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Studies on Deformation Characteristics of Conglomerate along Jonk River, Sonakhan, Balodabazaar District, Chhattisgarh

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ABSTRACT

Jonk river conglomerate occurs along the river Jonk of the late Archean-Paleoproterozoic Sonakhan greenstone belt in the northern-eastern part of the central India craton (CIC)/Bastar block of Central India. To quantify finite strain, the Rf/ϕ and Fry techniques were used. For the 3D strain analysis, conventional Flinn diagram was computed, on which variation of finite strain as computed from harmonic mean for the different localities, that most of the pebble shapes designates at the oblate field and have nearly plain strain ellipsoid.

INTRODUCTION

Strain analysis is common procedure for quantitative estimation of amount of deformation in the rocks. Finite strain determination can be carried out by noting principal strain axis for strain marker such as conglomerate pebbles. Many workers have developed different techniques to quantify strain in conglomerate. The first 3D strain analysis was carried out by Flinn in 1956. In early studies by Hossack (1968), Burns and Spary (1969) and Gay (1969), it was largely assumed that the ellipsoid pebble of conglomerate shows relict feature of deformation stages. Ramsay (1967) and Ramsay and Hubber (1983) provided comprehensive review of methods in the analysis of strain in conglomerates. Probably the most widely used methods is Rf/ϕ analysis (Ramsay, 1967; Dunnet, 1969; Lisle, 1985), making use of aspect ratios and orientations of the pebble in several planar sections of a conglomerate outcrop, either from measurements in the field or from field photographs. Here both photographs and field measurements are dealt, which gives Rs the tectonic strain ratio from the various means of axial ratio of pebbles that are assumed as negligible viscosity contrast with their host rock and an originally spherical, or sub-spherical shape.

For the computation of Rf/ϕ and Fry methods, computer based programme EllipseFit 3.4.0 software is used (Vollmer, 2011) while for the computation of Flinn's diagram *Flinn Plot (Roday, 2003)* is used. EllipseFit is suitable for determining two- and three-dimensional strain using various objects including centre points (Fry analysis), lines, ellipses, and polygons. EllipseFit includes procedures for complete fabric and strain analyses, including image processing, digitizing, calculation of two-dimensional sectional ellipses, and combination of sections to obtain three-dimensional ellipsoids (Vollmer, 2011). For Flinn diagram, the Flinn plot software by P. P. Roday (2003), for Windows 32-Bit platform is used for plots to display the finite strain data.

GEOLOGICAL SETTING

The Sonakhan greenstone belt of central Indian craton (CIC) covers an area of about 1200 sq km. It trends NNW-SSE direction for about 40km from Sonakhan in the north to Remra (21°17"N: 82°46"E). The Sonakhan Group of Paleoproterozoic divided into lower Baghmara formation, middle formation as Arjuni and upper Bilari formationa. The lower predominantly consists of volcanic suites, mainly meta-ultramafites, schistose and massive metabasalt, meta-gabbro, pyroclastics of intermediates to basics composition, ignimbrite, rhyolites, acidic tuff, pebbly tremolite-actinolite schist, carbonaceous argillite and ferruginous sulphide-bearing chert (Mondal et al., 2009). The upper Arjuni Formation unconformably overlies the Baghmara Formation by a thick sedimentary pile and starts with Jonk river conglomerate. The Jonk river conglomerate mark the unconformity between the Baghmara Formation and Arjuni Formation, which is polymictic in nature and demonstrate bimodality in matrix composition. The matrix is mainly meta – arkosic and chlorite /biotite rich greywacke but at some place near to Rajadevri and up to north Arjuni, it is totally replacing by volcanic matrerials. The Jonk conglomerate is sandwiched between Baghmara and Arjuni formations and constricted to Jonk river only (Das et al. 1990). The conglomerate horizon is marked by ill-sorted pebble, cobbles and boulders with preserved striations marks. The pebbles of granite, gneiss, acidic volcanic rocks, porphyries, amphibolite, metabasalts, quartzites, quartz veins, BIF, jasper, phyllites and schists. Since the strain analysis of conglomerates can give the true results if the clast matrix ratio is assumed to be low as 90:10. Here the clast versus matrix ratio varies with average from 90:10 to 10:90. Bilari Group essentially comprises basic and acid intrusive and extrusive (Das et al., 1990). All three-formation rest on a gneissic basement, the Baya gneissic complex.

DEFORMATION PATTERN

The Jonk river conglomerate are concentrated along the river Jonk trending NW-SE extended for a length about 24 km with huge deformed boulder, pebbles and cobbles shapes, before disappearing beneath the Mesoproterozoic Chhattisgarh Supergroup cover sediments. The Sonakhan green stone belt trending the NW-SE forms a broad synformal basin with steep dipping NNW-SSE trending axial surface. The aforesaid belt shows two phases of deformation. The first deformation produces (F1) NNW-SSE trending subvertical schistosity, and associated steeply plunging isoclinal fold, mineral lineation having almost downdip alignment on the schistosity surface. The F2 folding has produced broad open flexures with NE-SW axial planes, and has resulted into culminations and depressions due to interference of fold patterns. Most of the large-scale folds developed in the region are synformal (Chawade, 2010). Some of the shear sense have been marked out by outlining the alignment of mean orientation of long axes of pebble on schistosity surface is nearly downdip.

In the vertical section pebble are sub perpendicular to the schistosity the pebbles are sub-elliptical, and mean orientation of the long axes is parallel to the schistosity trace indicating normal compression (Fig.2a). On the horizontal surface, the effect of sub-horizontal dextral simple shear is seen. These features indicate that shear is, long axes of pebble are aligned with oblique to the schistosity

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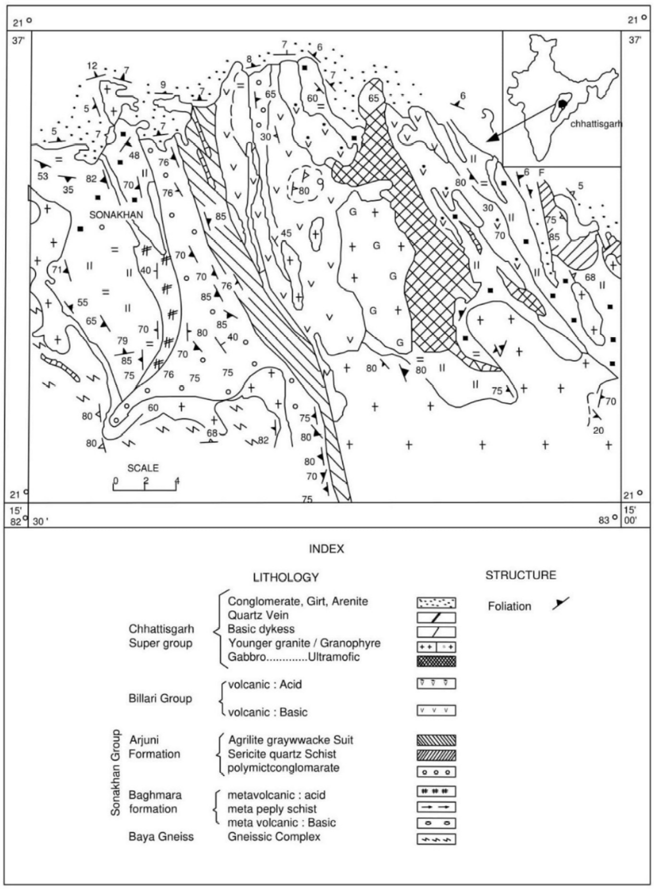

Fig.1. Geological map of Sonakhan belt, Raipur, Chattisgarh district (modified after Das et al. 1990 and GSI, 2006)

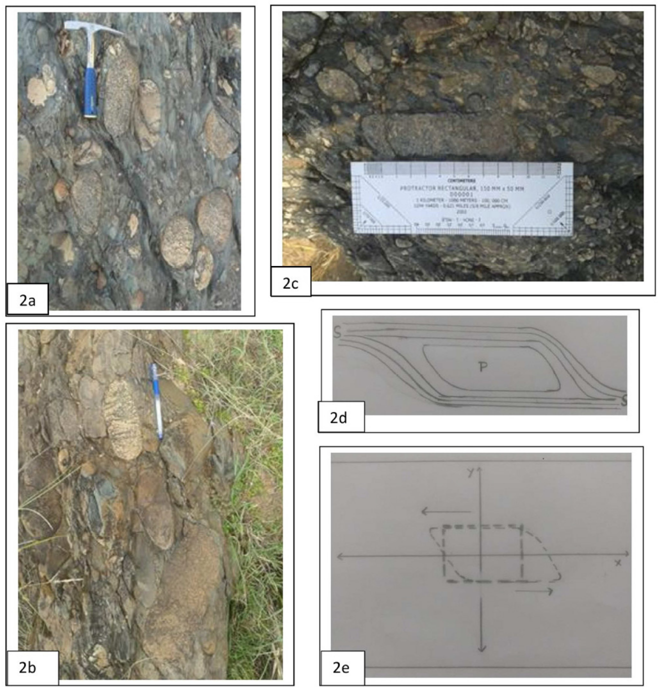

Fig.2. (a) Vertical section of Jonk conglomerate facing east showing the pebbles of long axes aligned parallel to schistosity trace indicating normal compression. **(b)** Horizontal section of Jonk conglomerate showing long axes of pebble oriented oblique to the trace of schistosity in clockwise sense (horizontal XY plane). (**c** and **d**) Pebble showing diagonally opposite angular corners and other two opposite corner in round shape. **(e)** illustrates a superellipse (n=4) deformed by simple shear with movement directin parallel to x-axes (y=2.5). The resultant shape has the characteristic angular and rounded corners (Dasgupta et al. 2013).

with clockwise sense (Fig. 2b), the matrix around the pebbles are asymmetrically deflected of schistosity trace (Fig. 2c and d).

It is commonly found in the Jonk river conglomerate that some pebbles show distinctive shape characteristics of an asymmetry with diagonally opposite angular corners and other two opposite corner in round shape (Fig. 2c and d). Treagus and Lan (2000, 2003 and 2004) have shown that similar shapes are developed in incompetent objects in both pure shear and simple shear if the initial shapes are squares with their sides askew to either the elongation and shortening directions (pure shear) or the shear direction (simple shear). Their model is applicable in the present case because the granitic pebbles are expected to be more or less same competent than the volcanic matrix. We propose that this shape was formed by simple shear deforming an initial superellipse (Gardner, 1965; Lisle, 1988; Roday and Katpatal, 1993) formed by earlier pure shear. A superellipse has the general formula, $(x/a)^n+(y/b)^n = 1$. Where n is >2, the shape is a rectangle with rounded corners. Figure 2e illustrates a superellipse (n = 4) deformed by simple shear with movement direction parallel to x-axes (y = 2.5). The resultant shape has the characteristic angular and rounded corners (Dasgupta et al., 2013).

FINITE STRAIN MEASUREMENT

The finite strain analysis has been performed along 24 km strike length of Jonk river conglomerate section out of which 22 sample different location has been chosen at more or less equal intervals. Samples localities are shown on Fig. 3. Whole length of 24 km of conglomerate horizon is demarked arbitrarily with five structural domains named as D1 to D5 as shown in map (Fig.3).

To get the best results, the collected data for strain analysis were from conglomerate rich horizons containing low competency contrast between pebbles and matrix and well-defined planar and linear fabric elements. In each domain an oriented sample was taken for strain analysis and measurements were made for Rf/ϕ, Fry methods and Flinn plot. In strain studies the evidence for volume change is commonly equivocal (Mohanty and Ramsay, 1994), but in some cases, volume change can be discounted (Srivastava et al., 1995; Bhattacharyya and Huddleston, 2001). Volume change during deformation can affect the shape of the finite strain ellipsoid (Ramsay and Wood, 1973). Therefore, throughout this analysis, we have assumed constant volume deformation. Length-to-width ratios of pebbles were determined from measurements made on YZ plane which is nearly horizontal, parallel and perpendicular to the schistosity plane. For the Rf/ϕ and Fry methods YZ plane photographs are used. The method relies on the following assumption (1) the foliation plane coincides with the XY-plane of the strain ellipsoid, (2) the stretching lineation defines the long axis of the strain ellipsoid, and x is the angle between the X-axis of the elliptical strain marker and the reference line schistosity trace and (3) the deformation was isochoric (constant volume).

In order to determine the 3D geometry of the finite strain ellipsoid in Flinn plot, the above described method was used to estimate the tectonic strain ratios in the XY and YZ principal planes. After the collection of data, the harmonic mean was used as it effectively normalize and give good results (Lisle, 1977).

$$\text{The Harmonic Mean (H)} = n/\Sigma(1/R_f)$$

here n= total number of measurements, R_f = final axial ratio of the deformed pebbles. The arithmetic mean of these measurement is of little value and will consistently give inaccurate results. Flinn diagram is prepared for each (Fig.3) domain as representative samples with only objective to show deformation plot. Flinn (1962, 1978) devised

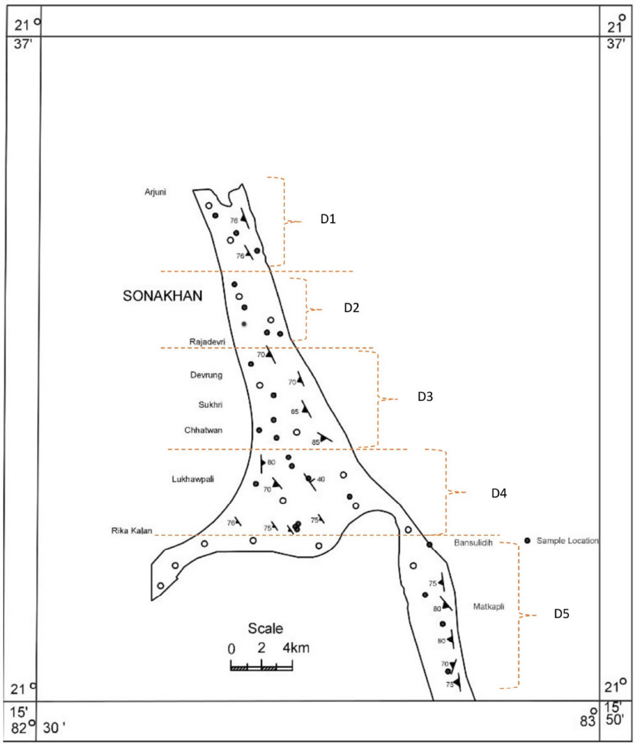

Fig.3. Conglomerate horizon map showing sample location.

a parameter, k, to define the overall shape of the ellipsoid given by Roday and Katpatal (1992).

$$k = a\text{-}1/b\text{-}1,\ \ k' = \ln a/\ln b,\ \ a = b\,k'$$

Rf/ϕ Analysis of YZ Plane

Rf/ϕ analysis data was collected through a standard procedure. A planar surface was selected with pebbles within an area of generally 2m X 2m, of which photograph were collected for further strain analysis with EllipseFit software (Vollmer, 2011). Rf/ϕ analysis of YZ plane uses clast outlines traced from photographs and analysed using EllipseFit software developed by Vollmer (2011). The software automatically approximates shapes to ellipses. Such analysis produces tabulated measurements of long clast and short clast axes and long axis orientation, suitable for producing the required Rf/ϕ graphs and calculating all statistical data required for R_f population. Result of Rf/ϕ analysis of all five-structural domain from D1(north) to D5(south) is given Table 1.

Fry Analysis of YZ Plane

Fry analysis was done as per earlier described procedure. The same software (EllipseFit) has been used for Rf/ϕ analysis. Results from analysis of photographs for five different structural domains (D1 to D5) for same YZ plane as of Rf/ϕ analysis is given in Table 2 and shown in Fig.4. The most commonly reported methods for evaluating object finite strain are the harmonic mean of the object aspect ratios (Lisle, 1979) and the Rf/ϕ method (Ramsay, 1967; Dunnet, 1969;

Table 1. Result of Rf/ϕ analysis of YZ plane

D1	D2	D3	D4	D5
N = 59	N = 30	N = 101	N = 38	N = 57
Projection: Linear	Projection: Linear	Projection: Linear	Projection: Linear	Projection: Linear
Centroid: N = 59 R = 2.323 Phi = 176.80°	Centroid: N = 30 R = 4.051 Phi = 0.17°	Centroid: N = 101 R = 1.891 Phi = 33.16°	Centroid: N = 38 R = 1.775 Phi = 14.34°	Centroid: N = 57 R = 2.331 Phi = 2.55°

Table 2. Result of Fry analysis of YZ plane

D1	D2	D3	D4	D5
A = 9.152	A = 7.219	A = 0.818	A = 9.547	A = 4.526
B = 4.894	B = 5.129	B = 0.442	B = 4.004	B = 3.387
R = 1.870	R = 1.407	R = 1.850	R = 2.384	R = 1.336
F = 32.54°	F = 48.17°	F = 79.66°	F = 26.47°	F = 96.78°
RMS = 0.0607	RMS = 0.0691	RMS = 0.1266	RMS = 0.0768	RMS = 0.2254

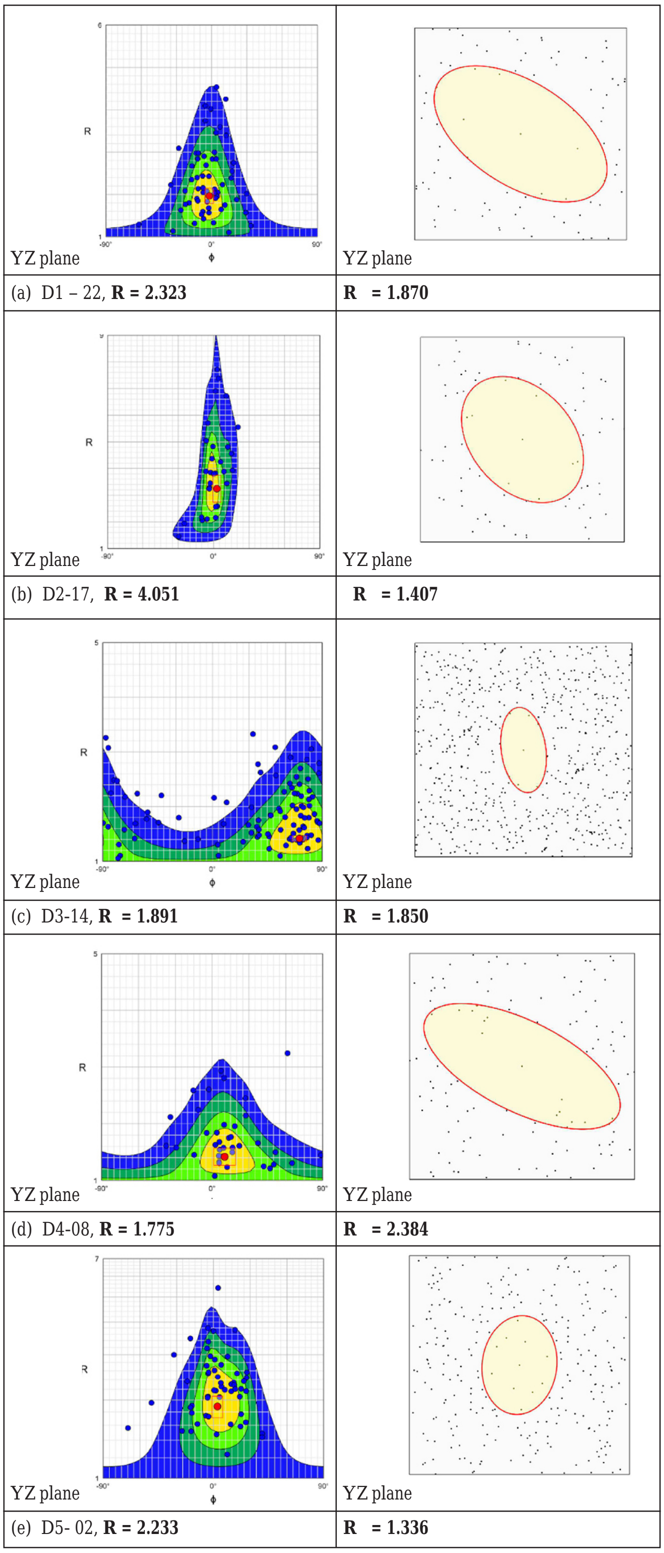

Fig.4. Rf/ϕ and Fry diagrams in the YZ-plane for D1 to D5 samples

Table 3. Result of Flinn Plot

←North				South→
D1 (near Arjuni)	D2 (near Rajadevri)	D3 (near Sukhri)	D4 (near Lukhawpali)	D5 (near Matkapali)
a = 1.724 b = 1.89 k = .808 D = .840	a = 2.383 b = 2.517 k = .912 D = 1.267	a = 1.524 b = 1.752 k = .697	a = 2.117 b = 5.109 k = .272	a = 1.93 b = 4.324 k = .248 D = 1.608

Lisle, 1985) by the eyeballing-in bestfit technique (Ramsay and Huber, 1983). The use of one of these methods alone may not furnish an accurate evaluation of finite strain because (i) the harmonic mean is always an overestimate of real strain (Lisle, 1979) and (ii) if the Rf/ϕ distribution is not symmetric the method does not provide a correct result. In this study, both methods are used in order to compare results and obtain an estimate of their accuracy. Likewise, the easiest and most used technique for the evaluation of bulk finite strain is the Fry analysis (Fry, 1979) is used.

Flinn Plot Analysis

After obtaining the three-dimensional principal strain values (Table 4), various deformation plots were prepared to depict the deformation. The effect of volume change during the deformation processes was ignored (Ramsay and Woods, 1973). The k parameter devised the shape strain ellipsoid (Katpatal and Roday, 1994). Here, in Flinn diagram, all point fall on the oblate field (Figs.5, 6, 7, 8, 9). K has zero value for the uniaxially oblate ellipsoid and a value of unity for plain strain. For an undeformed material, the plot begins at the point of origin. Figures 5, 6, 7, 8, 9 is Flinn diagram of each arbitrarily chosen structural domain from D1 to D5 of various localities. It is worth to notice that k values progressively approaching lower value from Arjuni (North) to Matkapali (South). From the plot of a against b for the entire strain data its notice that the data falls into oblate deformation type, mean k value around Arjuni ≈ 0.808, mean k value around Rajadevri ≈ 0.912, mean k value around Sukhri and Chandan ≈ 0.697, mean k value around Lukhawpali ≈ 0.272, and

Table 4. Flinn Plot's strain measurements for representative samples of five structural domain in the study area

Structural Domain – Sample no.	Avg. mean R_{xy}	Avg. mean R_{yz}	Avg. mean R_{xz}	Avg. mean k	HM R_{xy}	HM R_{yz}	HMR_{xz}	HM k
D1 - 22	1.72	1.90	3.168	**0.808**	1.64	1.56	2.603	**1.142**
D2 - 17	2.38	2.52	5.56	**0.91**	1.94	2.05	4.17	**0.894**
D3 - 13	1.52	1.75	2.60	**0.696**	1.43	1.56	2.27	**0.765**
D4 - 06	1.96	5.80	10.08	**0.272**	1.69	4.31	8.18	**0.209**
D5 - 02	2.00	4.32	8.63	**0.248**	1.70	3.62	6.21	**0.269**

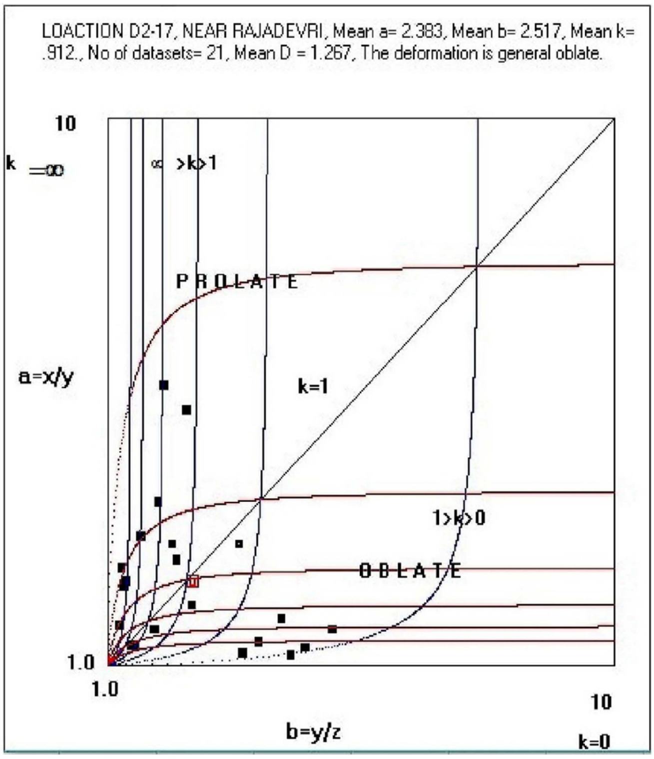

Fig.6. Flinn diagram for location D2-17 near Rajadevri.

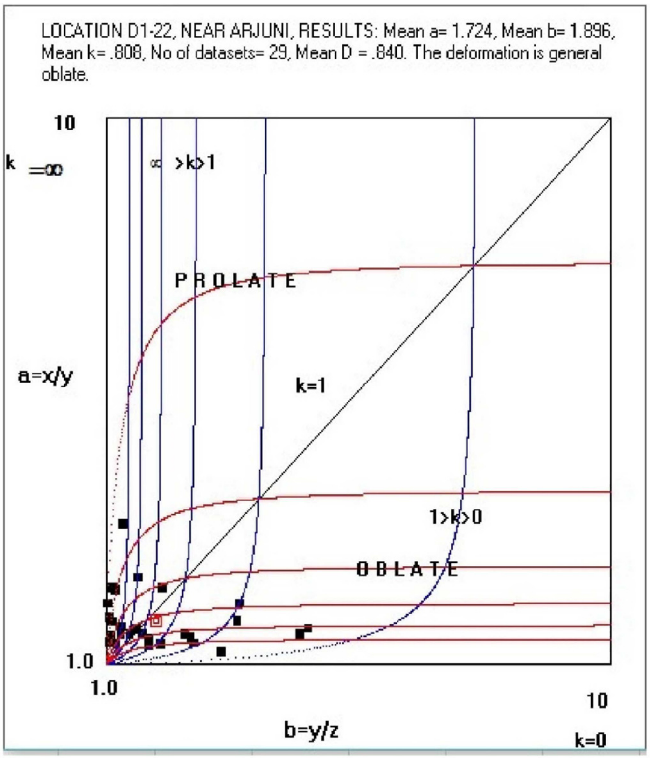

Fig.5. Flinn diagram for location D1-22 near Arjuni.

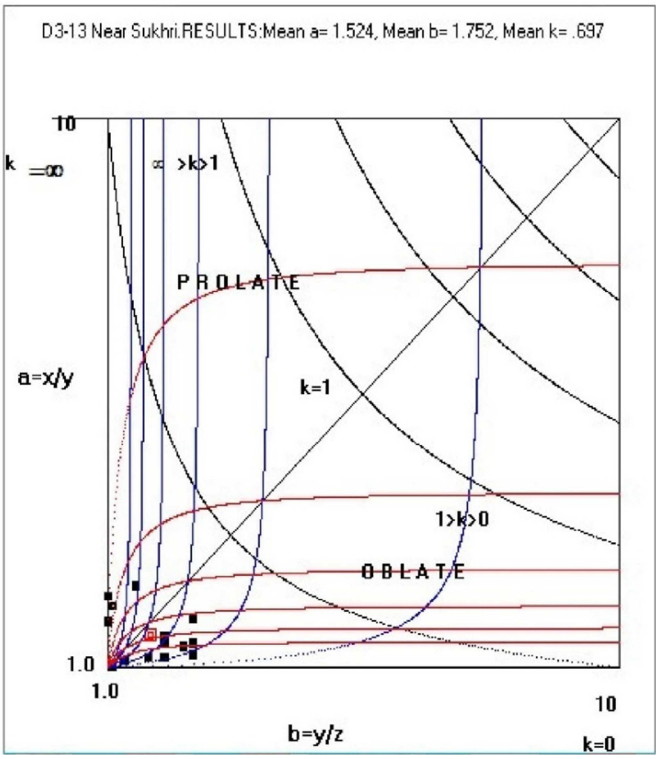

Fig.7. Flinn diagram for location D3-13 near Sukhri.

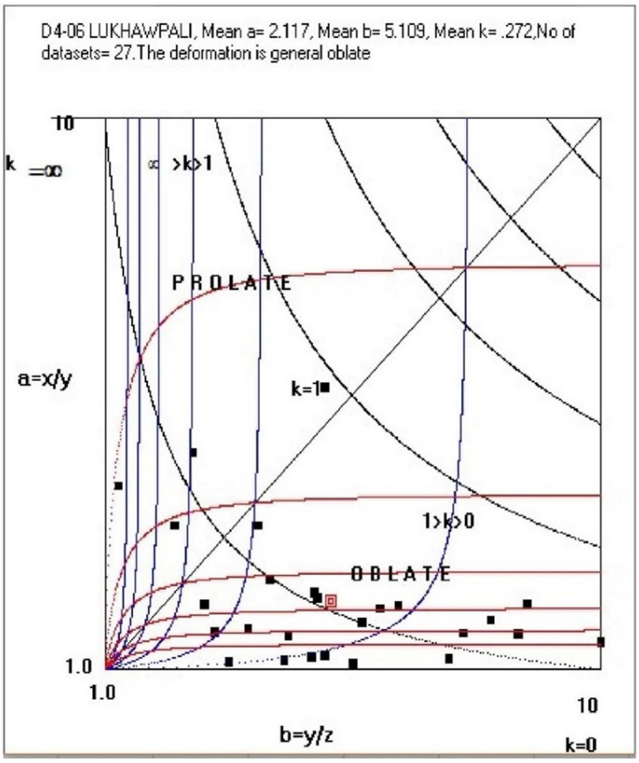

Fig.8. Flinn diagram for location D4-06 near Lukhawpali

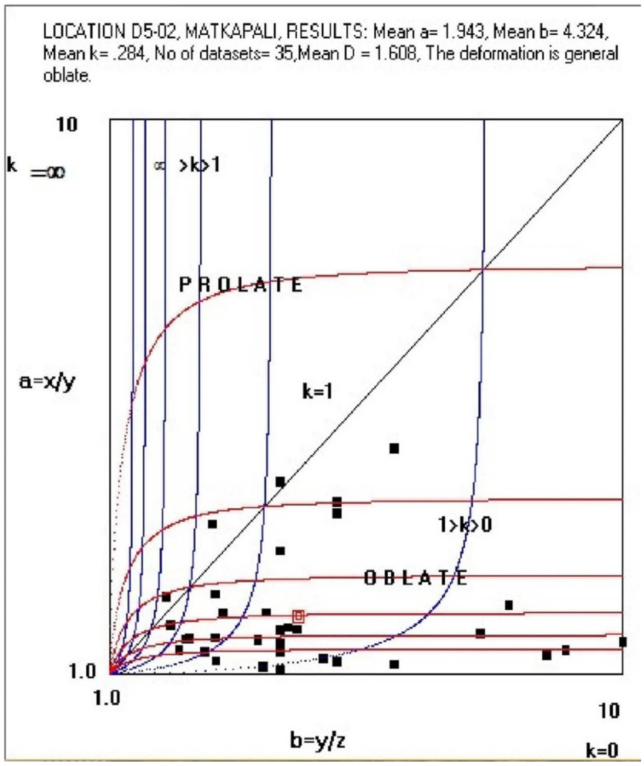

Fig.9. Flinn diagram for location D5-02 near Matkapali

mean k value around Matkapali is ≈ 0.248.The results of Flinn Plot is tabulated in Table 3.

CONCLUSION

With the relevant data collected from Jonk river conglomerate and computation of data in different graphs it is concluded that mean k values of different structural domain have oblate type deformation which have lower value at D5 (k = 0.248) when compared to D1 (k = 0.808). Pebble size gradually decreases from north (D1) to south (D5). Attempt is made to show that shear zone is present all along the strike length of conglomerate horizon. Attempt is also made to show that pebbles of mean orientation of the long axes is parallel to the schistosity trace indicating normal compression. The strain is homogenous in the localized outcrop but there is considerable strain heterogeneity on regional scale.

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