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Strain Conditions Indicated by Metamorphic Spots in the Igarra Schist Belt, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author EU wrote the first draft of the manuscript and analyzed the data. Author MIO designed the study and appraised data quality. Author EEU checked the protocol of the study and checked the grammar and language. Author EOI managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Strain has been analyzed from the metamorphic spots within deformed schist and phyllite in the Igarra schist belt, southwestern Nigeria. Strain magnitudes were obtained by using the graph of length against width of spots, Harmonic mean (H), and the $R_f/ø$ technique. The values of strain range from 1.95 – 2.99. The standard deviation of 0.4419 shows that the mean value of R_f is reliable. The direction of maximum elongation (λ_1) during the deformation is approximately parallel to the NW – SE direction. The difference between the direction of maximum elongation of the spots (NW – SE) and that of the phenocryst in granite (N – S) shows that there was a change of the maximum elongation (λ_1) axis during progressive deformation in this area which could be either as a result of a change in the regional tectonic axis of deformation or could be provoked by intrusion already having magmatic fabric at an angle to regional deformation. Thus, it is safe to suggest that during progressive deformation, there was either a rapid transition from the older NW – SE λ_1 direction in the schist/phyllite to the younger N – S λ_1 direction in

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the granite or the granite plutons crystalized at a remarkable slow rate to allow for a gradual transition of the maximum elongation axis. This work aims to discuss the deformation condition in the study area using metamorphic spots and buttress the deformation heterogeneity in the Igarra schist belt.

Keywords: Metamorphic spots; strain markers; Igarra; schist; phyllite.

1. INTRODUCTION

The analysis of the changes in the length of lines and/or angles between intersecting lines in deformed rocks gives the state of strain, a process which is known as strain analysis. Numerous methods can be used for strain analysis, however this study focuses on the determination of strain using objects that had initially elliptical, sub-elliptical, circular or sub-circular shapes and these objects are called strain markers. The basic technique of strain analysis for these markers involves calculation of the elliptical shape (R_f) and orientation (Ø) from the data collected from the field [1].

Metamorphic or reduction spots have been used for strain analysis in different regions of the world. In the Pyrenean Redbeds (“Col du Somport” area, France), reduction spots were analysed to investigate the possibility and limitations of palaeomagnetic works within strained regions [2]. [3] used metamorphic spots in northern Kyushu, Japan, to estimate the magnitude of strain. Strain analysis using ellipsoidal strain markers (clasts, xenoliths, porphyroclasts, phenocrysts, pebbles, microgranular enclaves, pressure shadows, mafic clots, among others) have been used to elucidate the deformation history, strain conditions, magmatic strains and pressure solution processes of different regions around the world [4–10].

In Nigeria, the concept of strain analysis has only recently received attention. [11] analysed bulk strain in the gneisses of parts of central Nigeria and got strain magnitude values between 1.6 and 3.8. [9,12–13] analysed 2D strain in the pan – African granitoids (600 ± 150) of southeastern, southwestern and northwestern Nigeria and got strain magnitude between 1.58 and 2.66 with a N – S direction of maximum elongation (λ_1). These works tentatively suggest that in Nigeria, the magnitude of strain in Pan - African granitoids seems to decrease from northern to southern with a consistent N – S λ_1 direction. The polymictic metaconglomerates in the Igarra schist belt, southwestern Nigeria have been studied by [14]. Their work suggests a transpressional deformation with a possible strain gradient.

The southern Igarra schist belt contains a wide variety of rocks within a relatively small area. These rocks include metasediments such as schists, phyllites, quartzites, marbles, metaconglomerates, calc-silicate and other rocks like granite-gneisses and prophyroblastic gneiss (Fig. 1) which have been intruded by the Pan-African syn-tectonic granites as well as late stage dykes of syenite, lamprophyre and pegmatite (Fig. 1). The metasedimentary schists are by far the most extensive rocks in this region. They are composed of upper greenschist facies metapellite with interlayered quartzite, marbles and metaconglomerates [15]. The metasediments (schists (pellitic and psammitic), marbles, quartzite, metaconglomerates) occur as a supracrustal cover on the older migmatites [16–20].

This works analysed the strain conditions (strain magnitude and direction of maximum elongation) tracked by the metamorphic spots which correlates to the deformation history during or shortly after the emplacement of the Pan – African granites because these spots formed from contact metamorphism between the granite and the schist/phyllite. A comparison of the results in this work with those of previous works on the granites of this region revealed the nature of progressive strain in this region.

2. MATERIALS AND METHODS

This work involves the detailed study of the schists and phyllites in the Igarra schist belt, southwestern Nigeria with particular reference to the straining of the metamorphic spots which developed as a result of contact metamorphism between the intruding Older granites and the schist [20–22].

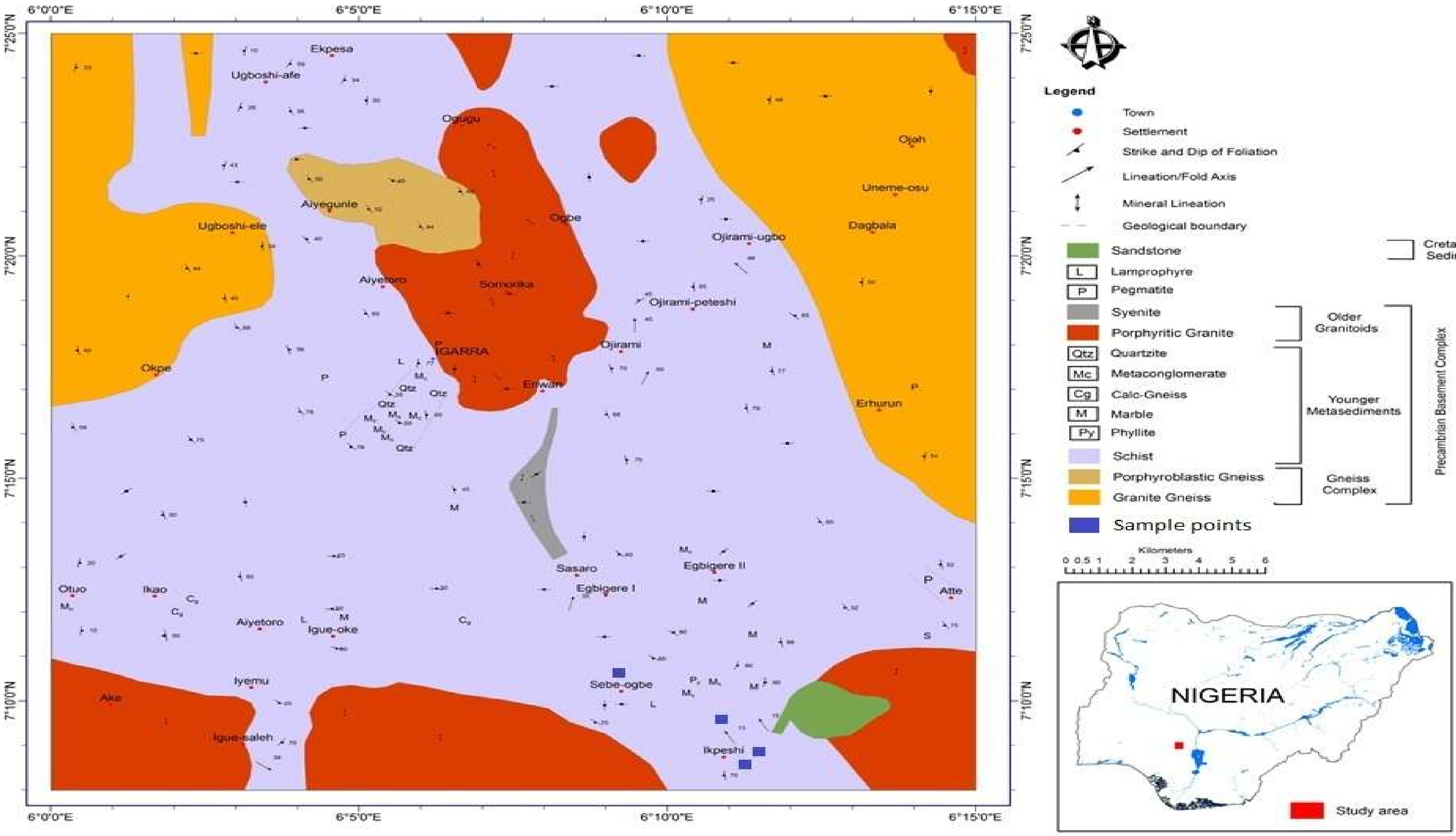

Fig. 1. Geologic map of the study area (Adapted from [20])

The length, width, and orientation of the long axes of the strain markers (spots) were measured in the field from the horizontal surface as well as the schistosity surface of the rock and the parameter R_f (R_{factor}) was computed using equations from [1] as shown below:

$$R_f = \frac{(1+e_1)}{(1+e_3)} \quad (1)$$

Where

$1+e_1$ represent length of long axis of the strain markers and

$1+e_3$ represent length of short axis of the strain markers.

Ø angle was also determined by measuring the angle between the long axis of the strain marker and an arbitrary reference line as explained in [1]. The arbitrary reference line for this work was fixed at 90° from the north.

The techniques used for strain analysis include

(1) A graph of length against width of the spots was plotted and the slope of the best fit line passing through the origin of the plot is a rough estimate of the strain magnitude.
(2) The Harmonic (H) mean was calculated using the following formulae:

$$H = \frac{n}{\sum 1/R_f} \quad (2)$$

Arithmetic ($\bar{R}$) and Geometric (G) means are also estimates of strain magnitude but the Harmonic mean (H) value is usually closest to the true strain value [23] thus only the H value was used for interpretation.

The standard deviation (SD) of the data was also computed to determine the reliability of the Harmonic mean value. This was done using the formula:

$$SD = \sqrt{\Sigma} (R_f - \bar{R}_f) / n \quad (3)$$

Where

R_f is the axial ratio of each strain marker (spot)

$\bar{R}_f$ is the mean of the axial ratios of all data point and

n is the number of data used.

(3) A graph of R_f on the ordinate and Ø on the abscissa was also plotted to derive the strain magnitude as well as the orientation of the long axis of the strain ellipsoid.

3. RESULTS

The schist and phyllite outcropping towards the south of Igarra contain metamorphic spots with oval to circular spots as a result of contact metamorphism between the schist/phyllite and the granites (Figs. 2 and 3). The spots are considered to be composed of mainly quartz and muscovite and in some cases they form porphyroblasts of cordierite and andalusite [21]. They either form circular to elliptical marks on the schist surface (Fig. 2a), occurs as small lumps which are probably more resistant to weathering than the host rock (Fig. 2b) or occurs as tiny holes on phyllite (Fig. 3a) thereby giving the rock a pitted surface. Their dimensions vary sharply with lengths ranging from 0.5 cm to 1.9 cm, width between 0.3 cm and 0.7 cm and the R_f ranges from 1.33 to 3.8. The spots occur in two major locations in the study area which is along the Sebe-Ogbe area (one outcrop studied) and around the Ikpeshi region (three outcrops studied). These spots are usually concentrated along foliation surfaces in the schist and phyllite but are also found on any horizontal outcropping surface. At first glance, it would seem that the spots are randomly oriented and this is because most of them have a roughly circular shape but upon closer examination of 81 spots which are clearly elliptical, we observed that most of their long axes are strongly oriented in the NW-SE direction (Fig. 3b).

3.1 Graph of Length against Width of Spots in Phylitte and Schist

Strain analysis is usually a time consuming study however there are simple and quick methods which gives rough estimate of the strain magnidude of the deformation that strained the marker. One of the simplest techniques of strain analysis is by plotting a graph with the length of the major axis of the strain marker as ordinate and the length of the minor axis (width) as abscissa, a line passing through the origin has an equation whose slope is an estimate of the average strain ratio (Fig. 4). The graph of length against width of the metamorphic spots (Fig. 4) shows that the estimated strain intensity from this method is 1.98.

3.2 Harmonic (H) Mean

The elliptical metamorphic spots (Fig. 3b) are basically oriented in the NW-SE direction with a fluctuation of less than 60°. The H values are given below.

$$H = 1.95$$

The SD value of 0.4419 shows that the Harmonic mean is reliable and there is very little volatility in the data set.

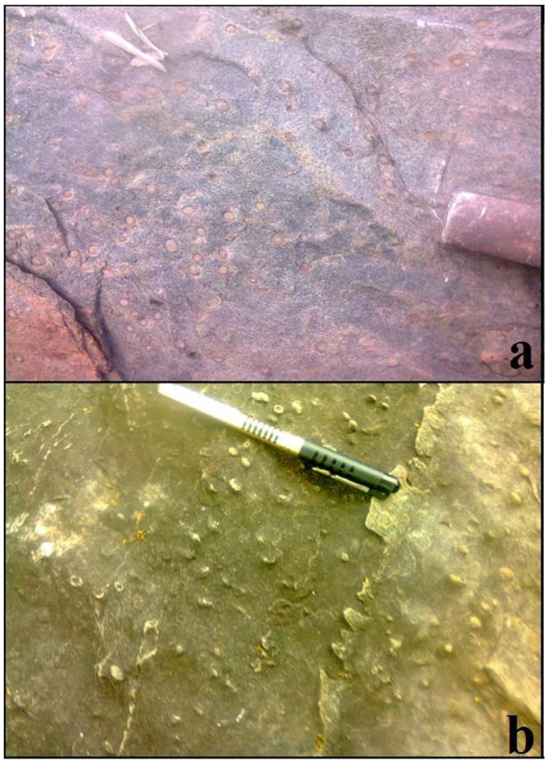

Fig. 2. Metamorphic spots in schist and phyllite. (a) Circular to oval metamorphic spot in schist at Ikpeshi (b) Metamorphic spots occurring as small lumps on the rock surface at Sebe – Ogbe

3.3 R_f / Ø Plot of Spots from Schist and Phyllite

The R_f/Ø plot (Fig. 5) of metamorphic spots shows that these spots are restricted in orientation with a fluctuation of about 55°. Their distribution is symmetrical about the long axis of the strain ellipse (Fig. 5) thus $R_s > R_i$ and the following equations can be used to derive the strain parameters.

$$R_s = (R_{f\,max} \times R_{f\,min})^{½} \quad (4)$$

$$R_i = (R_{f\,max} / R_{f\,min})^{½} \quad (5)$$

From Fig. 5, we have

$$R_{f\,max} = 3$$
$$R_{f\,min} = 1.33$$
$$Orn = -60°$$

Therefore, substituting into equation (4) and (5), we have

$$R_s = 2.99$$
$$R_i = 1.5$$

The λ_1 value from the "orn" is given as "Orn" = - 60°.

Therefore,

$$\lambda_1 = 90 – (- 60) = 150°$$

This value places the direction of maximum elongation (λ_1) in the NW-SE direction. This direction is quite different from the direction of maximum elongation (λ_1) derived from phenocrysts in the Igarra and Zaria granites which showed a N – S direction of λ_1 [9,13].

4. DISCUSSION

The schist/phyllites in the Southern Igarra schist belt contain metamorphic spots which were used to analyse the strain condition. Considering the fact that these spots formed by contact metamorphism between the schist/phyllite and the intruding granite, the deformation tracked by the spots were probably those active during or shortly after the emplacement of the granites thus the strain measured by these spots is Pan – African. The granites contain its own strain markers (phenocrysts) and they will be best applicable in determining the strain conditions after magma crystallization however, the spots may record strain conditions between magma emplacement and crystallization. The spots are sometimes circular but many are elliptical. The long axes of the elliptical spots are strongly oriented in the NW – SE direction. Strain analysis was done using various techniques. The graph of length against width obtained a strain value of 1.98, the Harmonic mean (H) of R_f which is considered as a useful indication of R_s when a quickly derivable estimate is required or when information about individual marker orientation is lacking [23] gave a value of 1.95 (with a SD of 0.4419) and the R_f/ø technique obtained a strain value of 2.99. The strain values here agrees with the observation of [20] who studied the strain condition in different rocks of the southern Igarra schist belt using different markers and techniques and concluded that the strain value in this region falls within 1.5 and 3.0. The $R_f/ø$ technique showed that the direction of maximum elongation (λ_1) during the deformation is in the NW – SE direction, this explains why the spots are preferentially oriented in this direction. Strain analysis in the granite of this region using the same technique [13,20] have showed that the spots are subjected to a higher strain and the λ_1 direction is N – S. This implies that the deformation here is different from those that affected the granite and because the granite intruded the schist [20], the schist is certainly older than the granite thus the NW – SE λ_1 direction most likely represents an older episode of deformation which gave way for a new λ_1 direction at about the time, shortly after and certainly before the strain markers in the granite (phenocryst and xenolith) began to acquire strain thus during progressive deformation, there was either a rapid transition from the older NW – SE λ_1 direction in the schist to the younger N – S λ_1 direction in the granite or the granite plutons crystalized at a remarkable slow rate to allow for a gradual transition.

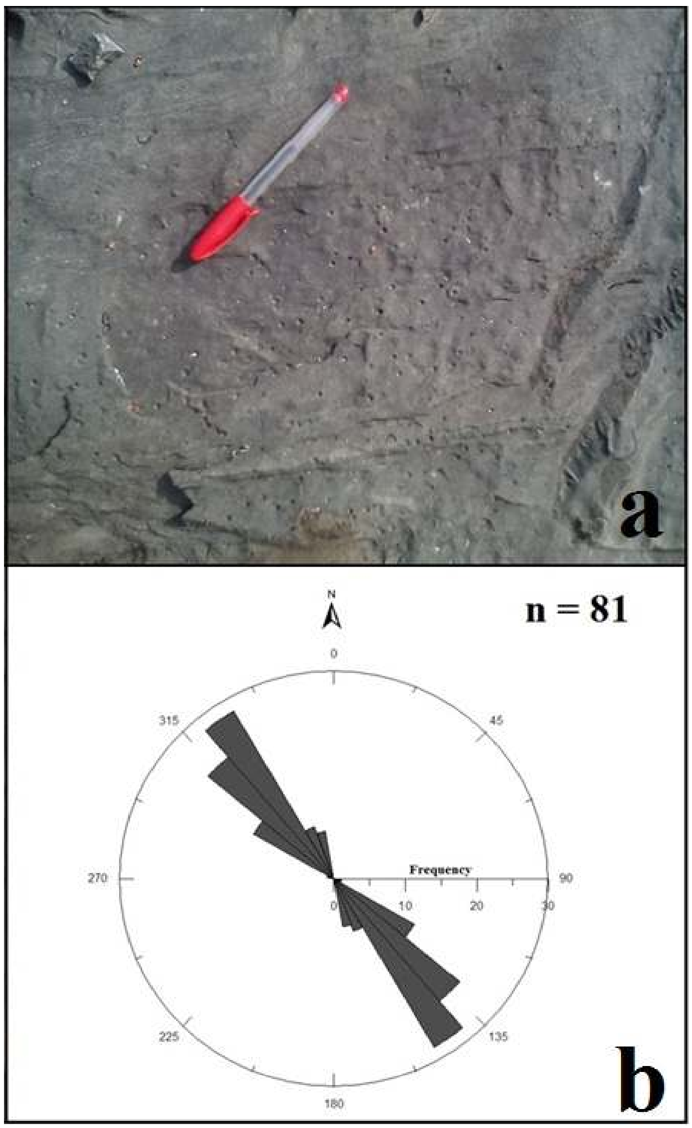

Fig. 3. Metamorphic spots in schist and phyllite and a rose diagram showing the spots preferred orientation (a) Metamorphic spots giving the rock a pitted surface at Ikpeshi (b) Rose diagram of the long axes of the metamorphic spot

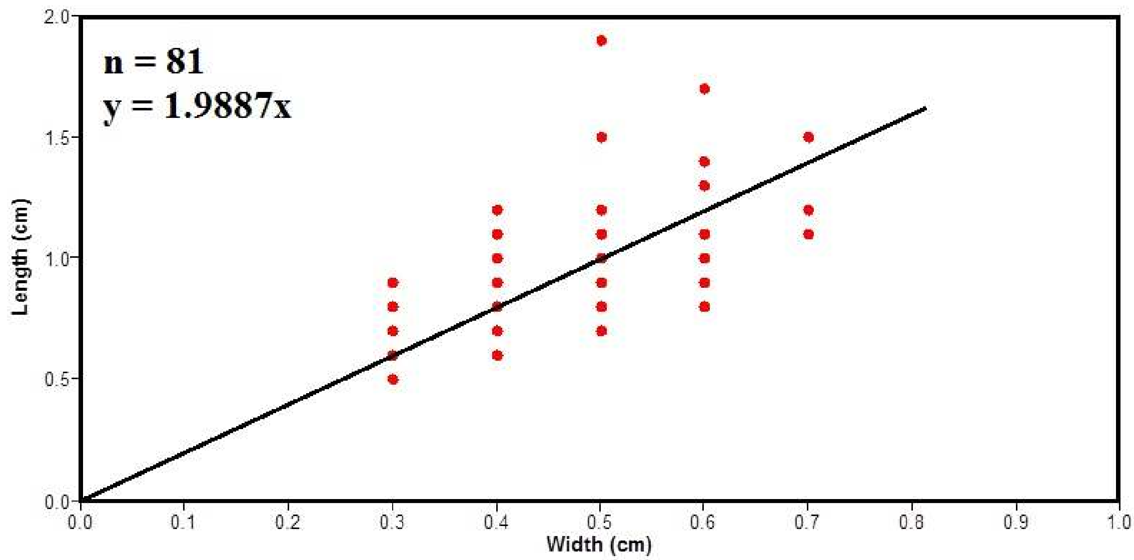

Fig. 4. Graph of length (1+e_1) against width (1+e_3) of metamorphic spots in phyllite and schist

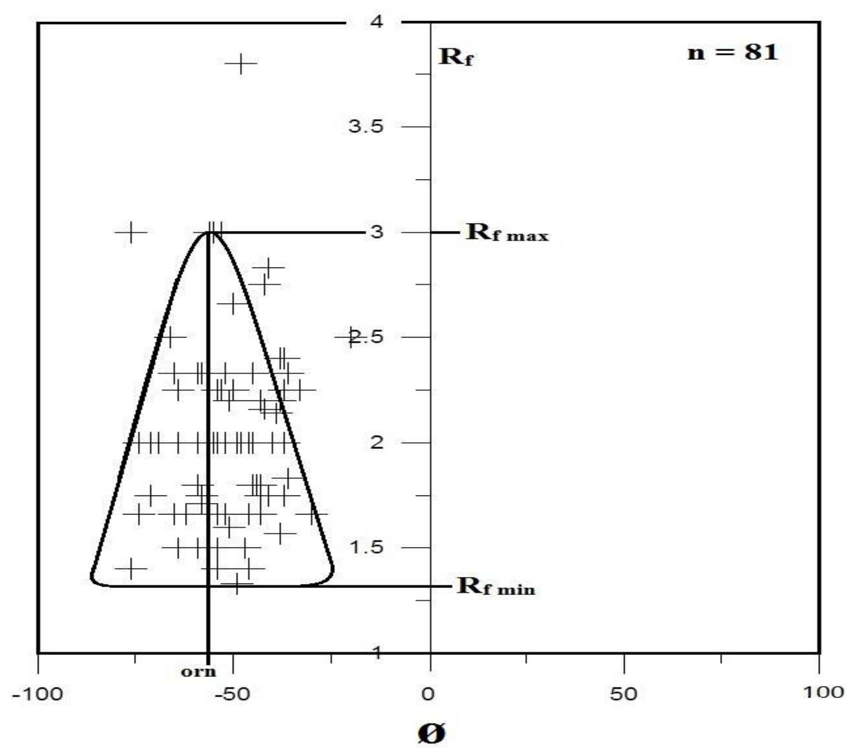

Fig. 5. R_f/Ø plot of metamorphic spots in schist and phyllite

5. CONCLUSION

Metamorphic spots in the schist/phyllite recorded the strain conditions obtainable during or shortly after the granite emplacement. The long axes of the elliptical spots in the Igarra region are oriented in the NW – SE direction which is also the direction of maximum elongation obtained from the R_f/ø technique. Strain values range from 1.95 to 2.99 and the strain condition from individual marker is heterogeneous and varies widely within this range. The difference between the direction of maximum elongation of the spots (NW – SE) and that of the phenocryst in granite (N – S) (see [13]) shows that there was a change of the maximum elongation (λ_1) axis at about the time, shortly after and certainly before the strain markers in the granite (phenocryst and xenolith) began to acquire strain. Thus, it is safe to suggest that during progressive deformation, there was either a rapid transition from the older NW – SE λ_1 direction in the schist/phyllite to the younger N – S λ_1 direction in the granite or the granite plutons crystalized at a remarkable slow rate to allow for a gradual transition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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