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Research Paper

Strain analysis of intraformational conglomerates of Shillong basin of Meghalaya, NE India

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ABSTRACT: *In the present work a simple algebraic method is applied to estimate the strain analysis of the intraformational conglomerates of the Shillong basin considering the deformed pebble as strain markers on plane section. The strain ratios are also estimated by following the Fry and R_f/ϕ methods of strain analysis. The strain ratios calculated from the algebraic method is in accordance with the results computed from Fry and R_f/ϕ method. The Mawpen and Naumile conglomerates show general prolate type of deformation while Elephanta conglomerate is characterized by general oblate type of deformation. Majority of the strain data in the flattening field for Elephanta and Smit conglomerates hints foliation dominated fabrics ($L < S$). On the other hand, plots for the Naumile and Mawpen conglomerates fall in the constriction field indicating dominance of linear fabrics ($S < L$) .*

KEY WORDS: *Conglomerates, Shillong Group, Strain, Shape matrix*

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I. INTRODUCTION

It is widely accepted that strain analysis quantifying the changes in shape and size due to deformation involves determination of the (1) strain orientation, (2) strain magnitude, and (3) patterns of strain variation. Geological strain analysis in conglomerates using stretched pebble as strain markers is considered as a common tool for quantitative estimation of amount of deformation in the rocks. Conglomerates containing stretched pebbles can be used for strain analysis and finite strain determination can be carried out by noting principal strain axis for conglomerate pebbles and the determination of the finite strain on a regional scale (Ramsay, 1967; Hossack, 1968; Dunnet, 1969; Elliot, 1970; Lisle, 1979; Treagus and Treagus,2002; Mulchrone et al., 2005). The long axes of the pebbles lie parallel to the direction of tectonic transport while the short axis coincides with the perpendicular direction of the plane of schistosity (Stephanson and Johnson 1976).

Devi and Sarma (2006) have mapped a number of conglomerates in the Shillong basin of the Shillong plateau, defining basal, interformational and intraformational status. The main impetus of the present work is to estimate the shape and orientation of the deformed pebbles of the intraformational conglomerates to delineate their strain history by using a simple algebraic method and to compare the results with those of computed results with those of computed results of R_f/ϕ and Fry Method.

II. REGIONAL GEOLOGICAL SETTING

The Shillong basin is an intracratonic depression within the picturesque Shillong plateau, the Precambrian cratonic block of NE India. The Shillong plateau is tectonically detached from the Indian peninsula by a large scale Garo Rajmahal tectonic depression. The Mesoproterozoic Shillong basin occupy es the central and eastern part of the plateau and confined dominantly in Meghalaya and partly in Karbi Anglong district of Assam (Fig.1). The meta sedimentary and meta volcanic rock association of the Shillong basin constitute the Shillong Group of rocks. The Shillong Group of rocks has two notable formations namely Lower Metapelitic Formation (LMF) and Upper Quartzitic Formation (UQF).

In the Shillong basin a number of conglomeratic horizons deserving basal, intraformational and intraformational status are observed. Basal conglomerates above the BGG, interformational conglomerates between the two formations of Shillong Group i.e LMF and UQF and intraformational conglomerates within the UQF are well exposed in the basin (Fig.2). Nongbri and Laitsopliah conglo merates deserve basal status separating the SG from BGG and Cretaceous Tertiary sequences respectively. Nongkhya, Sumer and

Mawmaram conglomerates are persistent interformational conglomerate that separate LMF from UQF. Four notable conglomerates namely Naumile conglomerate, Mawpen conglomerates, Elephanta conglomerate and Smit conglomerates bearing intraformational conglomerates are exposed within UQF although few are observed but not mapable. These conglomerates play very important role in the tectonostratigraphic history of the basin (Devi and Sarma, 2006).

The lithosetting of the basin is NE-SW and shows a generalised dip towards SE at a steep to moderate angles, although on the outcrop scale the lithosetting dips either SE and /or NW directions which indicate the presence of a series of moderately large NE-SW trending synclines and anticlines and they are superposed by NW-SE trending regional warps resulting dome and basin structures the rocks of the basin are characterized by multideformational episodes imprinted in the form of planar, linear and other megascopic as well as macroscopic fold structures (Bhattacharjee and Rahman 1985). Strain analysis of the interformational conglomerates, the persistent Nongkhya, Sumer and mawmaram conglomerates have been studied by Devi and Sarma (2010) in detail and delineated their tectonostratigraphic status in the basin.

2.a Geologial setting of the intraformational conglomerates and their pebble characteristics and orientation

2.1.1 Mawpen Conglomerate: The conglomerate is seen near Mawpen along the Barapani-Umroi-Bhailungbum road and stratigraphically belongs to intraformation. The conglomerate band is comparatively thin and discontinued in the direction of strike. Pebbles are highly sheared showing sinistral sense (Fig.2.1). From Barapani Lake to Mawpen village, on way to Umroi, the rocks are dominantly massive quartzites where infrequent interlayerings of either micaceous quartzite or thin phyllitic rocks are seen.

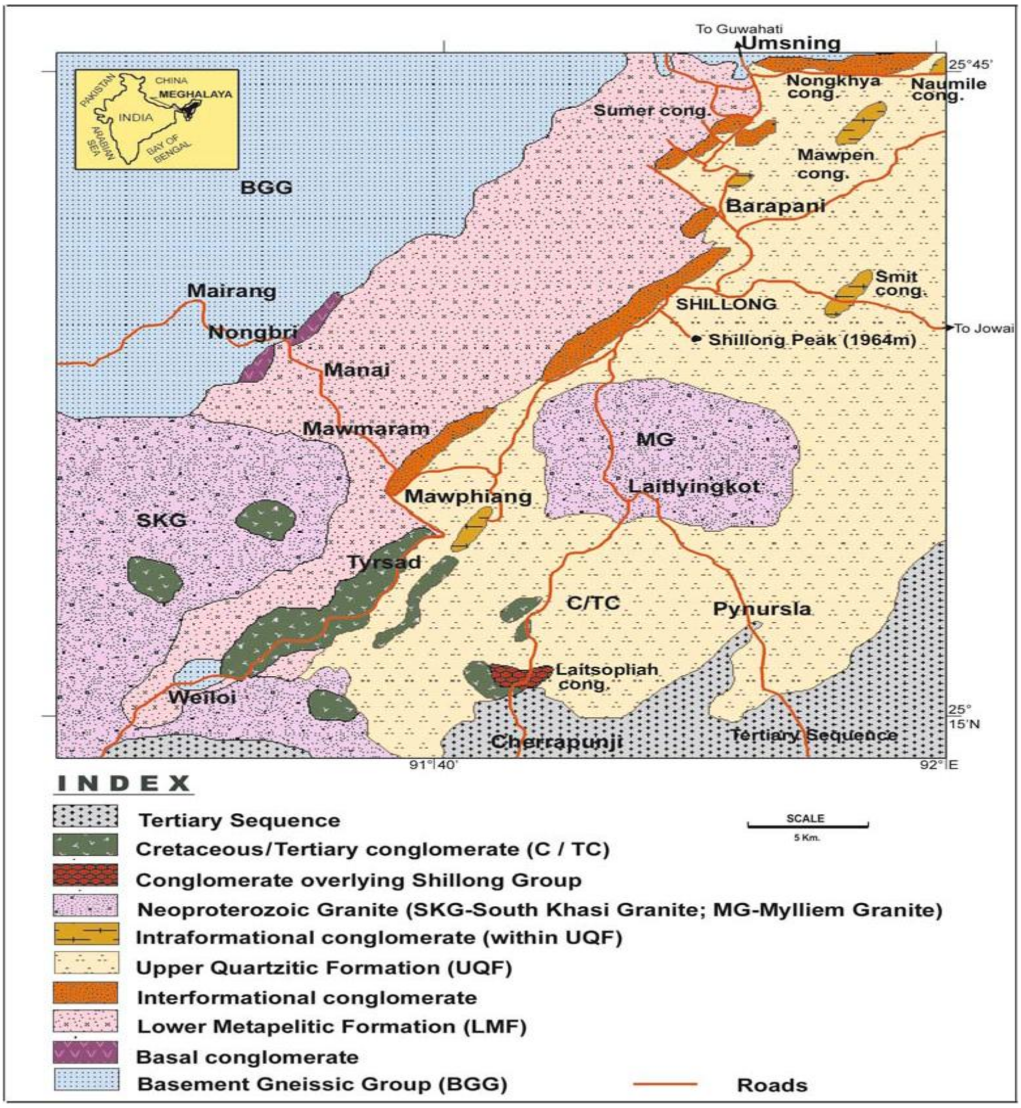

Figure 1. Geological map of the Shillong basin (after Devi and Sarma 2006).

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2.1.2 Naumile Conglomerate: It is exposed near Sohpdok (Naumile) village, at 13km. post from Umsning. The conglomerate is dark brown in colour with relatively small pebbles of either quartz or quartzite (Fig. 2.2). The conglomerate is of ferruginous type and hardly exceeds a few meter across. The average size of the pebble maintain 2:1 ratio and the strike direction of the bedding plane is 070^0 with a dip of 55^0 towards SE. Nearby the conglomerate a few Khasigreenstone (KG) layers are found and they are highly weathered. The ferruginous materials of the matrix may also be a leaching product of KG. The long direction of the stretched pebble is parallel to the strike direction of the lithological layering.

Fig. 2.1. Mawpen Conglomertae

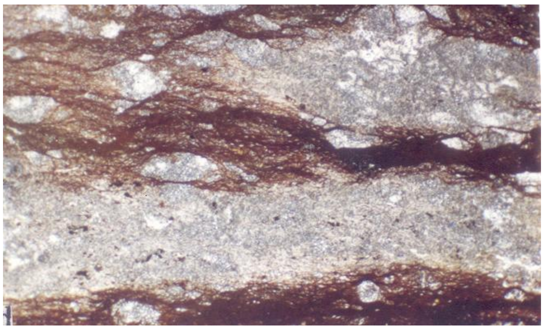

Fig.2.2 Naumile Conglomertae

2.1.3 Elephanta conglomerate: Along Shillong- Mawmaram -Nongbri Traverse, a conglomerate is observe d in Elephanta Falls (towards downstream) at 12 km post from Shillong. The area is a bit inaccessible for mapping due to thick forest cover. But the conglomerate and the rocks of the upper quartzitic formation are exposed. Here the conglomerate is composed of coarse pebbles and matrix pebble ratio will be nearly 50:50. Pebbles are mostly quartz pebble and due to staining other characters are hardly observable.

2.1.4 Smit Conglomerate: Aong Shillong- Smit- Jowai traverse, Smit is a typical area of 80% exposed surface quarries where from commercially quartzite slabs are exploited. From Smit to near Sung Valley, rock units belong to UQF and composed dominantly of massive to feebly schistose quartzites and intermittent thinly bedded phyllites). At Mawrisham (44 km. post) a very massive, hard, compact conglomerate with comparatively coarse pebbles of quartz and quartzite are seen, where occasionally metapelitic traces also can be seen in the form of pebbles. This conglomerate is named as Smit conglomerate or Mawrengkreng conglomerate and shows intraformational character.

III. Methodology for strain estimation

For the present purpose a simple algebraic method suggested by Shimamotto and Ikeda (1976) is applied to estimate the strain history of the interformational conglomerates. Subsequently the results are compared with Fry method and R_f /ϕ method of strain analysis.

3.1 Sample preparation and measurement

In the field, XY, XZ, and YZ sections were identified along the well-exposed natural joint planes where from transparent overlays were drawn and measurements were computed as per method suggested by Ghosh (1993). Three mutually perpendicular planes from **s**ome of the representative samples were sawn in the laboratory by section cutting machine to produce, where possible three oriented orthogonal faces, one parallel to the foliation or pebble/mineral lineation (X-direction of the strain ellipsoid), the other perpendicular to the foliation and lineation, and the third one is perpendicular to the above, thus representing XY, YZ and XZ section planes. Thin sections were prepared and various measurements of deformed mineral grains or pebbles were also taken. Each of the markers were marked by ink so as to avoid repetition and thus axial ratios (R_f) are worked out and their orientation (ϕ) is noted with reference to reference plane marked in the slides. Thus X (long), Y (intermediate) and Z (short) axes of the deformed markers are estimated and the average orientation (ϕ) is calculated.

Depending upon size and concentration of objects, they were either measured from photographs, transparent overlays, and sawn hand specimen or from thin sections. The data sets on XY, YZ and XZ planes were entered directly into the window based computer programmes for Fry and R_f /ϕ plot formulated by P.P. Rodday (2003). These computer programmes are proved to be more rapid and relatively interesting for the estimation of strain values.

3.2 The Algebraic Method: Shimamotto and Ikeda (1976) proposed a simple algebraic method both in 2D and 3D, to estimate the shape and orientation of the strain ellipsoid where they considered two basic assumptions such as (1) initial true ellipsoidal shape and random orientation and (2) strained homogenously with their matrix. They formulated the basic equations in matrix form and claimed that their method can precisely determine the shape and orientation of the strain ellipse if an infinite number of objects are measured. Ooids are the best suitable objects for the algebraic analysis of strain by their method as they are having same ductility with their enclosing groundmass.

In the present work only the 2D formulation of the method is considered for its simplicity. Shimamotto and Ikeda (1976) appear to be the first to have published the procedure of this method, adopting a description in terms of shape matrices. They considered an ellipse centered at the origin 'O' of the coordinate system with major and minor axes a, b (Fig.3.1).The ellipse is given by the equation

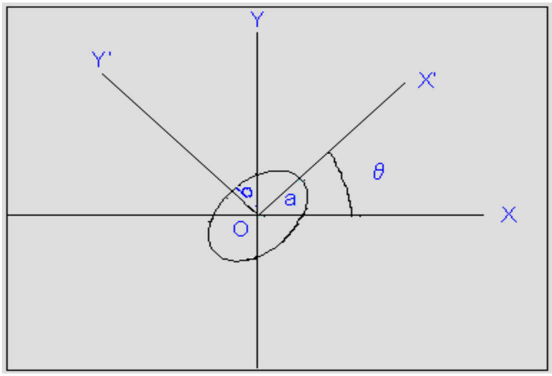

Fig.3.1 An ellipse centred at origin O of the coordinate system with major and minor axes a, b

$$\left(\frac{x'}{a}\right)^2 + \left(\frac{y'}{b}\right)^2 = 1 \qquad \ldots \qquad (1)$$

Where X' and Y' are taken parallel to the principal axes of the ellipse. Now the following equation is matrix representation of the ellipse.

$$[x\,y]\begin{bmatrix} f & h \\ h & g \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} \quad 1 \qquad (2)$$

$$\textit{where} \quad f = \frac{1}{R}\cos^2\theta + R\sin^2\theta$$

$$g = \frac{1}{R}\sin^2\theta + R\cos^2\theta$$

$$h = \left(\frac{1}{R} - R\right)\sin\theta\cos\theta$$

Here $\begin{vmatrix} f & h \\ h & g \end{vmatrix}$

is a symmetric matrix and called as shape matrix. 'R' is defined as the axial ratio of the strain ellipse while 'θ' is the orientation of the principal axis. In the present work, to calculate the shape and orientation of the deformed pebbles in plane section the above shape matrix is applied considering the same assumption as suggested by Shimamotto and Ikeda (op.cit.) and accordingly axial ratios (R) of different pebbles of conglomerates on three different planes viz. XY, YZ and XZ as well as the orientation of the major axes (θ) of the pebbles with reference to the reference line are measured. With the help of the values of R and θ, the components of the final shape matrix; f, g and h, for each pebble are calculated separately. After that f, g and h are averaged as f, g and h, which give the average final ellipse. Thus the strain ellipse of the system is given by the averaged final ellipse.

$$[x\,y]\begin{vmatrix}\bar{f} & \bar{h}\\ \bar{h} & \bar{g}\end{vmatrix}\left[\begin{matrix}x\\ y\end{matrix}\right]=1 \qquad \dots \qquad (3),$$

where $\bar{f}=\frac{1}{N}\sum_{i=1}^{N} f_i$

$$\bar{g}=\frac{1}{N}\sum_{i=1}^{N} g_i,$$

$$\bar{h}=\frac{1}{N}\sum_{i=1}^{N} h_i.[N = no.\ of objects]$$

The principal axes of an ellipse or ellipsoid are the eigen vectors of the shape matrix (Franklin, 1968). Considering this the shape (R) is estimated by measuring length of the principal axes and the orientation (θ) of the principal axes can be measured following the steps suggested by Shimamotto and Ikeda (1776). The shape and orientation of the Naumile, Mawpen and Elephanta conglomerate as per the above method is attempted in the present work using this algebraic method in 2D.

3.3 Fry Method:

One of the most successful and widely applied methods of geological strain analysis is the Fry Method forwarded by Fry (1972, 1979) and subsequently modified by Hanna and Fry (1979) where the distribution of centers or centroids of pebbles in the conglomerates can be determined. The basic assumption of this method is that before deformation the location of centers of intersections of marker objects has an isotropic but maintains no poison distribution law. Fry suggested a numerical approach, but in the present study manual and computerized procedures have been adopted both from field photographs (enlarged) and field transparent overlays of the pebbles of the conglomerates as per methods derived by Ghosh (1993); Twiss and Moore, (1992) and Hanna and Fry (1979). Fry's maps thus prepared from computerized procedures show an elliptical vacant area of no concentration around the central point (origin) and the resulting plots display an ellipticity and orientation as the strain ellipse. The long and short axial length and orientation can thus be measured directly. A number of diagrams are prepared from different sections of each conglomerate but only two representative figures are shown for reference (Figs. 3.2, 3.3). The values are tabulated (Table. 1). pact and mostly sigmoidally rotated but matrix is mostly arenaceous.

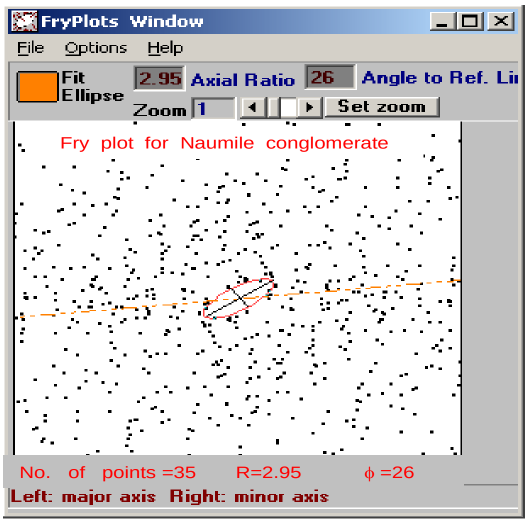

Fig. 3.2 Fry plot for Naumile conglomerate

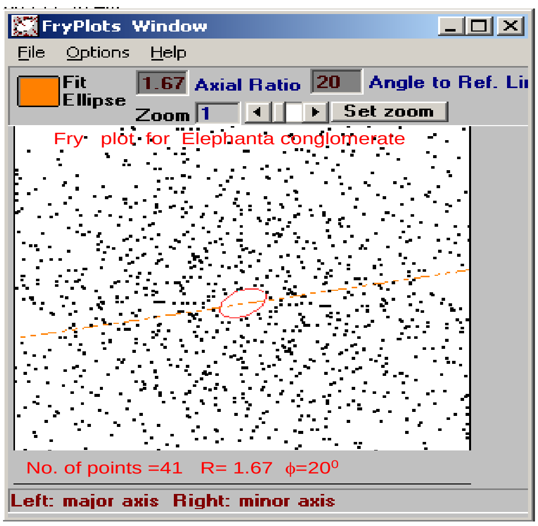

Fig. 3.3 Fry plot for Elephanta conglomerate

3.4 R_f / ϕ Method

The R_f / ϕ is a device for separating initial shape ratio and the tectonic strain ratio from the deformed shape ratio (Donald, 1979). Here a plot is made of log (R_f) and ϕ (the final long axis orientation of each ellipse represented by each deformed pebble). The axial ratio (R_f) and orientation (ϕ) of the pebbles are plotted along ordinate and abscissa respectively and the plots give finite strain (R_f) values by visual best fit into the standard R_i curves of Dunnet (1969). This classic technique was considerably developed by Dunnet (1969) and was extended further by Dunnet and Siddans (1971).

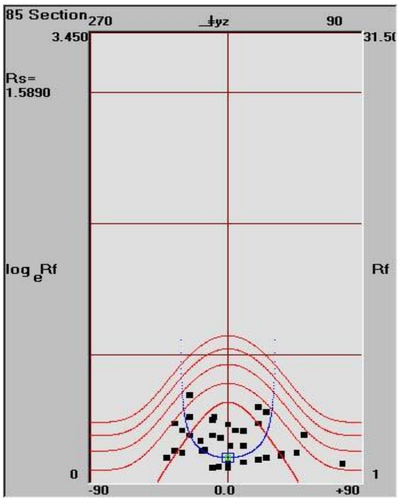

Fig. 3.3

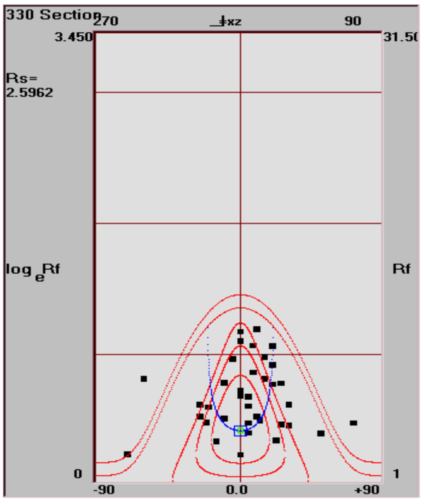

Fig. 3.4

Fig. 3.3, 3.4 R_f / ϕ plot in YZ and XZ section of elephanta conglomerate.

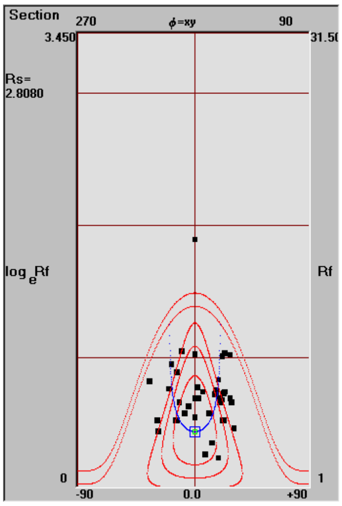

Fig. 3.5

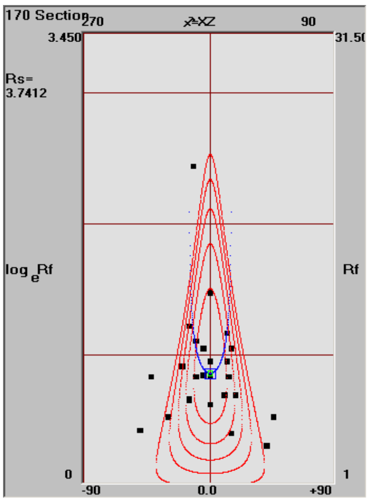

Fig. 3.6

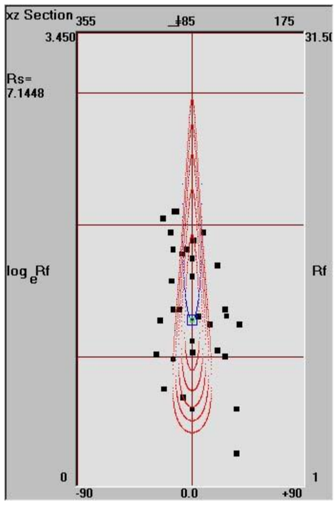

Fig. 3.7

Fig. 3.5 -3.6 R_f /ϕ plot in XY and XZ section of Naumile conglomerate, Fig. 3.7 R_f /ϕ plot in XZ section of Mawpen conglomerate

In the present work, a set of R_f/ϕ plots have been prepared accordingly using the software suggested by Rodday (2003) section wise from Naumile, elephant and Mawpen conglomerate (Figs. 3.4- 3.7). The results are shown in the Table.2.

Table.1 Computed results Fry method

Computed results	**Axial ratio(R)**	**Angle to reference line (ϕ)**	**Type of deformation**
Elephanta conglomerate	1.67 to 1.23	-20 to 5	General oblate
Naumile conglomerate	1.53 to 2.98	-26.2 to 18	General prolate
Smit conglomerate	0.68 to 1.00	0 to 5	Almost plane strain
Mawpen conglomerate	2.31 to 2.85	-10 to 30	General prolate

Table 2 Computed results R_f /ϕ method

Computed results	**Tectonic strain ratio (R_s) in**			**Max.fluc-tuation**	**Type of deformation**
	XY plane	**YZ plane**	**XZ plane**		
Elephanta Conglom.	------------	1.686 to 1.589	1.691to 2.596	65 to 70	General oblate
Naumile Conglom.	-----------	----------	2.808 to 3.863	60 to 64	General prolate
Mawpen Conglom.	-----------	-----------	6.456 to 7.144	60 to 65	General prolate

IV. DISCUSSION AND CONCLUSION

The Elephanta conglomerate is similar to Sumer conglomerate and their pebble - matrix relation is also identical (Devi and Sarma, 2010). Pebbles are relatively less stretched than Sumer conglomerate. Pebbles of the Naumile conglomerate are highly stretched and set in a ferruginous matrix. Smit and Mawpen conglomerates of intraformational status show almost identical pebble–matrix relations to Naumile conglomerate and they are highly stretched, more compact and mostly sigmoidally rotated.

The algebraic method is tested in these intraformational conglomerates of the Shillong basin and subsequently the results are compared with Fry and R_f/ϕ methods. It is observed that the estimated shape ratio and orientation of the pebbles calculated following the algebraic method are in accordance with the strain ratios computed by Fry and R_f/ϕ methods. The Mawpen and Naumile conglomerates show general prolate type of deformation while Elephanta conglomerate is characterized by general oblate type of deformation. Majority of the strain data in the flattening field for Elephanta and Smit conglomerates hints foliation dominated fabrics ($L < S$). On the other hand, plots for the Naumile and Mawpen conglomerates fall in the constriction field indicating dominance of linear fabrics ($S < L$) .

Only Fry method is followed for Smit conglomerate showing almost plane strain pointing towards strain free nature and not considered in R_f/ϕ and algebraic method.

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