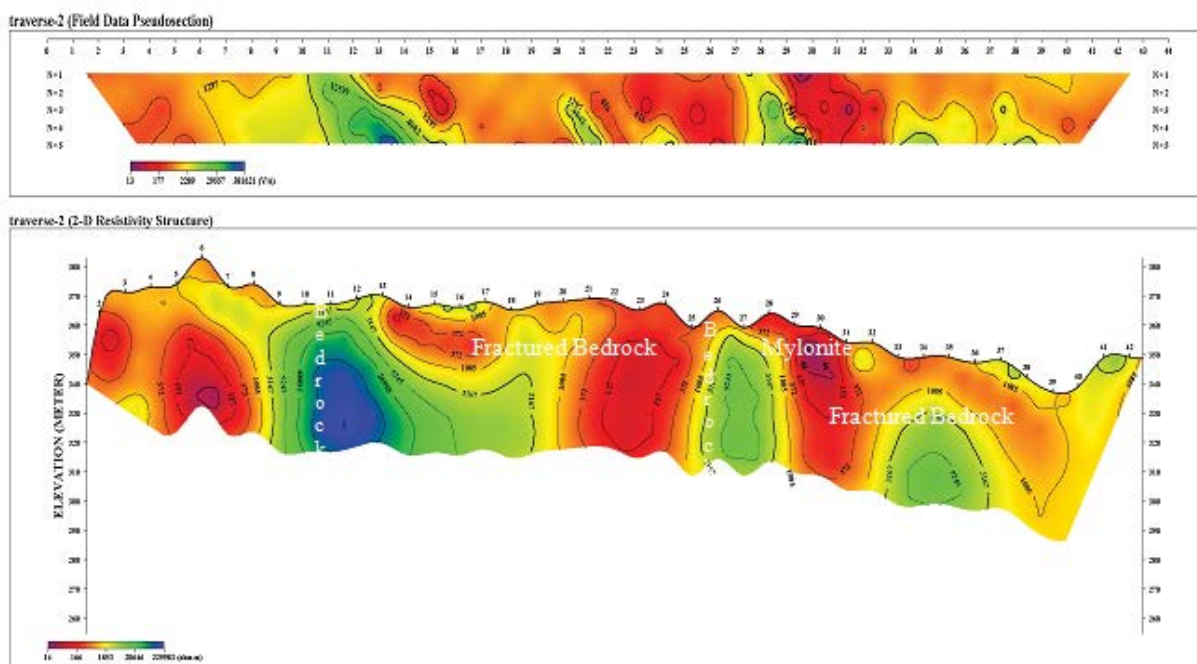


Figure 14: Diagram showing pseudosection of the field data (upper panel and inverted earth model (lower panel) of resistivity structure along traverse.

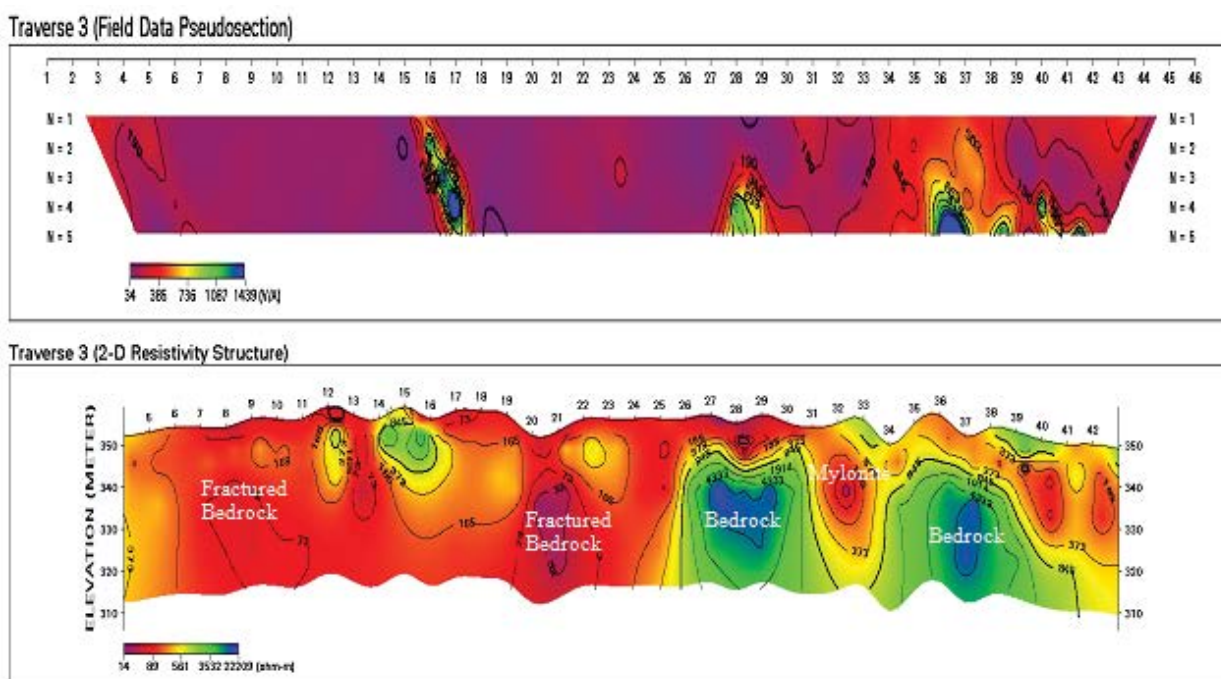


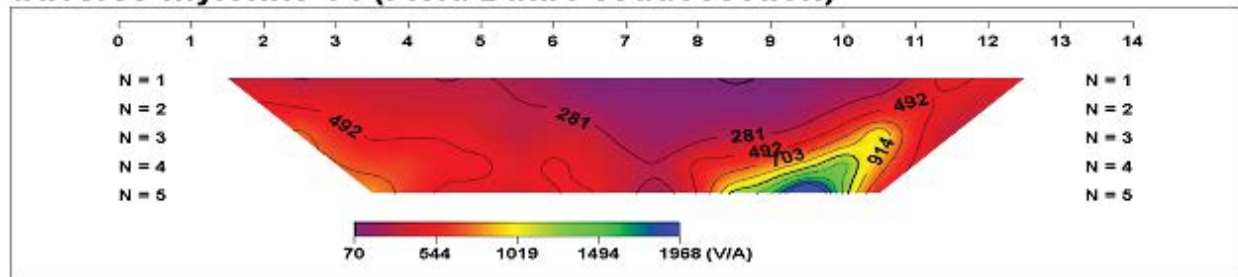
Figure 15: Diagram showing pseudosection of the field data (upper panel and inverted earth model (lower panel) of resistivity structure along traverse 3.

zone detected by the magnetic method coincided with the location of Mylonite in inverted resistivity section. The resolution of the subsurface images obtained from the synthetic resistivity data increases when the width extent of the Mylonitic zone is half the thickness of the overburden, but decreases as the thickness of the overburden increases.

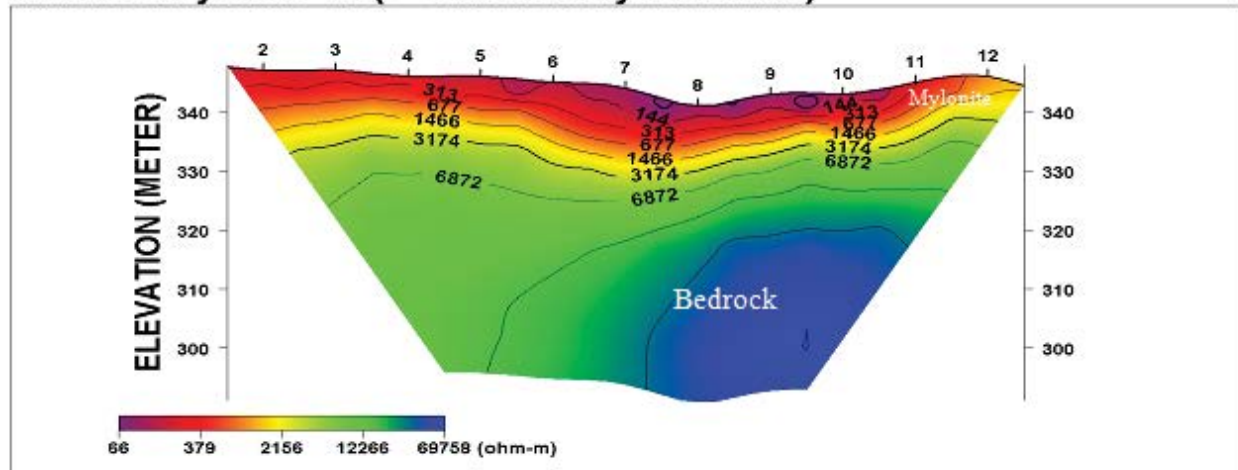
A good characteristic feature of the Mylonitic zone within a basement complex rock of South-western Nigeria was obtained with the use of two integrated geophysical methods. The results from the field data are in general agreement with the numerical modelling experimented results, in that, the synthetic models show depression signature which could be attributed to fault zone. The magnetic profiles show that the Mylonite is actually dipping

towards East this is obvious in profiles 1. Magnetic anomaly of a wavelength which indicated shallow basement magnetic source of about 10 m were obtain along Traverse 1,3 and 4 respectively while the high wavelength magnetic signature typify characteristics moderately deep source of about 22 m along Traverse 3. The magnetic Euler deconvolution model was shown to correspond to Mylonitic location since the major clustering of the field data coincide with low resistivity Mylonite. Therefore, the possible locations and width extent obtained from the interpretation of the magnetic anomalies and the inverted resistivity section generally agree to be within 5% which authenticate the validity of the quality of the data obtained from the field and perhaps, the efficacy of the inversion process used. Therefore, the results obtained from

### traverse-mylonite-04 (Field Data Pseudosection)



### traverse-mylonite-04 (2-D Resistivity Structure)



**Figure 16:** Diagram showing pseudosection of the field data (upper panel and inverted earth model (lower panel) of resistivity structure along traverse 4.

the integrated geophysical methods carried out in the study area indicates that the two results correlate quite well and they both confirm the existence of the Ifewara Mylonite/shear zone which is indicator of Ifewara fault zone.

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