Structural Geometry of Ikom Columnar Basalt in the Ikom – Mamfe Basin, Southeastern Nigeria

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Abstract

The Ikom columnar basalt is found in the western part (Nigerian sector) of the Ikom – Mamfe basin. This polygonal basalt shows a distinct geometry with a colonnade which has well defined polygonal faces overlain by an entablature with irregular geometry. The mineralogy of both the colonnade and entablature are similar containing plagioclase, pyroxene and olivine. These polygons show the dominance of pentagonal (5 – sided) and hexagonal (6 – sided) polygons with the preponderance of pentagonal (5 – sided) polygons. The low axial ratios and the non – preferential orientation of the long and short axes of the polygons strongly suggest a strain free or low strain condition of crystallization of this basalt. The fractures in the basalt are high angled and oriented in the NE – SW direction which is not related to known tectonics of the Ikom – Mamfe basin thus they probably developed from local processes related to overburden pressure. The overall geometry and exposure of the Ikom columnar basalt makes it a relevant site for geotourism.

Keywords

Ikom, Basalt, Columnar, Polygonal, Ikom – Mamfe Basin

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1. Introduction

This study examined the columnar/polygonal basalts in the Ikom area southeastern Nigeria, using field measurements and interpretation of various plots. The polygonal/columnar structures are well defined in the Ikom basalt. Columnar joints and polygonal faces are spectacular geological phenomena observed in many parts of the world and are thought to be formed by the solidification of basaltic lava [1 – 4]. Columnar structures have straight edges and parallel faces, they generally have polygonal cross-section with typical dimensions varying from few centimeters to meters in size. The column height is much larger than their cross sectional size. Columnar joints are rarely observed in thick lava flows and are common in thin flows [3]. In many places, well developed columnar structures (colonnade) are sandwiched between two irregular, fractured non columnar regions with a variety of shapes (entablature). Although it is generally agreed that columnar basalt are formed from the cooling of basaltic lava, the actual evolution of the columns and polygons remains debatable. One of the earliest proposals for the evolution of columnar basalts was by [1]. He proposed that the hexagonal structures in columnar basalt are caused by convection cells (Similar to the one observed in Benard-convection) in the molten lava before solidification. The Sosman model was based on experiments with wax and oil in a flat dish. [2] suggested that the molten lava contracts as it solidifies and cracks form due to thermal stress. [5] showed that in a homogenous medium, crack pattern tends to be irregular whereas a medium with coarse-grains would produce regular “columnar cracks”. They said that in brittle and continuous materials like basalt, cracks are unlikely to produce regular structures as observed in the columnar basalt. [6, 7] have argued that the slender, finger-like convection cells formed in a double diffusive system could represent columnar basalt, he argued this based on the similarities between double diffusive finger (DDF) and
columnar basalt structures. [8] observed that the model polygonal pattern obtained consists of convex, irregular polygons with a variable number of sides but in which pentagons and hexagons predominate. The algorithm successfully reproduces the rapid evolution from an initial, immature crack pattern to a pseudo-hexagonal mature one in which the average number of sides approaches six. [3] observed that these polygonal columns are bounded by 3 to 12 planar ‘facet’ fractures. Most frequently the number of longitudinal bounding facets is between 5 and 8 with the preponderance of columns exhibiting 6 or 7. Some flows are broken into neatly fitting 6-sided prisms with equal sides and angles. Such perfection, however, is by no means the rule as 5 and 7 sided columns are common and 4 and 3 sided columns are rare [2]. These equal sided and angle polygons are those that are thought to form in a stress free environment.

2. Geology of the Area

The Mamfe basin is the smallest and most southerly of basins associated with the Benue Trough and extends 130 Km east from the Lower Benue Trough as far as the Cameroon volcanic line [9]. These basalts occur in a flat low-lying topography of the Ikom – Mamfe basin which averages about 90m above sea level and is drained by the Cross River. The Ikom – Mamfe basin is a largely sedimentary basin that lies astride the border between southeastern Nigeria and southwestern Cameroon (Fig. 1).

The Ikom basalt is one of the major basalt flows in this basin [11]. The Cretaceous sediments beneath the basalts of the Mamfe basin are Aptian to Albian in age and are made up of sandstones, limestones, shales and mudstones. They were deposited by a major marine transgression that reached the Ikom – Mamfe basin via the Benue trough [9]. Geological evidence in the Lower Benue Trough however indicates a thickness of about 2000m for these pre-Cenomanian sediments which were preceded by limited volcanic activity of Aptian age [12] while the basaltic flow is less than 1km thick in the Ikom area [11]. The Ikom basalt is post Cretaceous in age, this was deduced from the age result obtained by [9]. The Ikom basalt is a Tertiary to Recent rock and it dominates the northwestern part of the Ikom – Mamfe basin embayment. The Ikom basalt is a dark coloured rock with well formed columns and defined polygonal faces and consists of both the colonnade and entablature.

3. Methodology

A technical approach was employed in the study of this basalt, the structural data were first collected before a general description was made. These structural data include:

- The number of sides of each polygon
- The length of each side of the polygon as shown in Fig. 2
- The length of the longest and shortest axes of each polygon
- The orientation of the longest and shortest axes of each polygon

Meanwhile at area of interest, the GPS co-ordinate, and elevation were collected as well as a general description. Joint data when available were measured and noted.

**Fig. 1.** Geologic and structural map of western Ikom – Mamfe basin, South Eastern Nigeria showing location of the basaltic flow (Modified after [10]).
4. Results

The Ikom basalt shows a well defined polygonal/columnar structure with a 20m thick entablature overlying a 3m thick colonnade (Fig. 3). The colonnade is a well defined columnar structure with vertical columns while the entablature is an irregular structure with less defined and inclined columns. In well exposed areas, the colonnade is usually “sandwiched” within the entablature. Well defined polygonal faces are also associated with the Ikom basalt. These polygonal columns are bounded by three (3) to eight (8) planar “Facet” fractures showing convex and concave cross fractures (Fig. 4). Most frequently the number of longitudinal bounding faces is between five (5) and six (6), with the preponderance of columns exhibiting five (5) faces. The longest side of the polygons is 0.75 m and the shortest side is 0.04 m while the longest axis is 0.55 m and the shortest axis is 0.13 m. This basalt is a dark coloured, fine-grained basic rock which exhibit a reddish brown-bluish colour when weathered. It was observed that the colonnade was far harder than the entablature and the surface of the entablature was somewhat coated with a shining material which may be due to mineralization or the occurrence of metallic minerals as at the time of its formation. Clayey sands and muds occur intermittently within the entablature, this made local quarrying of the entablature easy. They were also intensely jointed but these joints may not be of any tectonic origin because of the normal irregular nature of the entablature. It must be noted that the colonnade is far denser than the entablature.

Table 1. Modal composition of the colonnade and entablature.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Mineral</th>
<th>Modal composition (%)</th>
<th>Colonade</th>
<th>Entablature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plagioclase</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Pyroxene</td>
<td>30</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Olivine</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Pyrite</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Accessory minerals</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Fluid inclusion</td>
<td>5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Rock fragment</td>
<td>10</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

4.1. Thin Section Analysis

The Ikom basalt is a dark coloured, fine grained rock in which olivine phenocryst can be observed macroscopically. The thin section analyses showed that the colonnade and entablature have the same minerals but in different percentages (Table 1). Olivine is constant in both parts (Fig 5 a and b), while the shining surfaces of the entablature were justified by the presence of pyrite (Fig 5 b). Plagioclase was also constant in both rocks but there were more fluid inclusion in the entablature than in the colonnade (Fig 5 a and b).
4.2. Structural Analysis Data

A total of 125 polygons were studied and the structural data collected from the polygonal faces of the Ikom columnar basalt were recorded. The facet fractures, axial ratio, polygon axes and fracturing in this basalt were analysed.

4.2.1. Facet Fracture (Polygon Sides) Analysis

A histogram of polygonal column frequency versus longitudinal facet fractures was plotted for the 125 data points at the Ikom basalt (Fig. 6).

The histogram shows that the pentagonal (5-sided) polygons are the most frequently occurring in the Ikom basalt and also there is a gradual and continuous increase in the number of polygons as the faces increase (concave pattern) which peaked at 5-sided polygon and then a continuous decrease in the number of polygons as the faces increases (Fig 6). This pattern was also shown in the histogram plotted by [3] but their plot peaked at 6-faced polygons before the continuous decrease as the faces increased. It is observed that almost half the Ikom polygonal basalt is pentagonal (5-sided) and these make up about 47.2% of the entire distribution.

4.2.2. Axial Ratio Analysis

The axial ratios of 125 polygons measured at the Ikom columnar basalt were determined and a histogram of the axial ratio frequency against the axial ratio of the polygons was plotted (Fig 7). The axial ratio of each polygon was determined by dividing the length of the longest axis by the length of the shortest axis. It must be noted that a triangular polygon has no axis thus the axial ratio cannot be determined for such a polygon. The axial ratios of the polygonal faces of the Ikom polygonal basalts range between 1.03 – 2.60, with most of the polygons showing axial ratio between 1.1-1.4. These low axial ratios indicates that there was very little or no strain when the rocks were crystallizing, high strain condition would have produced polygons with high axial ratio.
4.2.3. Polygon Axis Analysis

[2] observed that some flows are broken into neatly fitting 6-sided prisms with equal sides and equal angles. He also said that such perfection are by no means the rule as 5 and 7 sided columns are common and 4 and 3 sided ones are by no means rare. Such neatly fitting prisms with equal sides and angles are those which would be thought to form in a stress free environment however this situation will be difficult to attain in natural setting because the basalt magma will probably continue to flow at least up to the time it crystallizes and the flow effect will most likely affect the side and angle relationship of the polygons such that even in a stress free environment, the angles and sides of the polygons may not be the same nevertheless, if the environment is under sufficient stress, the orientation of the long and short axes may be related to the direction of the maximum and minimum principal stresses. This necessitated the rose diagram plot as shown in Figs. 8 and 9. These plots were prepared to determine if there is any preferred orientation of the long or short axes, but from these plots, there is no preferred orientation of the long and short axes thus suggesting a little or no stress condition as at the time of formation of this basalt.
4.2.4. Fracture Analysis

Joints are linear or curvi-linear discontinuities in a rock. In the Ikom basalt, apart from the columnar joints which are not of any tectonic origin, other joints cutting across or terminating on the columns also occurred (Fig. 10a). These joints usually cut across the vertical columns but they usually do not cut through the polygonal faces and even when they did, it created a plane along which polygonal faces were formed. Sometimes these joints are so dense that they propagate through the lower colonnade into the upper entablature, although quarrying activity created joints, they did not propagate into the lower and denser colonnade. Ladder fractures are spectacular type of fracture which is usually associated with columnar basalts, these fractures are found in the Ikom basalt (Fig. 10b).

These ladder fractures are usually orthogonal to the facet surfaces on the outside of the column but are often convex or concave away from the edges of the column and are sometimes seen to have originated at or near an impurity or bleb in the basalt [3]. As regards the formation of columnar fractures, [3] suggested that there are different generations of fractures, initially tensile fractures probably of random orientation spread to interact and define a reasonably extensive block and as cooling proceeds, the block contained with the first generation of fractures eventually generates tensile stress of sufficient magnitude for fractures internal to the block to develop and because many of the fractures appear to form with random orientation, the number of
fractures which eventually bound a polygonal column of rock would be dictated by chance. They also said that soon after the polygonal fractures develop, they would be penetrated by ground or connate water and hydration reactions would occur at the surface of these fractures and also to some small distance into the column, these reactions would tend to cause expansion or at least slow down the shrinkage process of the relatively thick skin of the column thus the shrinkage may be reverse in the skin area but continues unimpaired in the interior, it is this differential shrinkage that [3] suggested gives rise to the formation of ladder fractures.

A total of 30 joint data were measured in the Ikom basalt and the rose diagram (Fig. 11) shows that there is a much preferred orientation of the joints in the Ikom basalt in the NE-SW direction. A dip diagram was constructed for joints in the Ikom basalt (Fig. 12). This diagram shows that the tectonic joints in the Ikom basalt are high angle (70-90°) which is typical of extension fractures [13, 14].

5. Discussion

Columnar basalts are very interesting geological features which occur in only a few regions around the world. The most extensive and well studied polygonal basalt is probably the Giant Causeway columnar basalt in the UK. In Nigeria, columnar basalts are not common but they have been reported to occur in Numan in Borno State [15], Bachit in Adamawa State, Gulani in Borno State [16], Gahwang/Yembe in Plateau State [17] as well as in Ikom (Cross River State; this work). All these polygonal basalt in Nigeria have been studied for geotourism purposes however this work analyses the Ikom columnar basalt to identify the dominant facet fractures and the strain conditions at the time of emplacement and crystallization of this basalt. The Ikom columnar basalt shows a distinct structural geometry with a colonnade which has a well defined polygonal faces and it is overlain by an entablature with irregular, usually inclined geometry (Fig 3). The petrology of both sections (colonnade and entablature) shows the dominance of plagioclase, pyroxene and olivine (Table 1) with the highly fractured entablature containing more fluid inclusion and the competent colonnade containing more olivine. The histogram of the polygonal faces plotted against their frequencies show that the pentagonal (5 – sided) polygons are dominant (Fig. 6) and the plot generally shows a concave pattern (Fig. 6). This concave pattern has been reported for the Giant Causeway columnar basalt in Ireland but there, the hexagonal (6 – sided) polygons are dominant [3]. Analysis of the axial ratios of the long and short axes of the polygons reveals low values ranging from 1.1 to 1.4 (Fig. 7). These low values probably represent a low strain or a strain free condition of emplacement and/or crystallization of the Ikom basalt. Though it is believed that polygonal basalt in a strain free environment would have equal sides and angles [3], in an ideal/natural setting, such situation is at best difficult to attain because the basalt magma will probably continue to flow at least up to the time it crystallizes and the flow effect will most likely affect the side and angle relationship of the polygons such that even in a stress free environment, the angles and sides of the polygons may not be the same. Analysis of the long and short axes of the Ikom polygonal basalt show that the axes are not preferentially oriented in any direction and this further buttress the point that this
basalt probably crystallized in a strain free environment. Fractures in the Ikom columnar basalt are high angled (Fig 12) and are oriented in the NE – SW direction (Fig 11). This orientation of fractures has not been identified by fracture studies in the Ikoma – Mamfe basin within which the Ikom columnar basalt is found [10], [14], thus they are most likely not related to any tectonic activity in this Tertiary – Recent basalt but may be associated with local stresses developed from overburden pressure long after the crystallization of the basalt. The Ikom columnar basalt also develops ladder (horizontal) fractures (Fig 10) and the general geometry of this basalt makes it a good geotourism site in Nigeria.

6. Conclusion

The Ikom columnar basalt, like other important columnar basalt around the world has well defined polygonal faces. These polygons show the dominance of pentagonal (5 – sided) and hexagonal (6 – sided) polygons with the preponderance of pentagonal (5 – sided) polygons. The low axial ratios and the non – preferential orientation of the long and short axes of the polygons strongly suggest a strain free or low strain condition of emplacement/crystallization of this basalt. The fractures in the basalt are high angled and oriented in the NE – SW direction which is not related to known tectonics of the Ikom – Mamfe basin thus they probably developed from local processes related to overburden pressure. The overall geometry and exposure of the Ikom columnar basalt makes it a relevant site for geotourism.

References