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Research Paper

An Integrated Geophysical approach towards the Delineation of a Fractured Zone at Ifeawara – Ile-Ife, Oyo State.

Amakiri, A. R. C., Amechi B. U., Amonieah, J. and Otugo, V.
Department of Physics. Rivers State University, Oroworukwo Port Harcourt.
Corresponding author: Dr. A. R. C. Amakiri; E-mail: amakiri.arobo@ust.edu.ng

Abstract
An integrated gravity and magnetic method was executed along a suspected fracture at the Ifewara-Zungeru fault zone, Southwestern, Nigeria. A hand held gravimeter and magnetometer were used for the measurements, covering a total profile of 1800m; a total of 32 stations were mapped with a station spacing of 60m. Appropriate software was used for the delineation of the anomalies. The depth to surface of the suspected fault/fracture was estimated at 168m and 171m for the gravity and magnetic surveys respectively. The thickness of the fault was also estimated to be 62.9m using the step model method. The ratio of the structure height to its thickness (h/I) was obtained to be 2.67, implying that the fault structure is a reverse fault.
Keywords: Fault, Anomalies, Magnetic, Gravity, fractured, Gneiss

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I. Introduction

The gravity and magnetic surveys have witnessed increased utilization in the global world, for various geological, geophysical and environmental applications. Both gravity and magnetic phenomena are natural phenomena. The two geophysical methods, resulting from the natural phenomenon of gravitational attraction and magnetism are essentially based on potentials. They are non-invasive and non-destructive techniques. The both methods consist of two major processes; firstly, the measurement of the field anomalies on or above the surface of the ground and secondly, the interpretation of the measured anomalies in terms of the variation in rock properties in the subsurface earth, which in turn gives Insight to knowledge of the geology of the area being investigated (Paterson and Reeves, 1985).

Existing geophysical studies have established that there is an active seismic fault in Nigeria (Oluwafemi et al., 2018; Tsalha, et al., 2015;). The fault was named the Ifewara-Zungeru fault due to the bearing of the line of the fault as it trends through the Ifewara zone of south-western Nigeria (Adepelumi *et al*., 2008). This active Fault is shown as the thick black line trending Northwest to Southwest in the map in Figure 1. The main aim of this study is to delineate the trends of the subsurface fault structures, and the objectives include; to determine the depth of the basement surface, and to delineate the fractu red zones of the study area.

1.1 Geological setting of the study area

The study area is Ifeawara, Ille Ife in the Southeastern part of Nigeria. The Ifewara zone in the south west region of Nigeria is over lain with the Schist belt in the complex basement of Nigeria. It has been evidenced that nearly over half of the total surface area of Nigeria is made up of the basement complex formation. The major compositions of Nigeria's lithosphere are mainly the metavolcanic rocks, the metasedimentary rocks, and the migmatite rocks. (Oluwafemi, et al. 2018).

Nigeria lies approximately between latitudes 40 N and 15 0N and Longitudes 3 0E and 14 0 E, within the Pan African mobile belt in between the West African and Congo Cratons. The Geology of Nigeria is dominated by crystalline and sedimentary rocks both occurring approximately in equal proportions (Woakes et al., 1987). The geology of Nigeria is made up of three major litho-petrological components, namely, the Basement Complex

Younger Granites, and the Sedimentary Basins. The Basement Complex, which is Precambrian in age, is made

up of the Migmatite-Gneiss Complex, the Schist Belts and the Older Granites. The Younger Granites comprise several Jurassic magmatic ring complexes cenered around Jos and other parts of northcentral Nigeria. They are structurally and petrologically distinct from the Older Granites. The Sedimentary Basins, containing sediment fill of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida Nupe) Basin and the Dahomey Basin (Obaje, 2009). The study area (Ifewara) is underlain by the sedimentary formation and the crystalline rocks of the basement complex type. These rocks are mainly granitic in composition and in different stages comprising mostly amphibolite and amphibolite schist with intercalation of talc bodies (De Swardt, 1953, Ajayi 1981, Elueze, 1977; 1981; 1982; Olade, 1978).

II. Background theory

2.1 **Gravity survey**

From a geophysical point of view, a gravity anomaly is thought of as the difference a measured gravity value and a predicted value for the same point derived from some theoretical reference model (Chapin, 1996).

The Newton's law of universal gravitation is the basis for the gravity method of geophysical exploration. The universal gravitation law is given as,

$$g = GM/r^2 \qquad (1)$$

where M is the mass of the earth, G is the universal gravitational constant and r is the radius of the earth. The unit of *g* is usually the milligal.

The value of *g* varies in different parts of the earth surface, since r is not a constant because of the earth's ellipticity and the centrifugal force due to the rotation of the earth. These variations are taken into account by the international gravity formula (USEPA, 2016),

$$g = 9.780318 (1\ 0.00053024 \sin^2\Phi - 0.0000059 \sin^2 2\Phi). \qquad (2)$$

were, g = acceleration of gravity in m/s^2, and Φ = latitude in degrees.

This Equation gives the sea level values of gravity at latitude Φ. The measured value of g corrected to sea level is generally found to be greater or smaller than the theoretical value calculated from the international gravity formula. The difference is due to inhomogenities in the crust and upper mantle, and it is the small anomalies due to near surface inhomogenities in the crust that are of interest in mineral exploration.

These gravity anomalies are caused by density differences in the underlying rocks and although most ore bodies have high density contrast with the surrounding country rocks. The gravity anomalies are concealed by features such as salt domes, oil bearing structures, ore bodies, undulations of rock strata, etc.

The gravity technique provides information regarding the density distribution in the subsurface and can identify anomalous geological features (of varying density) in order to detect structural or lithological contrasts in the subsurface. The success of the gravity method depends on the different earth materials having different bulk densities (mass) that produce variations in the measured gravitational field. These variations can then be interpreted by a variety of analytical and computerized methods to determine the depth, geometry and density that causes the gravity field variations. The gravity method produces an ambiguous, non-unique solution for the subsurface structures. Therefore, precise gravity interpretation requires a number of data reduction techniques so as to eliminate all other spurious effects and only be left with those that are caused by the geological variation in the sub-surface. Both the gravity and magnetic methods employ potential fields, implying that they are the spatial derivatives of their respected fields.

2.2 Magnetic surveying

This is the oldest geophysical method reported to have been used in prospecting for iron ore in the 17^{th} century. Some physical properties such as ferromagnetic, susceptibility and natural magnetization distributed in the ground, convey information about the subsurface geology of the earth, even if the rocks could not be identified. Each of these properties is the source of a potential field which is intrinsic to the body possessing that property and which acts at a distance from it. The strength of the magnetic field is in proportion to its magnetization.

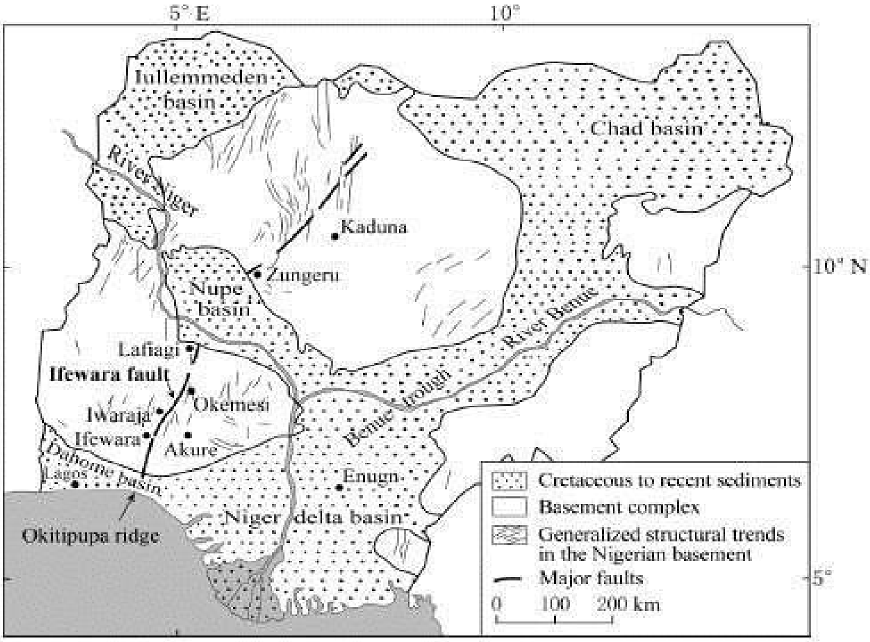

Fig 1. The Ifewara-Zungeru fault on the Nigerian Map (Tsalha, et al., 2015)

Magnetic measurements in applied geophysics are often carried out as a relative determination in which the values of one or more elements of the magnetic fields at any point are measured as differences from the values at a suitably chosen base point.

Magnetic survey is a geophysical method that images the anomalies in the earth’s magnetic field due to magnetic sources underneath the ground. The magnetic method of geophysics is useful for the detection of underground pipes, buried objects, oil and gas exploration and investigations of archaeological sites.

The magnetic fields measured are horizontal, vertical, and total components. The vertical components and the total components are mostly used in several studies to delineate faults, fractures, depth to magnetic basement, and other geological structures (Folami, 1982). The magnetic method is very suitable for locating buried magnetite ore bodies because of their high magnetic susceptibility (Young and Droege, 1986).

The magnetic survey is a powerful tool for delineating the geology (lithology and subsurface structure) of buried basement terrain. Such a survey, maps the variation of the geomagnetic field, which occurs due to changes in the percentage of magnetite in the rock, it reflects the variations in the distribution and type of magnetic minerals below the Earth’s surface (Mekonnen, 2004). Magnetic minerals can be mapped from the surface to greater depths in the rock crust depending on the dimension, shape, and magnetic property, of the rock. Sedimentary formations are usually nonmagnetic and, consequently, have little effect, whereas mafic and ultramafic igneous rocks exhibit a greater variation and are useful in exploring the bedrock geology concealed below cover formations (Mekonnen, 2004). The magnetic method is a vital geophysical exploration method for the study of the distribution of magnetic minerals in the upper sub-surface layers of the earth's crust (Ojo et al. 2014).

III. MATERIALS AND FIELD PROCEDURES

3.1 INSTRUMENTATION

3.1.1 Gravity survey

In the relative gravity measurement, a portable Worden master gravity meter (gravimeter) 1216 model 3 was used. It has an accuracy of 0.0948 gu when operated under good condition. It has a mass M, kept at an unstable equilibrium by a zero-length quartz spring, whose one end is attached to an arm inclined at an angle. The magnetic data was measured with a flux gate magnetometer (Fig.2).

The magnetometer measures the vertical component of the earth’s magnetic field. The magnetometer Seintrix model MF-2, consist of two identical coils wound in series in opposite directions around ferromagnetic elements of extremely high permeability. The coils are energized by an alternating sinusoidal current which drives the cores beyond saturation at the top and bottom of each cycle. The MF-2 is a completely new concept in vertical force fluxgate magnetometers. These instruments, which are designed for fast and accurate mineral ground surveys, are orientation independent, self-leveling and require no tripod.

The flux gate magnetometer (Fig. 2) is equipped with a range selector switch so that negative scale readings can be obtained over a wide range of field strengths. The instrument has a built-in hemisphere polarity switch providing two overlapping ranges. For the Northern hemisphere the full range is +80,000 to - 20,000 gammas, and reversible for the Southern hemisphere.

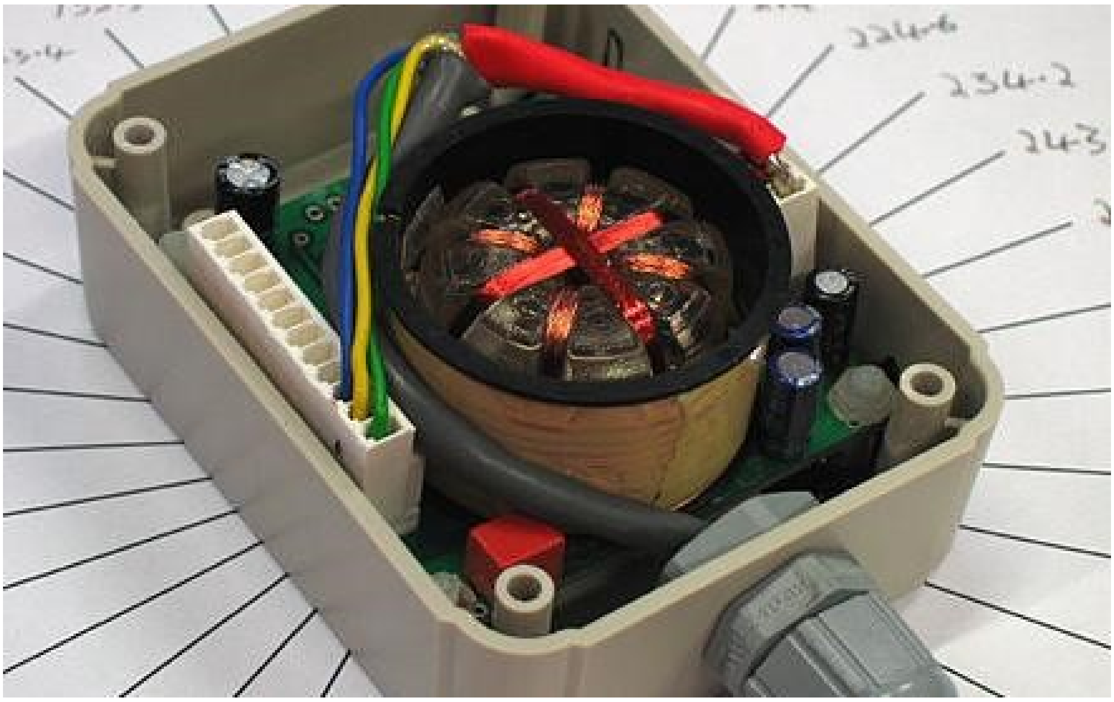

Fig. 2: Typical Fluxgate magnetic meter

3.2 FILED PROCEDURE

3.2.1 Gravity survey

The relative gravity survey was carried out at the site of the suspected geologic fault on a transverse line totaling 1800m. a total of 32 stations were mapped with a station spacing of 60m. the gravimeter which requires a little operator skill is simple to read. The reading of the base station was reported after every two hours interval. This was done to correct for instrumental drift which is usually due to elastic creep in the spring. However, the elevation reading was also taken simultaneously with the gravity measurement for elevation correction.

In reading the gravity meter a tripod stand was first balanced with the inbuilt spirit leveling. On the tripod the gravimeter was equally leveled with the spirit leveling component while reading was taken. With the horizontal light beam balanced on the reference line, the relative gravity of the location was read directly from the scaled window indicator. It should be noted that the gravimeter does not give the absolute gravity reading but the relative values which are adequate for mineral survey.

However, the gravimeter is replaced with the altimeter (for elevation) on the leveled tripod stand. In using the altimeter which has a capacity of 1000 – 5000ft was to record the elevations of the 32 stations along the traverse line. The locations elevation which is read directly on the altimeter is indicated through a pointer which runs over a scale marked on the instrument.

Table 1 show the readings of both the elevation and gravity values of the 32 stations mapped out.

3.3.1 Magnetic survey

The relative magnetic survey was conducted along the transverse across the geologically faulted zone with station intervals of 60m mapped out. The magnetometer required a semi-skilled to obtain accurate readings. The spirit leveling was maintained as the selector control was set to x = 1000k range, Observations were taken within a minute as the switch is turned on; this gives directly the absolute value of the vertical field indicated by a pointer over a calibrated scale.

Two readings were taken at each station as a check against very strongly localized sources since the spread is as much as 60m apart. However, in carrying out measurements, it was ensured that the operator do not carry any steel or metallic material.

3.4 DATA INTERPRETATION

3.4.1 Gravity data

Basically, the interpretation of gravity measurements requires that some corrections be made to separate the field spurious noise from the wanted signal. It is only when these corrections are made that the data can be ready for interpretation. The factors for correction include elevation, drift, and Bouguer correction. Topography terrain and latitude corrections were not considered in this report, since the survey was carried out on a flat horizontal plane. Besides, the data were collected mostly in the East – West direction and the survey area did not cover a very large extent.

However, in analyzing the data, a plot of the Bouguer anomaly g_B was made against the station distance.

The Bouguer anomaly g_B is the gravity anomaly corrected for the height at which it is measured and the attraction of the terrain. It is given as,

$$g_B = g_F - \delta_{gB} + \delta_{gT} \quad (3)$$ were,

δ_F is the free air gravity anomaly, δ_{gB} is the Bouguer correction, and δ_{gT} is the terrain correction

The Bouguer correction δ_{gB} allows for the gravitational attraction of rocks between the point of measurement and sea level. In this study the Bouguer correction was evaluated to be ± 0.117 (mgal/m)

The free air gravity anomaly δ_F *is* the gravity anomaly corrected for height alone; it is related to the observed gravity measurement, $g_{obs.}$ by the expression,

$$g_F = g_{obs} - g_\lambda + \delta_{gF} \quad (4)$$ were, δ_λ is the correction for latitude, and δ_{gF} *is* the free air correction.

The free air correction (δ_{gF}) is the amount that must be added to the measured gravity at a height h, to correct it to the reference level, and is given as,

$$\delta_{gF} = \frac{2g}{R} \, x \, h \quad (5)$$

It is the value added to a measured gravity reading to compensate for the change in gravitational field with height above sea level, assuming there is only air between the measurement station and see level. In this survey it was taken to be ± 0.3085 (mgal/m).

From the plot, the nature of the fault was delineated crudely by considering the ration h/I (Grant, 1965). This ratio is found to range from 1 for – 90° to 0.06 for 15°, for a normal fault; and from 1 to 16 for a reverse fault of the same angle of dip.

3.4.1.1 Use of the Step Model

In the interpretation of the fault, we located the points X_1 and X_2 from the graph; such that $x_1 = 480$ and $X_2 = 900$. Also noting that, $\Delta g_1 = 2.5$ *and* $\Delta g_2 = 14.5$

Then, using Grant and West (1965), the height to the structure was estimated as,

$$h = \frac{x_2 - x_1}{2.5} \quad (6)$$

and the thickness, l, of the fault structure was estimated from the relation,

$$l = 14\left(\frac{\Delta g_2 - \Delta g_1}{\Delta_\rho}\right) \quad (7)$$

Where ρ is the infinite slab density usually considered to be the average density of the earth's crust, and taken as $2.67 \times 10^3 kg/m^3$.

The depth of the fault structure was alternatively evaluated using the relation,

$$h = 0.56\left(\frac{g_2 - g_1}{Smax}\right) \quad (8)$$

Where, Smax is the maximum slope taken as 0.4.

3.4.3 MAGNETIC DATA INTERPRETATION

In interpreting the magnetic field data for the relative magnetic measurements collected at Ifewara, the diurnal variations and corrections were ignored. This was because the data was collected within an interval of three hours which may not play any significant role in magnetic anomaly of the zone.

The plot of the field data against the station distance was executed and the depth to the surface of the suspected fault was consequently estimated using the relation in Eq. 9,

$$H = \frac{x_m \left(x_{1/2}\right)}{2(x_m^2 + x_{\frac{1}{2}}^2)^{1/2}} \quad (9)$$

Were,

X_m = distance between maximum and minimum peak values

$X_{1/2}$ = distance between two parts H = depth to surface.

Precaution was taken to put away Iron objects such as large belt – buckles, watches, pocket, knife or small magnets, as these may affect the readings slightly. Besides, care was taken to guard against taking readings close to iron or steel objects such as pipelines, fences, bridges, railroads and cars.

Table 2 shows the magnetic field readings taken for 26 locations conducted at Ifewara,

IV. Results and Discussion

4.1 Gravity anomaly profile

The gravity field data is shown in Table 1 and Fig. 3, Fig. 3 is the Bouguer correction anomaly of the study area.

The Relative Gravity results obtained in the study are shown in Table 1, while the Bouger anomaly correction is shown in Figure 2. Table 1 indicates that the relative gravity observed ranges from 1840.25 to 1899.50 Gamma for distances of 0.00 and 1080 m respectively. The free air corrections ranged from a minimum value of -7.7125mgal/m at a distance of 1800m to a maximum value of +22.2120 mgal/m at a distance of 1080m; the Bouger correction ranged from -7.371 to +3.159 mgal/m at a distance of 1140m and 480m respectively. The Bouger anomaly varied from - 6.7032 mgal at a distance of 1800m to +19.4025 mgal corresponding to a distance of 1080m, and the Bouger gravity ranged from a minimum of 167.7525 mgal to a maximum of 198.1920 mgal at a respective distance of 1800m and 1200m.

Table 1: RELATIVE GRAVITY MEASUREMENT, THE CORRECTION AND CALCULATED BOUGUER ANOMALY.

S/N	Distance (m)	Time taken (hr)	Elevation (m)	Relative gravity	Relative gravity x dial const. (0.0948)	Free air correction dgf = ± 0.3085 (mgal/m)	Bouguer correction = ± 0.117 (mgal/m)	Bouguer gravity (gb) (mgal)	Bouguer anomaly (dgb) (mgal)
0	0.00	15.39	1179	1840.25	174.4557	-	-	-	0.0000
1	60.00	15.48	1179	1845.10	174.9155	0	0	174.9155	+0.4598
2	120.00	16.12	1178	1842.10	174.6311	+0.3085	-0.117	174.8216	+0.3658
3	180.00	16.25	1177	1846.00	175.0000	+0.6170	-0.234	174.583	+0.9273
4	240.00	16.37	1178	1845.20	174.9200	+0.3085	-0.117	175.5112	0.6558
5	300.00	16.44	1186	1842.30	174.6500	-2.1595	+0.819	173.3095	-1.1462
6	360.00	16.49	1194	1840.60	174.4900	-5.8615	+2.229	170.4675	-3.9882
7	420.00	17.05	1198	1836.50	174.1000	-4.6275	+1.755	171.6175	-2.8382
8	480.00	17.19	1206	1834.40	173,9000	-8.3295	+3.159	168.7295	-5.7262
9	540.00	17.25	11.95	1837.30	174.1800	-4.9360	-1.872	171.1160	-3.3397
10	600.00	17.30	1195	1878.00	175.1900	-4.9360	-1.872	172.1260	-2.3297
11	660.00	17.45	1192	1846.30	175.0300	+2.1595	-0.819	176.3705	+1.9148
12	720.00	17.52	1172	1855.40	175.9000	+2.1595	-0.819	177.2305	+2.7748
13	780.00	17.54	1153	1861.40	176.4600	+8.0210	-3.042	181.1479	+7.0233
14	840.00	17.59	1142	1876.80	177.9200	+12.0315	-4.563	185.3885	+10.9328
15	900.00	18.00	1112	1888.00	179.0000	+17.5845	-6.669	189.9155	+15.4598
16	960.00	18.04	1112	1890.10	179.2000	+17.5845	-6.669	190.0036	+15.5479
17	1020.00	18.07	1114	1898.70	180.0000	+20.0525	-7.605	192.4425	+17.9918
18	1080.00	18.10	1107	1899.50	180.0700	+22.2120	-8.424	193.8580	+19.4025
19	1140.00	18.14	1116	1896.60	179.8000	+19.4355	-7.371	191.8165	+17.4088
20	1200.00	18.17	1131	1888.20	197.0000	+14.8081	-5.616	198.1920	+13.7363
21	1260.00	18.20	1142	1878.40	179.0700	+11.4145	-4.329	185.1555	+10.6998
22	1320.00	18.04	1179	1882.60	178.4700	+0.0000	0.000	178.4700	+4.0143
23	1380.00	18.15	1143	1873.50	177.6100	+11.1060	-4.212	184.5040	+10.0483
24	1440.00	18.21	1156	1860.40	176.3700	+7.0955	-2.691	180.7745	+6.3188
25	1500.00	18.26	1172	1851.40	175.5100	+2.1595	-0.819	176.8508	+2.3948
26	1560.00	19.30	1178	1841.60	174.5800	+0.3085	+0.117	174.7715	+0.31593
27	1620.00	19.38	1193	1832.00	173.6700	+4.3190	+1.638	170.9890	-3.4667
28	1680.00	18.43	1201	1827.00	173.2000	-6.7870	+2.574	168.9870	-5.6870
29	1740.00	18.49	1201	1824.00	172.9100	-6.7870	+2.574	168.7070	15.7487
30	1800.00	18.55	1204	1820.90	172.6200	-7.7125	+2.925	167.7525	-6.7032
31	1860.00	18.59	1200	1821.30	172.6600	-6.4785	+2.457	168.6322	-5.8235
32	1920.00	19.05	1189	1826.30	173.1300				

From the gravity data, using the step model, Equation (Equ. 4), the depth to the fault structure was estimated to be 168m and the thickness of the fault structure as estimated from Equation (5) was 62.9m. Again, using the half slope model, Equation (6), the depth to the structure was reestablished as 168m.

We infer therefore that the ratio of the structure height to its thickness (h/I) is 2.67, which indicates a reverse fault.

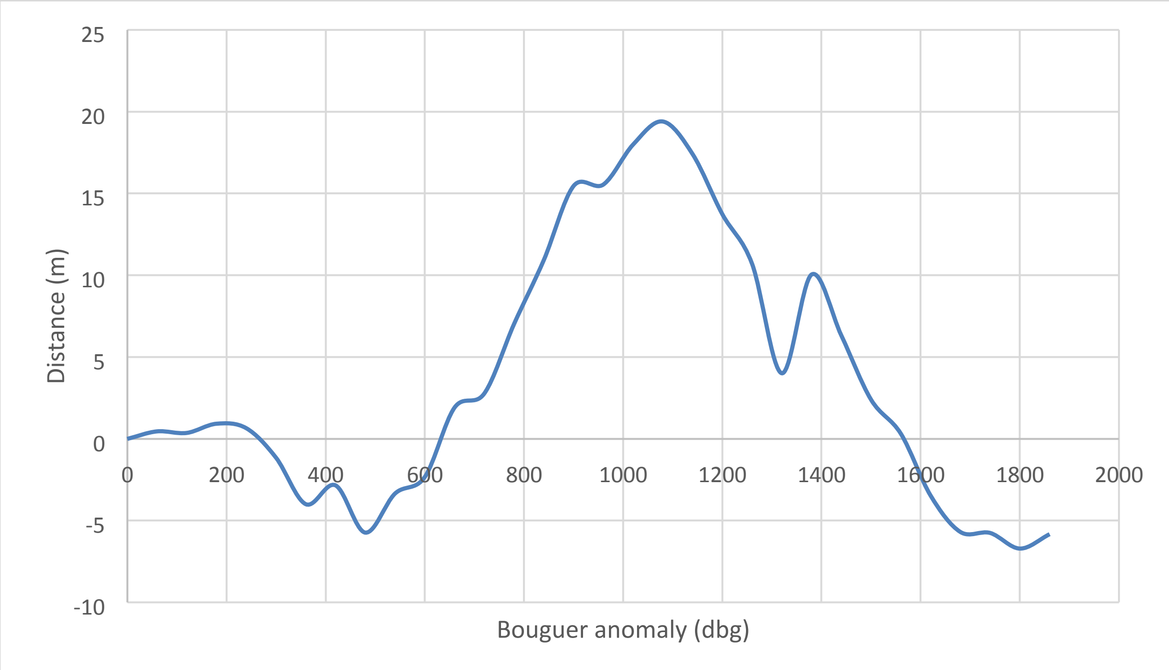

Fig. 3: Gravity Bouguer anomaly correction profile

4.2 Magnetic anomaly

The magnetic data obtain from the field is shown in Table 2 and Figure 4. Fig. 4 is the magnetic anomaly profile of the study area. The mean values of the magnetic fields observed as indicated in Table 2, ranges from -20 to 48 gamma at station distances of 1620/1680m and 1260m respectively.

Table 2: MAGNETIC SURVEY DATA

S/N	STATION DIST (M)	TIME (S) 1	TIME (S) 2	OBSERVATION (X 100K) 1	2	MEAN (GAMMA)	REMARKS
1	0	3.44	3.44	26.00	24.00	25.00	High tension
2	60.00	3.51	3.53	34.00	36.00	35.00	Wire, nearly
3	120.00	3.56	3.57	38.00	32.00	35.00	Cars
4	180.00	3.59	4.00	40.00	40.00	40.00	Motorcycle mech
5	240.00	4.05	4.06	38.00	42.00	40.00	culvert
6	300.00	4.09	4.10	34.00	38.00	36.00	Iron, water pipe
7	360.00	4.11	4.12	42.00	38.00	40.00	Close to
8	420.00	4.13	4.15	42.00	38.00	40.00	Building and
9	480.00	4.17	4.18	38.00	44.00	41.00	High tension wire
10	540.00	4.20	4.22	30.00	28.00	29.00	
11	600.00	4.24	4.25	40.00	28.00	34.00	
12	660.00	4.26	4.27	42.00	42.00	42.00	Culvert
13	720.00	4.29	4.30	38.00	38.00	38.00	
14	780.00	4.34	4.35	36.00	39.00	37.50	
15	840.00	4.36	4.37	38.00	40.00	43.00	
16	900.00	4.38	4.39	45.00	42.00	43.00	
17	960.00	4.46	4.47	46.00	47.00	46.50	
18	1020.00	4.54	4.55	38.00	40.00	39.00	Bridge & iron sign post
19	1080.00	5.04	5.05	38.00	34.00	36.00	
20	1140.00	5.06	5.07	38.00	34.00	36.00	
21	1200.00	5.08	5.09	44.00	46.00	45.00	
22	1260.00	5.12	5.13	40.00	48.00	44.00	
23	1320.00	5.16	5.17	48.00	40.00	44.00	
24	1380.00	5.18	5.19	48.00	40.00	44.00	
25	1440.00	5.21	5.24	36.00	44.00	40.00	Sign post hills
26	1500.00	5.26	5.28	36.00	38.00	37.00	
27	1560.00	5.58	5.59	- 1	1	0	
28	1620.00	6.10	6.12	- 20	- 20	- 20	

29	1680.00	6.17	6.17	- 20	- 20	- 20

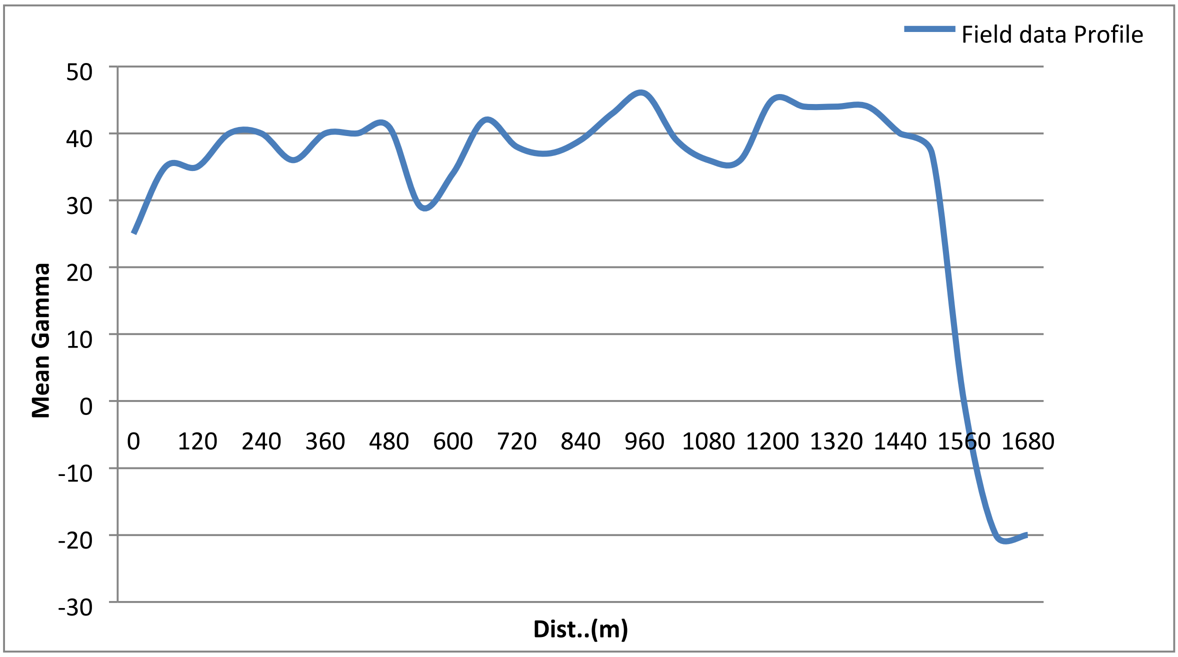

Fig .4: Magnetic survey profile of Ifewara fracture

From the magnetic profile (Fig. 4), using Equation (9), the depth to the fault structure was estimated as 170m below the subsurface. From the graph plotted (Fig. 4) the values of X_m and $X_{1/2}$ were estimated; the calculated value of the depth to the surface was again found to be 170m below the ground.

V. Conclusion

An integrated approach has been adopted in this study for the investigation of the fault structure in Ifewera, Southwestern Nigeria. The gravity and magnetic methods were executed on the study.

Magnetic properties of different types of soil display different aspects of soil mineralogy. The minerals that are present in soil are either natural (through lithogenesis, pedogenesis) or of anthropogenic origin (industrial residues).

From the gravity data, the depth to the fault structure was estimated to be 168m and the thickness of the fault structure was estimated to be 62.9m. The ratio of the structure height to its thickness (*h/I*) is obtained to be 2.67, implying that the fault structure is a reverse fault. From the magnetic survey, the depth to the fault structure was estimated to be 170m below the subsurface, which confirms the estimated gravity depth.

Conflict of Interests

All the authors of this publication do declare that, there is no form of conflict of interests whatsoever regarding the publication of this Article

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