MORPHOLOGY AND EVOLUTION OF INSELBERGS ON A PART OF THE BASEMENT COMPLEX OF WESTERN NIGERIA

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ABSTRACT

This study examined the morphological properties of ten selected inselbergs in Igbajo District of Central Western Nigeria in a bid to draw useful inferences on the long-term evolution of the landscape. Topographic and geologic sheets of the study area provided the basic information for the study. Additional data were acquired on the field using land surveying method (with Digital Global Positioning System and Total Station). The equipments facilitated the determination of the geographic coordinates of the landforms. The data were processed using ArcGIS 10.3. Triangular Irregular Network (TIN) in ArcGIS was used to generate the morphology of the landscape from the topographic data. Morphometric data pertaining to basal area and perimeter; relative relief and elevation (above the sea level); and slope length and maximum slope angle of the inselbergs were determined on the TIN generated. The morphometric data of the inselbergs showed 41.4% variation in basal area and 63.9% variation in perimeter. There were also 41.9% variation in slope length, and 47.4% in relative relief. There was however relative uniformity in the results for angle of maximum slope as well as the elevation of inselbergs above the sea level with the values of 17.1% and 13.1% as their variation indices respectively. The study showed that morphology of inselbergs studied was variable and concluded that the evolution of the inselberg landscape was via two stage process of deep weathering and stripping.

Key words: Etchplanation, Inselbergs, Landforms, Landscape evolution, Morphology.

INTRODUCTION

Inselberg is a descriptive term for rock hills which occur in clustered groups (massifs) or in isolation (Campbell, 1997), and rise sharply above the general level of the surrounding (Migon, 2004). It is generally believed that all inselbergs are produced by the lowering of the surface around it (Migon, 2004; Pope, 2013), and had survived the denudation actions by reason of their greater resistance (Kesel, 1973). The underlying factors behind the greater resistance of the inselberg however remain contentious with petrological variation and structural differences in rocks most commonly suggested (King 1975; Thomas 1978; Twidale 1998).

Morphologically, several variants of inselbergs have been registered though a convenient grouping into three broad classes is widely held (Thomas, 1994; Twidale, 1998). These are domed inselbergs, castellated inselbergs, and boulder inselbergs. The domes are generally characterised by dominant convex-upward slopes, developed on poorly jointed massive rock with little regolith at the surface (Twidale, 1998; Migon, 2004; 2006). They are generally known as bornhardts though low-angled and massive variants have been termed whalebacks (Jeje, 1973). Their domed morphology is enhanced by pressure release (Pope, 2013) while the preferential weathering is due either to variation in density of fracture or rock type (Twidale, 1998). Castellated inselbergs on the other hand are produced from well-jointed rocks which are nonetheless rooted in the bed rock (Migon, 2004). Detailed morphological analysis of this type reveals forms with semblance to towers or pillars separated along joint-aligned avenues. Finally, boulder inselbergs are composed of loose boulders, chaotically lying one on top of another and above a rock base or weathered mantle. They are popularly referred to as tors (Linton 1955).

Many tropical basement terrains are characterized by undulating plains dotted by inselbergs of various shapes and sizes (Thomas, 1994; Romer, 2007). They have been the subject of several studies e.g. Falconer (1911), Thomas (1965), Jeje (1973), Faniran (1974) in Nigeria; King (1975) and Selby (1977) in Southern Africa; and Twidale and his students (alone, 1982), (with Bourne, 1976), and (with Campbell,1997) in Australia. These studies examined various aspects of inselberg morphology and evolution but there were differing opinions among scholars from varying environments (Thomas, 1965; Jeje, 1973; King, 1975; Selby, 1977). Arguments have revolved around the role of climate in evolution of the landforms, importance of weathering as a precursor to the massive types (e.g. bornhardts) and the influence of rock structure and lithology in evolution of landforms.

Nevertheless, one factor that is beyond doubt is the antiquity of inselbergs with most believed to be no younger than pre-Tertiary in age (Twidale, 1998). The implication of antiquity is the inherent challenge it poses to observation of process (Faniran, 1974) since process is very slow and occurs over a time span of up to 10^6 years (Thomas, 1994). This therefore leaves observation of morphology of inselberg as the only verifiable means of gaining full understanding of evolutionary process. This paper aims to contribute along this line of research. The objective is to determine certain morphological properties of selected inselbergs from the central Western Nigerian Basement terrain and draw useful inferences about the evolution of the landscape from the observation of morphology.

THE STUDY AREA

The study was carried out in Igbajo District of Central Western Nigeria. The study area is situated approximately 49 km north of Ilesha and 50 km northeast of Osogbo, two major settlements in Osun State. The area lies between Latitudes 7° 53´ and 7° 57´N, and Longitudes 4° 41´ and 4° 52´E, and has a number of settlements, namely: Iragbiji, Otan-Aiyegbaju, Ada, Igbajo, and Iresi (Figures 1 and 2).

The topography of the study area is characterised by a cluster of domed-shaped hills of varying configuration. While some hillslopes are bare, some have boulders scattered over their surfaces, while others are covered by soil less than 10 cm thick. The Igbajo terrain is deeply weathered though emergent domes and inselbergs rise abruptly from gentle well-dissected pediment slopes cut into schists, gneisses, and migmatites (Burke and Durotoye, 1970; Thomas, 1994).

Igbajo District lies within the Koppen's A_f climatic zone, characterized by a short dry season (November - March), and a rainy season having a bi- modal rainfall distribution with peaks around June/July and September, and an intra-season low in August. This latter is a period of heavy cloud cover, relatively low temperature and minimum rainfall. It has been termed the

'August break' (Iloeje, 1976). Annual rainfall is ~1500 mm, mean annual temperature is ~27^{0}C and the relative humidity is estimated to average over 75% though the figure could surpass 90% during the rainy season. The archetype vegetation in the study area is the Tropical Rainforest. This has however been degraded into Derived Savanna through human activities such as farming, lumbering, and fuel wood production (Adejuwon and Jeje, 1975).

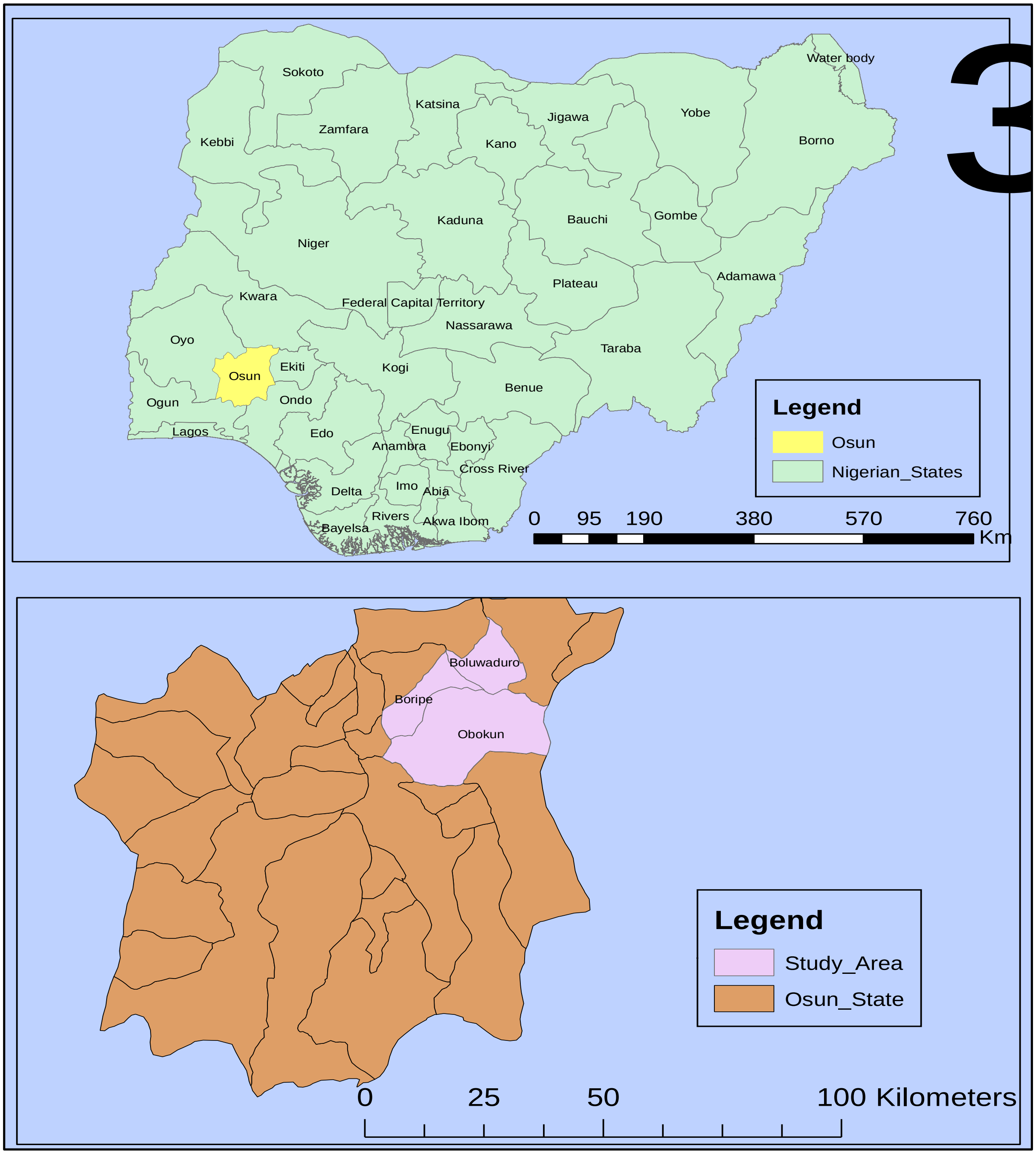

Figure 1: Nigeria Showing the States, and Osun State Showing the LGAs in the Study Area
Source: Office of the Surveyor General of the Federation

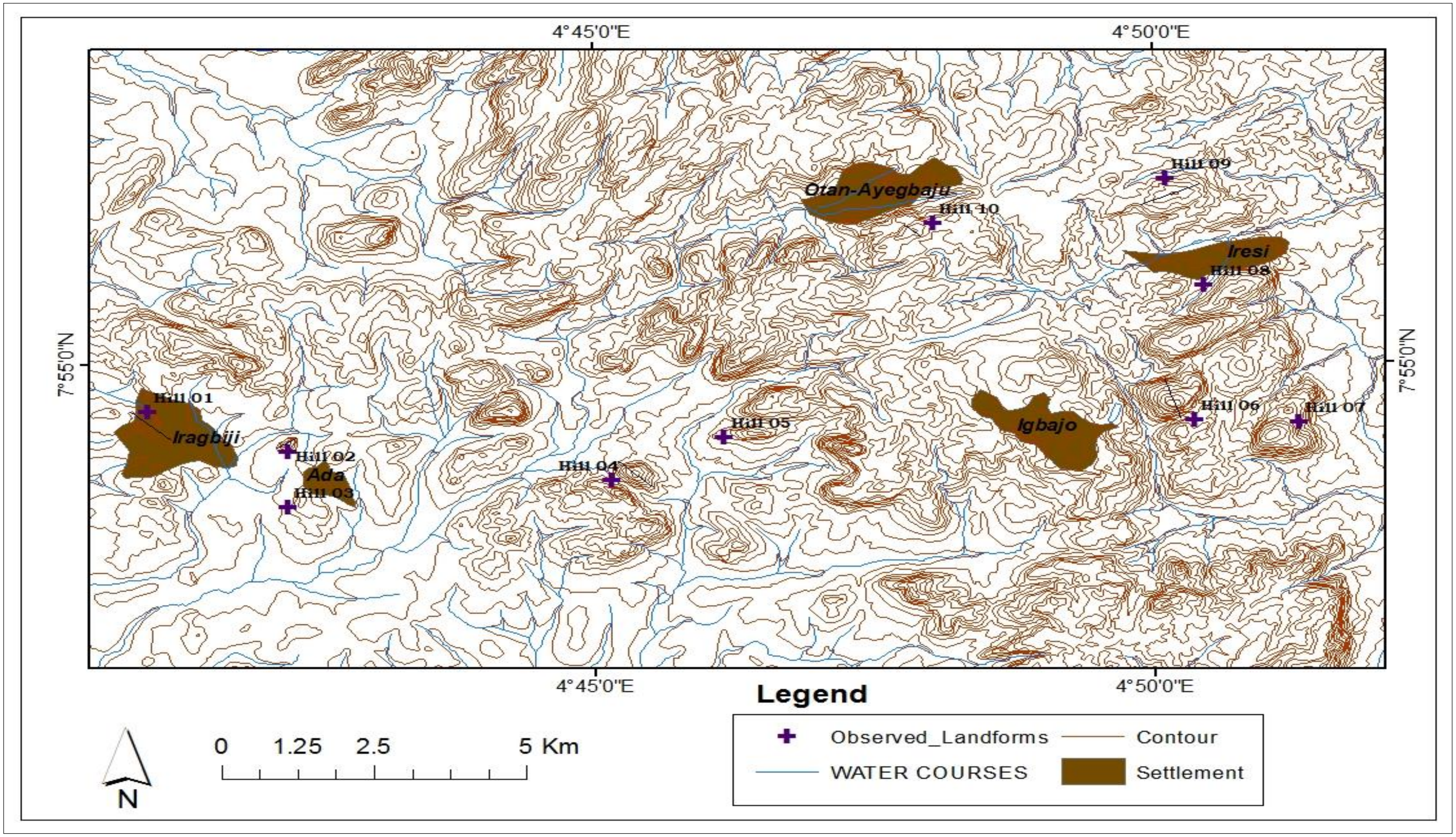

Figure 2: The Study Area with Inselbergs Studied
Source: Digitized from FSN 1966; 1:50,000 Ilesha Topographic Sheet 243 NW and NE

Geology of Igbajo Area

The study area lies on the Precambrian Basement Complex region of central western Nigeria and therefore belongs to the Pan African mobile belt east of the West African Craton (Hubbard, 1975; Rahaman, 1976). The Nigerian Basement Complex comprises granite intrusive of the Pan-African orogeny emplaced within schist and migmatites. They reflect syn-to-post collisional environment (Afolabi et al., 2013). Thomas (1976) remarks that syn-kinematic granites can be described as early orogenic rocks and are often dominated by quartz-diorites and granodiorites. They are commonly characterized by microcline and oligoclase and possess biotite and hornblende. Post-kinematic granites on the other hand, are generally true granites containing orthoclase and microcline in association with albite. The Igbajo intrusive body probably belongs to the latter group (post-kinematic) as observation of thin sections showed the dominance of alkali-feldspars (plagioclase - in form of oligoclase, and microcline), quartz and biotite as the main mineral constituents (de Swardt, 1953; Afolabi et al., 2013). The granitic pluton on which the landscape is built is flanked to the west by granite-gneiss, to the southeast by undifferentiated migmatite and gneiss, and to the northeast by schist and epidiorite complex (Figure 3). The granites are the coarse porphyritic type and form a discrete plutonic body with area of about 120 km^2. The body outcrops in several places as inselbergs with elevation reaching 670 m above sea level in Igbajo. Grains are quite large with biotite flakes reaching 0.6 cm by 0.8 cm as well as alkali feldspars variants averaging 1 cm by 2.4 cm measured in selected samples (Afolabi et al., 2013).

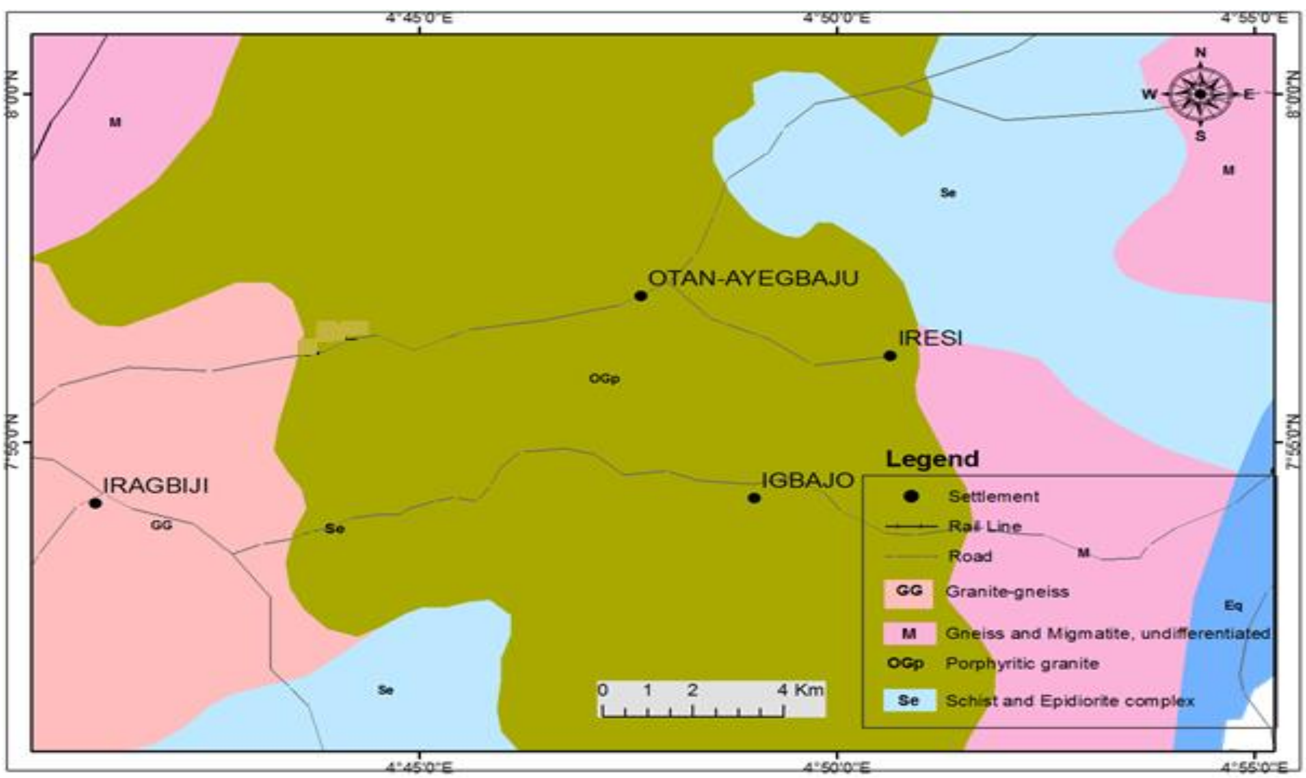

Figure 3: Geology Map of the Study Area
Source: Extracted from Nigerian Geological Survey Agency (NGSA) Iwo Sheet 38

MATERIALS AND METHODS

The study involved field survey of inselberg slopes and remote sensing analysis. It was carried out using the 1:250,000 Geology sheet (Carter, 1965), and two sets of the 1: 50,000 Topographic map series of Nigeria (1965 Nigeria Series Ilesha North East and North West) for field investigation and subsequent determination of morphometric parameters. Field investigation was conducted in the Igbajo granitic terrain covering Iragbiji, Ada, Igbajo, Iresi and Otan-Aiyegbaju settlements. The field investigation was with the aid of digital survey equipment such the Global Positioning System (GPS) and Total Station.

The Total Station facilitated the determination of the geographic coordinates and elevation of various points on the inselbergs studied at a high level of precision (0.025 m accuracy). Information was recorded in the form of X, Y and Z (i.e. eastings, northings and elevation). Rocks samples were collected on the field for simple identification at the laboratory of the Department of Geology and applied Geophysics, Obafemi Awolowo University, Ile-Ife. Inselbergs' morphology was carefully observed to take note of weathering patterns, weathering related forms and the presence of other structural properties.

The two topographic sheets (1:50,000, 1965 Series Ilesha North East and North West) covering the study area were georeferenced, and digitized to extract settlements, roads, contours and river, in a Geographic Information System (GIS) environment. The geographic data on inselbergs' location obtained with digital survey equipment were also exported into the ArcGIS software. The entire surface of each landform was mapped with readings obtained for each spot in the form of XYZ earlier highlighted. Triangular Irregular Network (TIN), a GIS technique was employed to generate the Digital Terrain Model (DTM) of the study area from the topographic data. The determination of morphometric parameters was achieved on the DTM and on the digitized topographic map. Morphometric parameters of landforms determined are: ground **area** covered by the inselberg; basal **perimeter** of the landform; **relative relief** (height of the landforms above the pediment); **elevation** (height of the inselberg's base above the sea level); **slope length** (defined as maximum slope length); and **slope angle** (represented by the angle of the steepest slope; Young, 1970) of the inselbergs.

RESULTS AND DISCUSSION

Morphometric Properties of the Inselbergs

Data on morphometric parameters of inselbergs determined are presented in Table 1. The table indicates that the perimeter of the inselbergs ranges from 1.131 km to 5.075 km with a mean of 3.202 km. The standard deviation (σ) and coefficient of variation (CoV) are 1.324 and 41.44%, respectively. The ground area covered by the inselbergs ranges from 0.094 km^2 to 1.177 km^2 with a mean of 0.659 km^2. The σ and CoV respectively are 0.421 and 63.88%. The values for coefficient of variation indicate that there is considerable variability both in area and perimeter of inselbergs in the study area.

The length of the longest slope has a range of between 270.9 m and 1168.9 m with mean of 755.0m. The standard deviation (σ) and coefficient of variation (CoV) are 316.14 and 41.87% respectively. The maximum slope angle on the other hand ranges between 23° And 40° with a mean of 33.80°. The standard deviation (σ) and coefficient of variation (CoV) are 5.77 and 17.07% respectively. The data for the CoV showed that whereas considerable variability exist for the length of slopes, angle maximum slope appeared to be fairly uniform.

Relative relief of the landforms has a range between 31.70 m and 138.02 m respectively. The mean is 78.95 m while the standard deviation and coefficient of variation are 37.41 and 47.38% respectively. The value for the CoV showed that considerable variability exists in the relative relief of inselbergs of the study area. Elevation of inselberg above the sea level revealed a range of between 410.68 m and 593.14 m, with mean of 477.69 m and standard deviation and CoV of 62.72 and 13.13%, respectively. The value of the CoV showed that the elevation of the inselbergs above the mean sea level is fairly uniform (see Figure 4).

The results obtained for the area and perimeter, two parameters showing areal coverage, of the landforms studied indicate a relatively wide variation and positive correlation. The relative relief of the inselbergs also show a wide spread about the mean implying that the inselbergs attained varying heights above the surrounding plain.

In addition, there was a significant positive correlation between relative relief and area of inselbergs. This implies that taller inselbergs also occupy wider areal extent compared to the low-lying ones. The result varies from the one reported in Akande (1989) in which a negative correlation was observed for the two parameters. Negative correlation implies that low-lying inselbergs were more massive in areal extent compared to taller inselbergs. While it appeared reasonable to expect low domes to be more massive than high rising ones as they await further exhumation, the result from the present study indicates that the relationship between areal extent and relief of inselbergs may not be straightforward.

Table 1: Morphometric Properties of the Inselbergs Studied

S/n	Residual landform	Perimeter(km)	Area(km^2)	Slope length(m)	Relief(m)	Elevation(m)	Slope Angle ($^\circ$)
1	Hill 01	1.476	0.163	352.982	47.78	410.89	30
2	Hill 02	1.131	0.094	652.200	38.57	430.72	31
3	Hill 03	2.143	0.258	270.927	46.72	408.56	40
4	Hill 04	2.537	0.429	777.895	109.74	410.68	33
5	Hill 05	5.075	1.177	733.126	80.09	530.97	40
6	Hill 06	3.996	0.981	1057.558	138.02	517.81	39
7	Hill 07	4.239	0.977	1168.926	96.59	484.62	28
8	Hill 08	4.115	0.895	1067.277	123.33	471.71	36
9	Hill 09	4.181	1.159	990.196	76.96	517.82	38
10	Hill 10	3.128	0.458	478.832	31.70	593.14	23
11	**Mean**	3.202	0.659	755.00	78.95	477.69	33.80°
12	**Std. (δ)**	1.327	0.421	316.14	37.41	62.72	5.77
13	**CoV.**	41.44%	63.88%	41.87%	47.38%	13.13%	17.07%

Source: Authors' Analysis

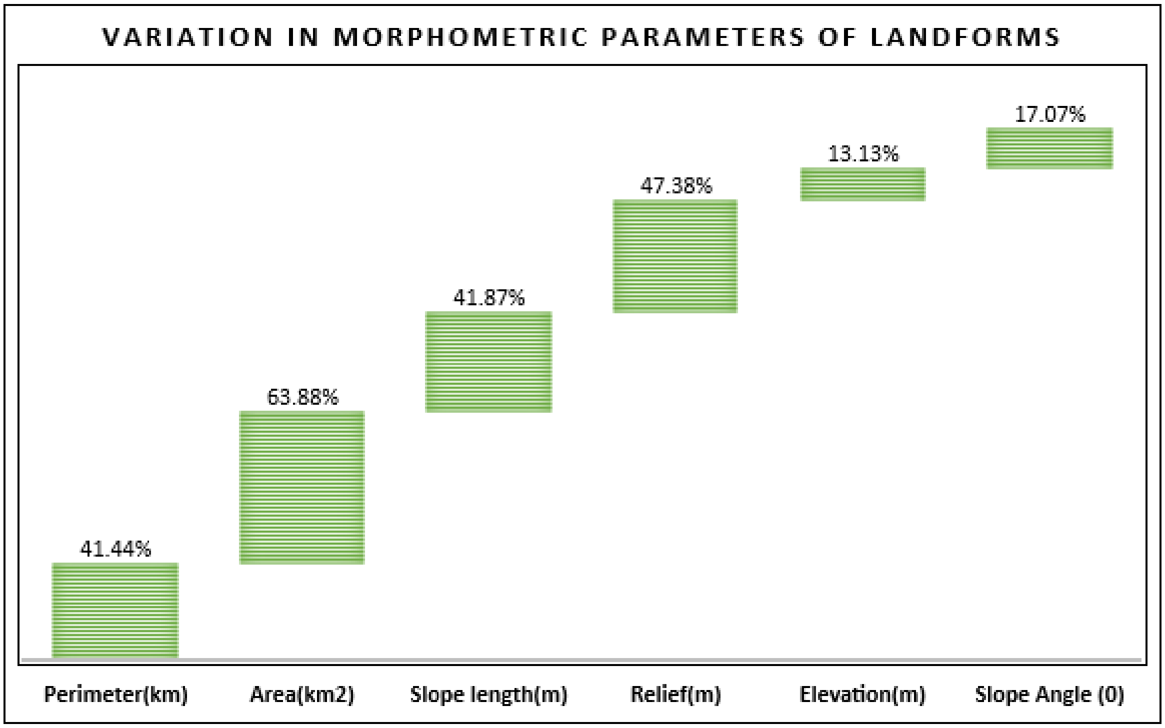

Figure 4: Coefficient of variation of morphometric parameters of inselbergs studied
Source: Authors' Analysis

Correlation of the Morphometric Parameters

The correlation among the various morphometric parameters of inselbergs determined in this study is presented in Table 2.

Table 2: Correlation of inselbergs' parameters

	Relief	Elevation	Area	Slope length	Slope angle	Perimeter
Relief	1.000	0.042	0.622	**0.795****	0.421	0.583
Elevation	0.042	1.000	0.593	0.298	-0.179	**0.660***
Area	0.622	0.593	1.000	**0.760***	0.411	**0.970****
Slope length	**0.795****	0.298	**0.760***	1.000	0.152	**0.680***
Slope angle	0.421	-0.179	0.411	0.152	1.000	0.333
Perimeter	0.583	**0.660***	**0.970****	**0.680***	0.333	1.000

***. Correlation is significant at the 0.01 level (2-tailed)*
**. Correlation is significant at the 0.05 level (2-tailed)*
Source: Authors' Analysis

Table 2 indicates that strong positive relationships exist between basal area and the perimeter ($r = 0.97$; $p < 0.01$), area and slope length ($r = 0.76$; $p < 0.05$), and slope length and perimeter ($r = 0.68$; $p < 0.05$) for inselbergs studied. Slope length is also positively correlated with relative relief ($r = 0.79$; $p < 0.01$) but weakly correlated with slope angle ($r = 0.152$; $p < 0.05$). Most importantly, a correlation coefficient 'r' of 0.042; $p < 0.05$ was observed for inselberg's relative relief and elevation above the sea level. This implies that there exists no relationship between inselbergs' elevation above the mean sea level and the height of the inselbergs studied (Figure 4).

Correlation analysis was used to elucidate the existence of an association between inselbergs relief and the elevation of their base above the sea level (highlighted in Table 2). The import of this relationship for evolutionary model is in its capability to confirm or refute a suggestion that inselbergs have zonal distribution. They are believed to be related to escarpments characterised by deep dissection, or generally located with some bias towards regional watersheds and decrease in size away from them (Kesel 1973; King 1975). Alternatively, they are viewed as azonal features (Thomas, 1994) with no obvious physiographic tendencies (Jeje, 1973). In case of observations supporting azonal distribution of landforms, credence is given to structural control (an important point in the etching hypothesis). If on the other hand zonality of forms is observed, structural control becomes less relevant (King, 1975; Thomas 1978). In effect, if results reveal positive correlation between inselbergs' relief and the elevation of their base above the sea level, that would imply that the high-rising inselbergs are located in the highest point in the region. This scenario would offer a strong support for the pedimentation and scarp retreat model. Otherwise, the structurally controlled etching model of inselberg evolution would be implied.

The result of the correlation analysis which yielded an $r = 0.042$ ($p < 0.05$) shows that inselbergs' elevation above the sea level has no relationship with the height attained by the inselbergs (see Figure 5). It can thus be inferred that inselbergs of variable heights occur at different locations (be it valley side or on regional highlands) as permitted by underlying structure and lithology of rocks. The response of structure and lithology to long term chemical weathering appeared to be the determinant factor in inselberg's relative height. This result offer support for the structurally controlled azonal distribution of inselbergs and ultimately showed that their evolution was by the 2-stage process of etching and stripping of weathered saprolite. The remark above also agrees with conclusions from earlier studies in other parts of the Basement terrain of Western Nigeria (Jeje, 1973; Faniran, 1974).

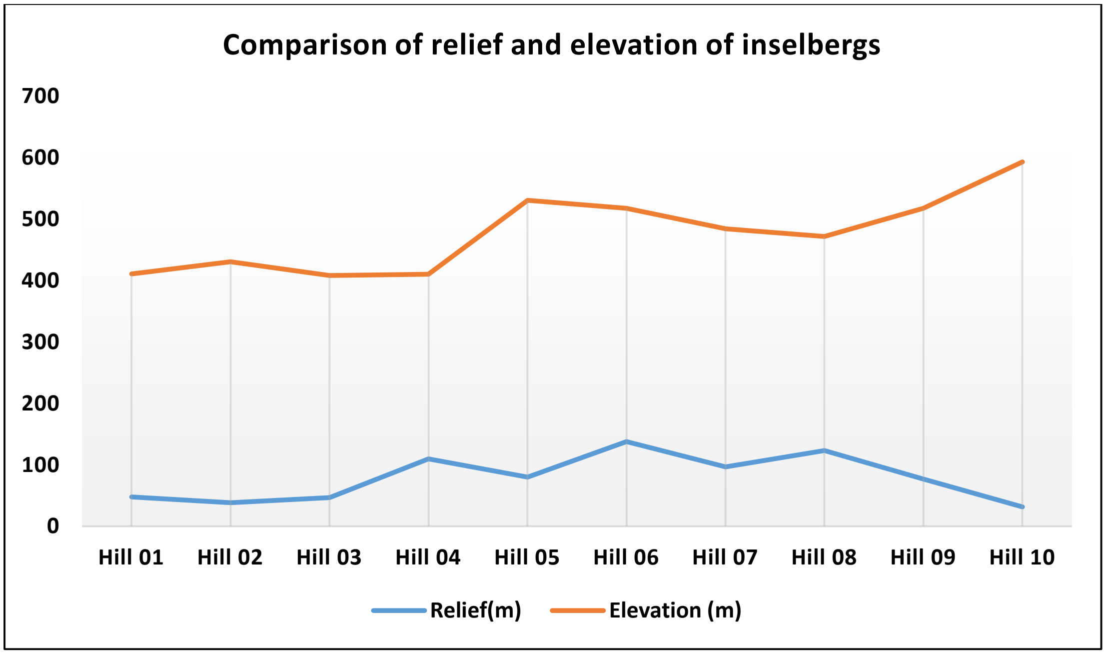

Figure 5: Relative Relief (m) and Elevation (m) above Sea Level of Inselbergs Compared
Source: Authors' Analysis

Evolution of Inselbergs

Arguments pertaining to the evolution of inselbergs generally revolve around two opposing models. The first relates to land denudation associated with pediplanation, while the second is associated with deep weathering followed by multi-cyclic stripping of regolith. A third proposition is hinged on equifinality credited to Von Betalanfy (1950) but supported indirectly by many researchers (e.g. Thomas, 1974, 1978; Musarurwa and Mandaza, 1983; Whitlow, 1983). The main thrust of this argument is that related forms can evolve via different processes.

Any of the above hypotheses can provide a plausible explanation of the evolution of inselbergs. But as remarked by Twidale (1998), all that is plausible is not necessarily true. The veracity of a landscape evolution theory rests on the amount of field situations it is able to account for (Twidale 1998). In this regard, several observed features on the inselberg landscape studied provide support for the two-stage process of deep weathering and stripping of saprolite. The most important evidences include regolith-fresh rock interface observed along road cuts (Plate 1) and coexistence of boulders and corestones in profiles which is indicative of on-going exhumation (Plate 2). These evidences support etching and stripping as the pathway of evolution of the inselbergs studied.

Plate 1: Road Section Showing Fresh Rock Buried under Weathered Regolith

Plate 2: Coexisting Boulders and Corestones

CONCLUSION

The objective of this study was to determine the morphology of inselbergs in the study area with a view to ascertaining the long-term evolution of the inselberg landscape. The results showed that considerable variability exists in the morphology of inselbergs in the study area. A greater level of variation was observed in the areal coverage (area and perimeter) and the altitude (relative relief) of the landforms above the surrounding plain. On the other hand, low level of variation was observed in the angle of maximum slope of the inselbergs as well as the elevation of their bases above the sea level. Also, it is the conclusion of this study that inselbergs in the study area evolved via the two-stage process of etching and stripping of weathered saprolite.

However, it was observed that the close proximity of the inselbergs studied coupled with the fact that all they are all members of a rock family (i.e. the Igbajo pluton) may have impacted on the degree of variability observed in their morphology. In view of this, a comparative analysis of morphology of inselbergs over contrasting geology is suggested as an area of further study. Such study will be highly beneficial as it would reveal the role of geology in inselbergs' morphological variation.

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