Research article

STATISTICAL STUDY OF ALIGNMENTS OF VOLCANIC AND SUB-VOLCANIC BASIC ROCKS IN HAWAL BASEMENT COMPLEX, NORTHEAST NIGERIA

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ABSTRACT

This work utilizes the nearest neighbour statistical approach to examine the distribution of basic rocks within Hawal Basement Complex, a terrain of dominantly metamorphic and igneous rocks. The data sources used are geological and aeromagnetic maps. The technique compares characteristics of observed set of distances between pairs of nearest points with those that would be expected should the points be placed randomly. The results from 51 bodies over three blocks of the study area give indices between 1.5- 2.0, which are indications of regularity/alignments of the basic bodies. In the alignments 29% follow N-S direction, 53% NW-SE and 16% NE-SW, while 2% forms a conjugate relationship in a WNW-ESW/ENE-WSW in the Yola Basin. The alignments correlate with major river courses/foliation trends in the Basement Complex. This work makes it possible to appreciate tectonic trends and control of emplacements of the magmatic bodies which are not easily discernable on published aeromagnetic or geological maps. The mineralization significance of results of this work is presented. The nearest neighbour statistical technique can be applied in the country in exploration, especially for directionally occurring bodies.

Key words: volcanic, tectonic, magnetic anomalies, foliation, Pan-African deformation, mineralization.

INTRODUCTION

The Hawal massif is the northeast segment of the Nigerian crystalline Basement Complex. The study area is located within longitudes $12^0 00^/$ and $13^0 30^/$ E, and latitude $9^0 30^/$ and $11^0 00^/$N (Fig. 1). It is bounded westward and southwards by the two arms of the Cretaceous Benue Rift, namely Gongola and Yola Basins respectively. Northwards it is bounded by the Chad Quartenary Basin. The area is drained by rivers such as Hawal, Yedseram, Song, Kilange etc. The Biu Plateau is located NW and has an average height of about 700 m above sea level. The River Benue drains the southern part of the area.

Bassey et al. (2012) presented a brief account of the geology of the Hawal Basement Complex. The earliest formed crustal materials observed in the area are mafic xenoliths or amphibolites fragments in gneisses and migmatites of probably Proterozoic age (Dada, 1998). The gneisses and migmatites are the most widespread rocks and often occupy the low elevation areas. These metamorphic rocks are marked by NW-SE folds, foliation, shear zones and faults. Intrusive to them are granitoids of the Pan African orogeny (700 $\pm$ 150 Ma). The Pan African deformational direction is mainly NE-SW and N-S. The Pan African deformation affected already existing metamorphic rocks producing polyphase deformations e.g pre-existing folds were refolded along NE-SW and N-S directions in places producing axial planar foliation. The Cretaceous witnessed the formation of the sedimentary basins which are infilled with clastic and argillaceous sediments. Mesozoic and Cenozoic magmatism saw the emplacement of basaltic bodies, with the main outcrops at Biu, Song and Michika areas (Fig.1). The major structural directions in the study area are NW-SE, NE-SW, and N-S. E-W structures are relatively few.

In about the last two decades a number of geological works have been done and published over the Hawal Basement area. These have covered petrology, structure and tectonophysics of the area. Islam et al.(1989), worked on the geology of the northern Mandara hills, Islam and Baba (1992) studied the geochemistry of the Older granite of the northern Mandara hills. The study areas of these researches however lies beyond the northern limit of the present work. Bassey (2006) wrote a doctoral thesis on structural geology of the Hawal massif. Bassey et al. (2006) did a LANSAT study of the northeast basement region and northern Cameroun. Baba (2008) wrote a doctoral thesis on the geology of Madagali area. The coverage also lies beyond the area of present work but is contiguous to it. Bassey et al (2012) analysed aeromagnetic map of the Hawal area with emphasis on lineament detection. Beside the above there are other works on areas of the Hawal basement complex that have been published in literature. These researches have helped to unveil many things on

the geology of the Hawal Basement terrain hitherto unknown. Benkhelil (1982, 1986) studied the alignment of volcanic rocks in the upper Benue trough. His work extended to the marginal zones of the Hawal Basement Complex.

The present work attempts to use a statistical approach namely the "Nearest Neighbour Analysis" (NNA) technique to investigate the extent of alignments of volcanic and sub-volcanic basic bodies within the Hawal Basement Complex. The method appears to be novel in this exercise particularly in the study area. The tectonic significance of the result of this study is explained. The study is an offshoot of the aforementioned doctoral thesis which has since been submitted and approved by the relevant institution in Nigeria. Similar studies were done by Von Veh and Németh (2009) on alignments of volcanic vents in Auckland, New Zealand, and also by Roberts et al. (2011) on mud volcano vents in Azerbaijan and Lusi, East Java.

METHODOLOGY

The present work makes used of aeromagnetic maps over the study area (sheets 133, 134, 135, 154, 155, 156, 175, and 176) as published by Nigerian Geological Survey (NGSA) as ½ degree sheets on a scale of 1:100,000. The maps are published as total intensity magnetic field, and regional correction was based as IGRF epoch date of 1st Jan 1994. The individual maps were photo-reduced at the same scale and a mosaic of the maps was produced and used in this study (Fig. 2). A work flow of the methodology is presented in Fig. 3.

On examination of the aeromagnetic anomaly maps (on scale of 1:100,000) of the study area, there are areas of anomalies of very high amplitudes, namely 32,900 to 33,050 gammas against a general background of about 32800 gammas . On comparison with the geological map (Fig. 1) some of these high amplitude anomalies coincide with the mapped basaltic rocks such as in Biu-Meringa area, Song and Michika areas. Other anomalies of the given range do not have correspondence on the geologic map. The former are named volcanic bodies, while the latter group are termed in this study as unmapped or sub-volcanic basic bodies. Sub-volcanic in the sense that there may be volcanic basic rock but unexposed.

The centres of these anomalies were marked out as circles on a transparency superimposed on the aeromagnetic mosaic map (Fig.2). The solid circles represent the mapped volcanic bodies (basalts) and the open circles represent the inferred volcanic or sub-volcanic bodies. A total of 51 of such centres were mapped and presented in Fig. 4.

The NNA method is utilized to analyse geo-spatial data to see alignment or randomness of such data. A good introduction to the technique is given by Getis and Boots (1978). Ripley (1981) provides a review of theory and application in various fields, as do Cliff and Ord (1981). Shaw and Wheeler (1994) and Bailey and Gatrell (1995) discuss computational aspects of the NNA. NNA compares characteristics of the observed set of distances between pairs of points with those that would be expected if the points were randomly placed. A summary of the mathematical theory and formulae are reviewed here.

The characteristics of a theoretical random pattern can be derived from the poisson distribution. If we ignore the effect of edges of our map the expected mean distance between nearest neighbour is

$$D_e = \frac{1}{2} \frac{\sqrt{A}}{N} \quad \text{……………………… (1)}$$

Where A=area of space containing the distribution,

and N=number of points

The density of points P is given as

$$P = \frac{N}{A} \quad \text{…………………………… (2)}$$

i.e. $\frac{No.\,of\,points}{Area}$, which is number of points per unit area.

The expected mean in a random distribution is calculated as

$$\frac{1}{2} \frac{\sqrt{N}}{A} \quad \text{……………………… (3)}$$

The expected mean is compared to the observed mean to give the nearest neighbour index R_n

$$R_n = \frac{Observed\ mean}{Expected\ mean} \quad \text{……… (4)}$$

In the present context we are dealing with observed mean distance (D_m) and expected mean distance (D_e)

Therefore $R_n = \frac{Dm}{De}$ ……... (5)

Where Dm = Observed mean distance in area under consideration and D_e = Expected mean distance.

$$D_e = \frac{1}{2\sqrt{p}} \quad \text{………………… (6)}$$

$$R_n = 2D_m \frac{\sqrt{N}}{A} \quad \ldots\ldots\ldots\ldots. \ (7)$$

R_n is the nearest neighbour index

More details of the technique can be found in Davis (2002).

From equation (7) above the figure arrived at is marched on the R_n scale of the nearest neighbour statistics. The scale is represented here (Fig. 5) in linear form.

In the present work the study area was divided into blocks a, b and c (Fig. 6). These divisions were based on the spatial concentration of the mapped volcanic and sub-volcanic centres, as some areas especially the north sector has no mapped volcanic/sub-volcanic centre. The area of each block is calculated using the scale of the map. Next the distance between the nearest pairs of centres (which were numbered) is measured to all centres in each block using the scale of the map to express the distance. See Fig.7 for explanation.

Then the mean distance for each block is computed viz:

$$D_m = \frac{sum\ of\ total\ distance\ measured}{the\ No.of\ centres\ in\ the\ block}$$

R_n for each block was computed using equation 7 and the result is shown in Table 1.

DISCUSSION

From the Table block a with R_n of 1.7 shows that the volcanic/sub-volcanic bodies approach a regular distribution (Fig.5). Benkhelil (1986) said that the lower Gongola Basin is guided by N-S trending faults which are well displayed in the Cretaceous sediments. He also posited that on the Biu Plateau the alignment of Quarternery volcanoes is in the N-S direction (see: Fig 6) in an area east of the Gongola River with great density of N-S normal faults. The Gongola River flows N-S (Fig.1).

In block b with an R_n of 1.5 the distribution is approaches a regular distribution. The volcanic bodies especially in Song area align along a N130 -150°. This was presented by Benkhelil (1982, 1986). This direction corresponds to a major deformational trend in the basement rocks manifesting as shear zones, faults and foliation. (Bassey 2006a, Bassey & Valdon 2011). River Song on the geological map Fig.1 flows in the NW-SE direction indicating tectonic control

In block c an R_n of 2 fits into a regular distribution. The volcanic bodies align in the N-S direction (see eastern part of Geological map-Fig. 1) which is a major tectonic direction that controls the flow of R. Yedseram

for about 80 km. This river is controlled by basement structure (Bassey et al., 2012). The N-S direction is the general direction of foliation and folding in the basement complex (Umeji 1991). Between Michika and Uba there is NE-SW alignment of eight sub-volcanic bodies along $N40^o$ (Fig.6). This is referred to in this study as the Uba trend, which was earlier recognized by Bassey (2006b). The author recognized other magmatic bodies (granitoids) occurring as hills aligned in the same direction consistent with the axes of majority of folds in the metamorphic complex in Uba area.

In the alignments in the three blocks, 29% follow N-S direction, 53% NW-SE and 16% NE-SW, while 2% forms a conjugate relationship in a WNW-ESW/ENE-WSW in the southern Yola Basin.

The mapped basic bodies belong to the newer basalt series (Geol. map of Nigeria 1994) of Tertiary to Quartenary age.

The R_n values for blocks a and c of 1.70 and 2.00 respectively fit into a regular distribution along a N-S direction. This indicates that the N-S direction is a major tectonic direction in the Hawal basement. This is a feature of Pan African orogenic belt that extends from Moroco in North Africa to West Africa (Ball and Calby1984). The N-S tectonic direction of block a can be considered as the Gongola trend while that of block c is the Yedseram trend. In the central block the NW emplacement trend of basic bodies can be considered as the River Song trend. Along this river course and beyond in Song town the basalt is exposed.

South of Shelleng and Song two alignments may be inferred along NW ($N100 -130^O$) and NE ($N70^O$), They form conjugate relationship (Fig.6).These alignments correlate with the two lineament directions found south of Shelleng and Song respectively in the Yola Basin (Fig.1).

The basalts of Biu Plateau results from superimposition of several lava flows, and rest unformably on the pan-African basement (Guiruad, 1989). Radiometric ages are Cenozoic and range from 7 Ma to 1 Ma (Grant et al., 1992).The basalts of lower Gongola area (Shani area) consist of transitional alkaline basaltic flows and have been given a Mesozioc age: 146 Ma $\pm$ 7.3 < ages, < 127 Ma $\pm$ 6.The Song basalt are also assigned the Tertiary age.

The basalts of the eastern sector seem not to have been dated precisely yet. Contiguous to the area (Mandara mountains) but in Cameroon Republic, Fitton (1987) studied and named the basalt there as alkali basalts, they are basalts of the Cameroun Volcanic Line. While Fitton & Dunlop (1985) gave ages of 30 and 33

Ma for basalt of the same area. These ages may apply to basalts of the eastern part of the study area (Michika-Mubi area). They are basalts of Cameroun Volcanic Line also.

The alignment of the volcanic rocks along pan-African deformational directions may have implications for mineral exploration. This is because the zones of alignments may serve as avenues of invasion by mineralizing fluids and subsequent deposition of minerals. The government of Adamawa state in 2004 had published a catalogue of minerals in the state. Among the minerals found are iron ore, cassiterite, manganese, uranium, trona, and magnesite. Precious stones published include garnet, aquamarine, amethyst, topaz and spinel. However the investigations of the occurrences of these minerals are still at infancy. Such investigations should consider the deformational /alignment zones identified in this study as targets.

CONCLUSION

The nearest neighbour analytical technique of geospatial data as applied in this study has enabled us appreciate the alignments of basic rocks in Hawal Basement Complex. This was not obvious initially except for the western sector of Biu-Shelleng area. The result of this study shows or gives additional evidence that there is tectonic control on the emplacements of the basic rocks. Their emplacements utilized pre-existing fractures or lineaments in the Pre-Cambrian basement Complex and are in close relationship with major river courses such as the Gongola, Song and Yedseram rivers. The alignment zones may serve as avenues of mineralization.

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Table 1: R_n values for the study area.

Block	A:area (km^2)	N:no. of centres	Dm	R_n
a	3600	10	16	1.7
b	6000	26	11.2	1.5
c	2760	15	13.5	2

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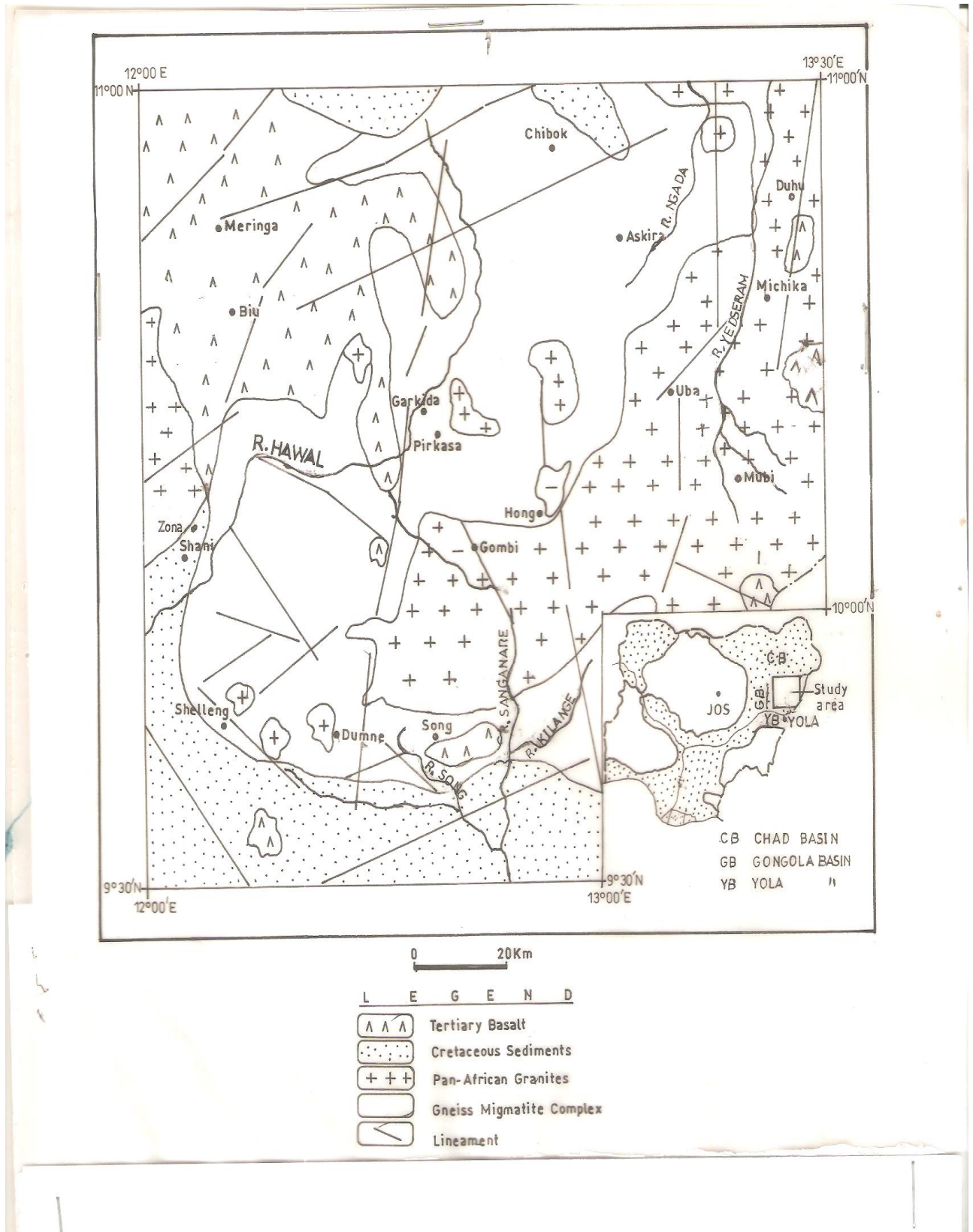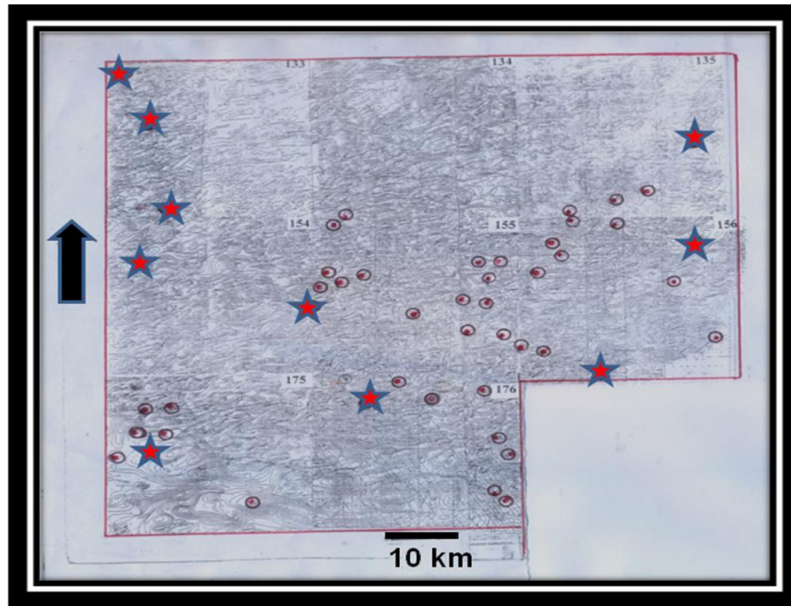7. Sketch of typical distribution of centres for NNA.

Figure 1: Geological map of study area. Inset Nigeria simplified geologic map.

Volcanic and subvolcanic centres in study area.

Figure 2: Volcanic centres (stars) and sub-volcanic centres (dotted circles) in study   area.
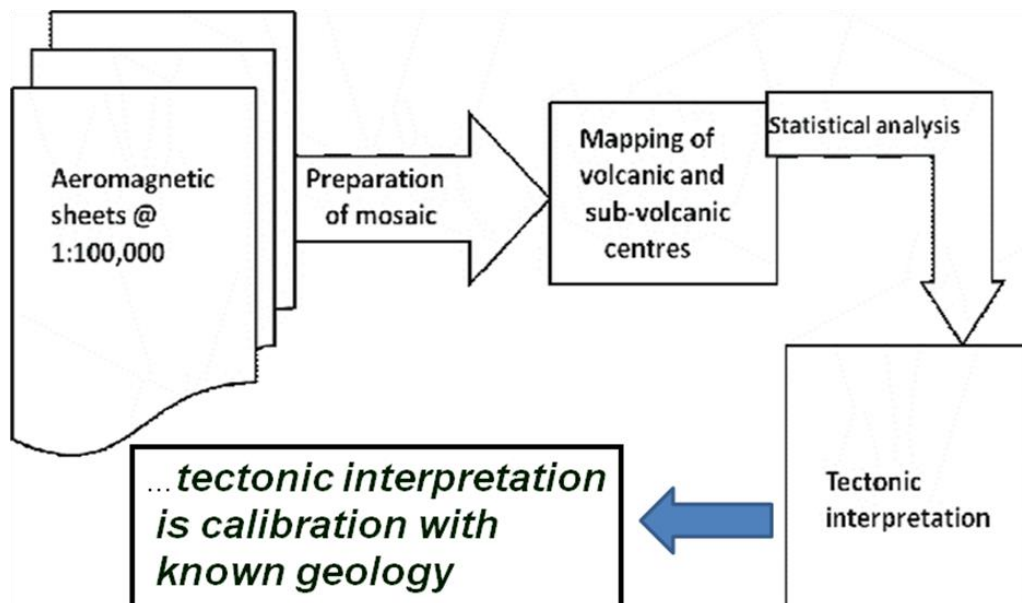
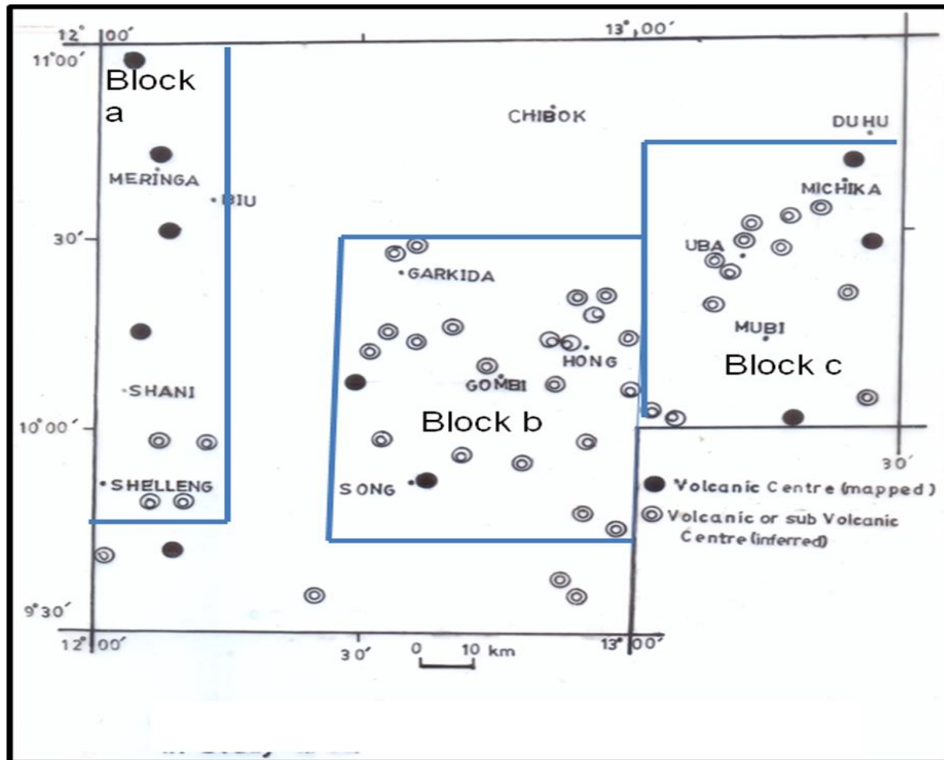

Figure 3: Work flow chart.

Figure 4: Map of volcanic and subvolcanic centres divided in to blocks.Light circles :sub-volcanic centres, dark circles :volcanic centres.

Figure 5: Linear scale of Nearest neighbour statistics (from Rossbacker,1986)
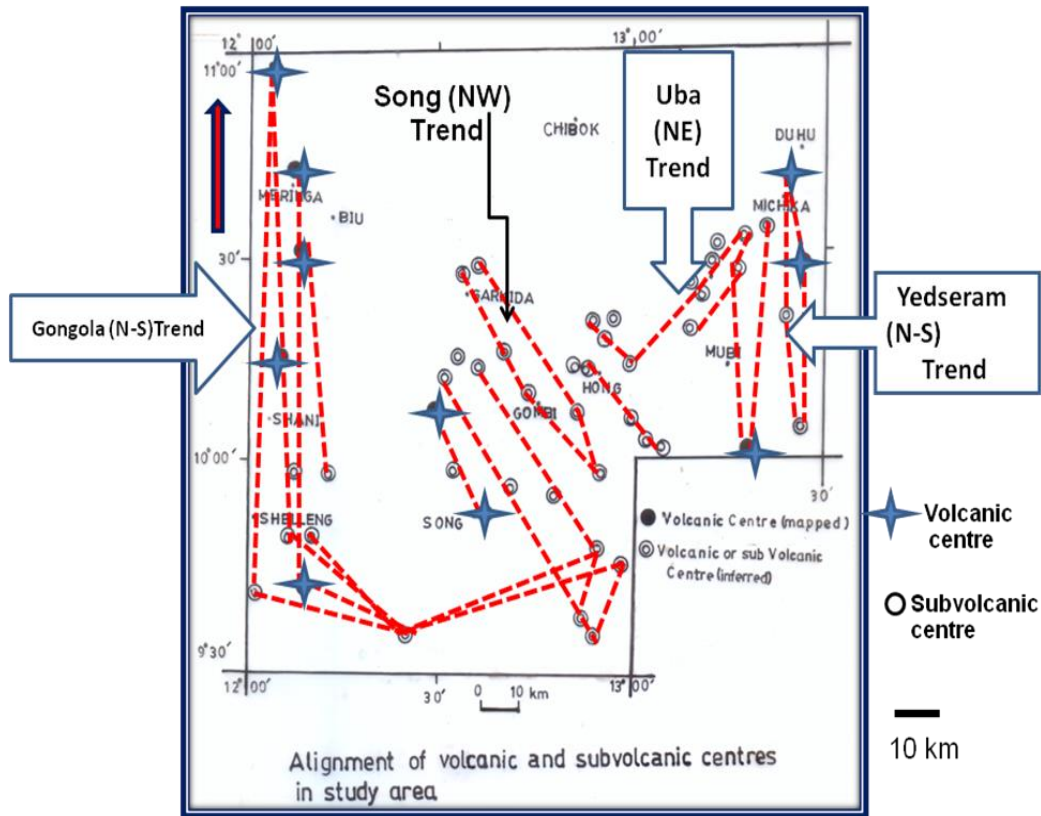
Figure 6: Map of alignment of volcanic and sub-volcanic centres based on R_n results.
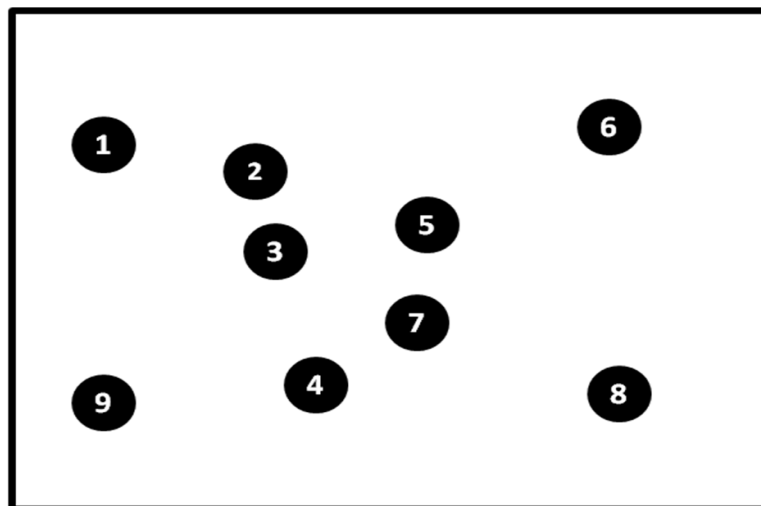

Figure7: Example of distribution of data for nearest neighbour analysis. The distance between any two closest neighbours is measured. Note: that a point may have a closer neighbour which may not be serial to it.