DETERMINATION OF FLUID PRESSURE CONDITIONS USING 3D MOHR CIRCLE IN AND AROUND G.R.HALLI REGION, CHITRADURGA SCHIST BELT, DHARWAR CRATON, SOUTH INDIA

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by

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CERTIFICATE

This is to certify that **Mr. Subhadip Das** (Roll No. 001420402007) of M. Sc. Final Year student of the Department of Geological Sciences, Jadavpur University worked under my guidance and completed the thesis entitled **"DETERMINATION OF FLUID PRESSURE CONDITIONS USING 3D MOHR CIRCLE IN AND AROUND G.R.HALLI REGION, CHITRADURGA SCHIST BELT, DHARWAR CRATON, SOUTH INDIA"** for partial fulfillment of the M. Sc. final examination 2019 in Applied Geology of the Faculty of Science, Jadavpur University, Kolkata.

Mr. Das has fulfilled all the prescribed requirements and this work has not been presented for any degree or diploma elsewhere.

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ABSTRACT

In this study, the orientations of 402 quartz veins occurring in metabasalts in and around G.R.Halli region (West Dharwar craton, southern India) are studied and finally used to plot the 3-D Mohr stress circle, which provides information about relative stress/fluid pressure (P_f) conditions, as well as stress state during P_f fluctuation and the formation of these veins. The quartz veins have a wide range of orientations, with two very prominent orientations NNE-SSW and NW–SE striking veins. Vein emplacement is inferred to have taken place under NW–SE compression that is known to have caused late deformation (D3) in the region. 3-D Mohr circle analysis indicates that the driving pressure ratio (R') was 0.87, which was a high fluid pressure phase and it reactivated previous fractures and finally produced veins with wide range of orientation. The study area has two more clusters of NW–SE oriented and NNE-SSW oriented veins indicationg two more fluid saturation phases. R' is calculated to be 0.31 and 0.38 from 3-D Mohr circle analysis at low P_f. The whole complex and wide orientation of veins formed in at least three phases. Using unscaled Mohr circle we can get an idea about local stress and fluid pressure condition and how the interplay between them helped in formation of the quartz veins in G.R.Halli region.

Key words:

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Introduction

1.1 General

The understanding of fluid transport through the crust is an important issue today. Tectonic deformations interplay with fluid transport and pressurization. In the past few decades, considerable research has been focused on understanding the linkage between fluid pressure fluctuation, formation of mesh of veins, and mineralization. The behavior of fluids has great implications in resource exploration, deep geological disposal of radioactive waste and carbon di oxide. The orientation and distribution of fractures is affected by the state of stress around the fractures. Thus the distribution of these veins can help us to determine not only the stress but also the fluid pressure condition at the time of vein formation. The study of such vein system is very crucial in understanding the crustal fluid flow and fluid dynamics in crust.

Fig 1.1: Field photograph of vein system in G.R. Halli, Karnataka, the host rock is meta basalt. (photo credit; Dr. Tridib Kumar Mondal ,Sreyashi Bhowmick, 2017)

Several past studies have advocated that cross-cutting mineralized veins evolve because of repeated cycles of increased fluid pressure, fracture reactivation/failure, fluid flow into the fractures, drop in fluid pressure and vein formation, followed finally by sealing of the fractures/faults. These vein systems are closely associated with many important hydrothermal mineralization like epithermal gold deposits, lode deposits, etc. throughout history of earth. Study of these vein systems may lead to stunning discovery of some scientific fact that can help us not only to understand the fluid dynamics in the crust but also to hold its economic revenue.

1.2 Objective

Mineral veins are fossils of episodic venting of fluids from deep earth. Understanding of their formation is important not only to mining but also to hydrocarbon exploration. Vein emplacement and mineralization are influenced, as well as controlled by fluctuation in P_f, the stress state and hence relative stress/P_f conditions are not expected to be constant during the cyclic variations of fluid flow. The complex mesh is formed by interplay between different phases of fluid expulsion in the crust. For the local stress analysis of vein system their orientation and distribution is necessary. The methods used by Jolly and Sanderson(1997) that is the use of unscaled Mohr could be effective to evaluate relative stress/P_f conditions during high and low P_f for a vein population. This study will use the data from vein system in G.R. Halli, southern India to evaluate a qualitative Mohr diagram and the orientations of principal axes of stress during different fluid phases. However, for a more complete evaluation of the stress state for conditions of high and low Pf, it is necessary to scale the Mohr circle.

1.3 Layout of the thesis

The following chapters of the thesis comprise a detailed presentation of data and inferences that help to establish the relation between local stress state and fluid activity and their role in formation of complex mesh of veins in and around G.R. Halli region of Karnataka which is a part of West Dharwar Craton (WDC). Chapter 2 consists of brief description of regional geology of the study area, chapter 3 focuses on the theoretical background of the topic and the methodologies of data collection and finally analysis of those data. Chapter 4 comprises of the results using different software and finally interpretation and conclusions.

Regional Geology of the study Area

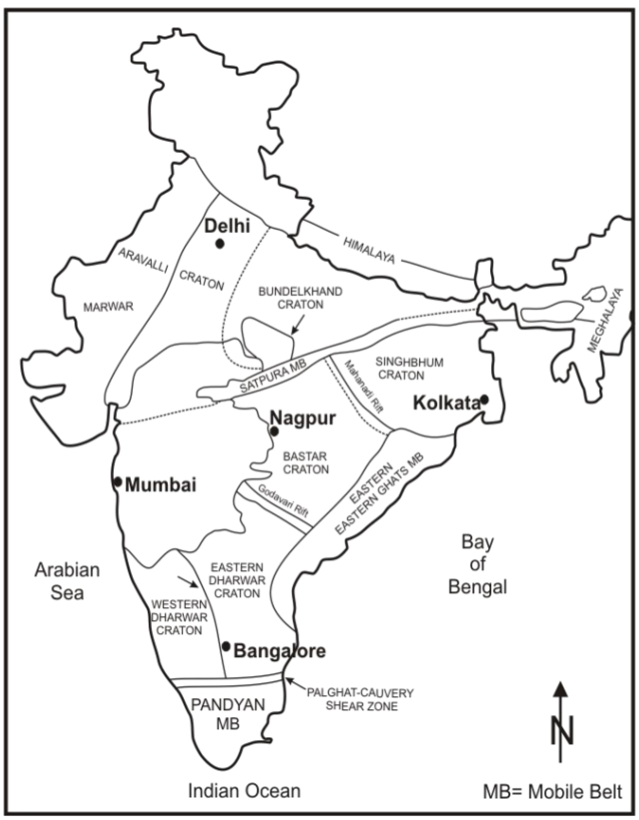
2.1 Introduction

The Chitradurga region represents the Archean-Proterozoic greenstone belt. Owing to frequent facies change and lateral persistence of formation this Chitradurga schist belt shows enormous lithological variation. The major litho-units recorded in this region are- meta-volcanics, polymictic conglomerate, phyllites, greywacke, orthoquartzites, limestone, dolomites, BIF bands and younger granites. The study area is located in southern India near G.R.Halli (Fig.2.1) in the western part of Dharwar Craton that with the Southern Granulite Terrain (SGT) forms the southern Indian shield. The oldest rocks of the region are the Peninsular Gneisses (3.4 - 3.0 Ga).

The Dharwar craton formed by accretion of West Dharwar Craton (WDC) and East Dharwar Craton (EDC) at 2.75 - 2.51 Ga. This zone of accretion is marked by the

Chitradurga Boundary Fault (CBF), which is also considered as easterly dipping thrust by some workers. The area around G.R.Halli comprises metabasalts (greenschistfacies/lower amphibolite facies metamorphism), metamorphosed greywacke-argillite interbanded with ferruginous chert and banded iron formation, polymict conglomerate, and ferruginous chert. Younger granites (~2.5 Ga) also occur in the western parts of the region around Mulgund. The Moyar Bhavani Shear Zone separates the Dharwar craton from the Southern Granulite Terrain (SGT) lying to its south. Gold has been reported in quartz veins within the metabasalts as well as metasedimentary rocks of the Gadag.

2.2 Regional Geology



d mobible belts (MB) in India (after Ramakrishnan and
the western Dharwar craton demarks the study area

The Indian shield is consisting of Precambrian metamorphic terrains and mobile belts (Fig. 2.1) that comprises low to high-grade crystalline rocks. These Precambrian terrains consist of continental crust and are known as cratons (Sharma, 2009). The Indian shield comprises five major cratons (Dharwar, Bastar, Singhbhum, Bundelkhand and Aravalli) and three mobile belts (Eastern Ghats, Pandyan, and Satpura).

These cratons are mainly Archean in age where as the mobile belts are of Proterozoic age (Ramakrishnan and Vaidyanadhan, 2010). The southern Indian shield consists of two major units- Dharwar craton in the north and Southern Granulite Terrain (SGT) in the south (Naqvi and Rogers, 1987; Chakrabarti et al., 2006) (Fig. 2.1). Dharwar

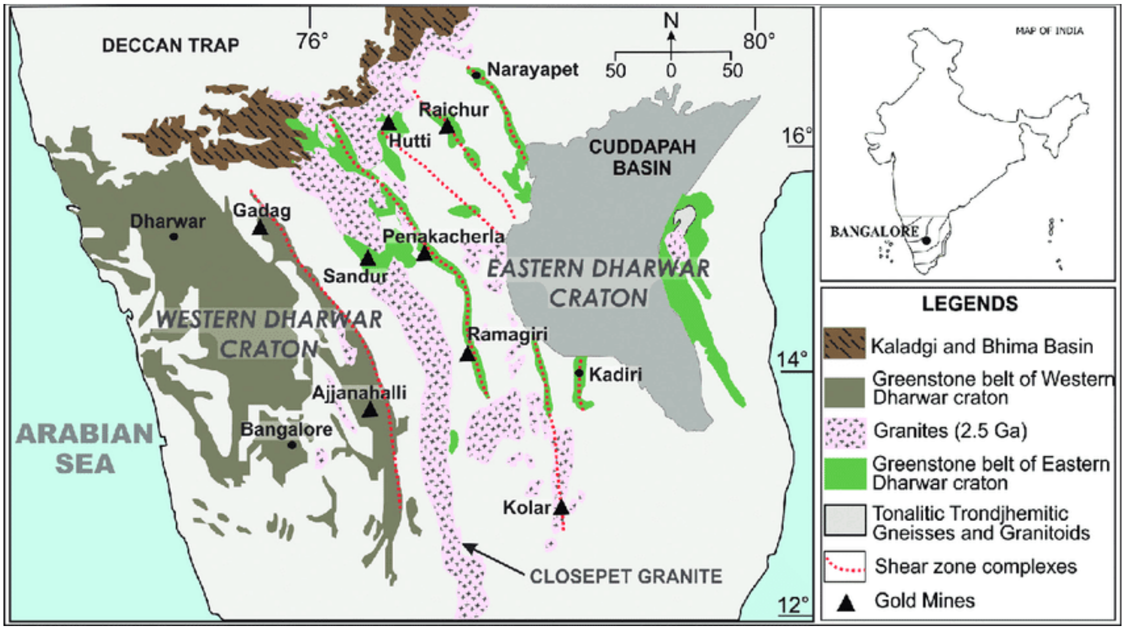


Fig 2.2: Regional Geological map of Dharwar craton showing all lithologies and major units

province exhibits granite-greenstone terrain mainly characterized by several NW-SE to NNW-SSE trending schistose rocks. The SGT is mainly characterized by charnockites, mafic granulites and khondalites which are intersected by several shear zones. Gneisses and supracrustal rocks of amphobolite facies are abundant along with granulite facies rocks. The radiometric dates obtained from SGT show the ages mostly vary between 3000 to 2000 Ma (Chakrabarti et al., 2006; Plavsa et al., 2012). Dharwar craton (3200 to 3400 Ma) is one of the oldest craton in Indian shield (Valdiya, 2010). It broadly comprises three major units - (1) Archean tonalite - trondhjemite - granodiorite (TTG) commonly known as Peninsular Gneissic Complex (PGC); (2) two generations of Archean Greenstone belts (‘schist belt’) represented by Sargur Group and Dharwar Supergroup rocks and (3) late Archean granitoids with or without mantle affiliation (Chakrabarti et al., 2006). According to Rogers (1986), the Dharwar craton is further divided in two tectonic blocks - Western Dharwar craton (WDC) and Eastern Dharwar craton (EDC) (Fig. 2.2), and the entire Dharwar craton is considered to have formed by the accretion of WDC and EDC at 2510-2750 Ma. The zone of accretion is marked by a shear zone, which is variously referred to as the Chitradurga shear zone.

<table>
<tr><td colspan="6">Proterozoic mafic dykes
Charnokites (2500 - 2600 Ma)
Younger granites (2600 Ma)</td></tr>
<tr><td rowspan="3">Dharwar Supergroup (2800 - 2600 Ma)</td><td rowspan="2">Chitradurga Group</td><td>Ranibennur Subgroup</td><td colspan="3">Greywackes with BIF, polymict conglomerate, volcanic (Maradihalli, Bellara, Medur)</td></tr>
<tr><td>Vanivilas Subgroup</td><td>Polymict conglomerates, cross-bedded quartzite, pelites, stromatolitic carbonates, biogenic cherts, BIF and Mn formation</td><td>Ingaldhal Volcanics</td><td>Tholeiitic basal-rhyolite suit (Tekalvatti, Jagar)</td></tr>
<tr><td colspan="2">Bababudan Group</td><td colspan="3">BIF and Carboneceous phyllites
Basalt-dacite suit (Locally pillowed) with minor ultramafics
Alternatnations of amygdular basalt, cross-bedded quartzites, pelites, minor BIF
Basal Quartz pebble conglomerates</td></tr>
<tr><td colspan="6">-------------------------------Fundamental Unconformity--------------------------------</td></tr>
<tr><td colspan="6">Peninsular Gneiss (ca. 3000 Ma)</td></tr>
<tr><td colspan="3">Sargur Group (>3000Ma)</td><td colspan="3">Ultramafic-mafic intrusive complexes (Holenatasipur, Nuggihalli)
Surpentinised komatiites, komatiitic and tholeiitic amphibolites, cherts, BIF
Garnet-biotite schist (with kyanite, sillimanite and staurolite)
Local marbles and calc silicates
Fuchsite quartzite with chromite and barites layer</td></tr>
<tr><td colspan="6">(?) Gorur Gneiss (3300 Ma)</td></tr>
</table>

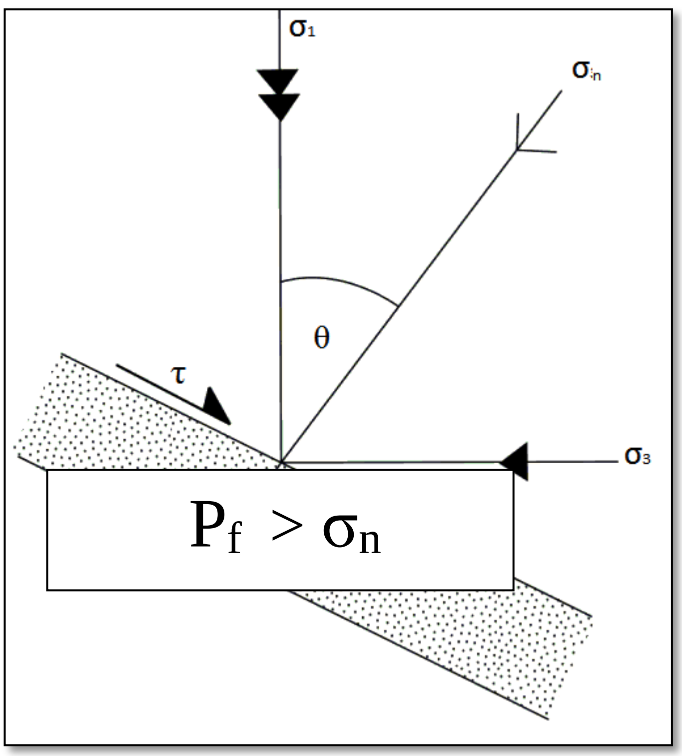
Table 2.1: Regional stratigraphy of West Dharwar Craton (WDC) (after Ramakrishnan vaidyanathan 2010)

2.3 Geology of the study area

The region has undergone three phases of deformation (D1, D2 and D3). D1 folds are tight to isoclinal asymmetric, while D2 folds are open to tight upright. The two fold populations are coaxial and developed during NE-SW directed regional shortening, which resulted in many NW-SE striking planar structural elements. D3 structures developed during NW-SE-directed regional shortening that produced regional warps with NE-striking axial surfaces. . D3 folds (regional open; NE-SW striking vertical axial plane) superimpose the earlier structures, forming culmination and depression in the region (Chakrabarti et al., 2006). Thus, the above studies indicate that the structural evolution of the Chitradurga schist belt is controlled by early NE-SW compression followed by late NW- SE compression. The fabric defining this anisotropy dilated during D3 (NW-SE compression). They envisaged that fluid flow was dominantly channelized along the NW-SE anisotropy during D3 with related vein emplacement during fluctuations between high P_f and low P_f conditions.

Theoritical Background, Methodology and Analysis of Data

3.1. Theoritical background



The upper crust is pervaded by fractures which provide planes for the fluids to exploit. The opening of a fracture is dependent on the fluid pressure and the local stress regime around the fracture. For fluid to open a pre-existing fracture the fluid pressure (P_f) must exceed the normal stress (σ_n).

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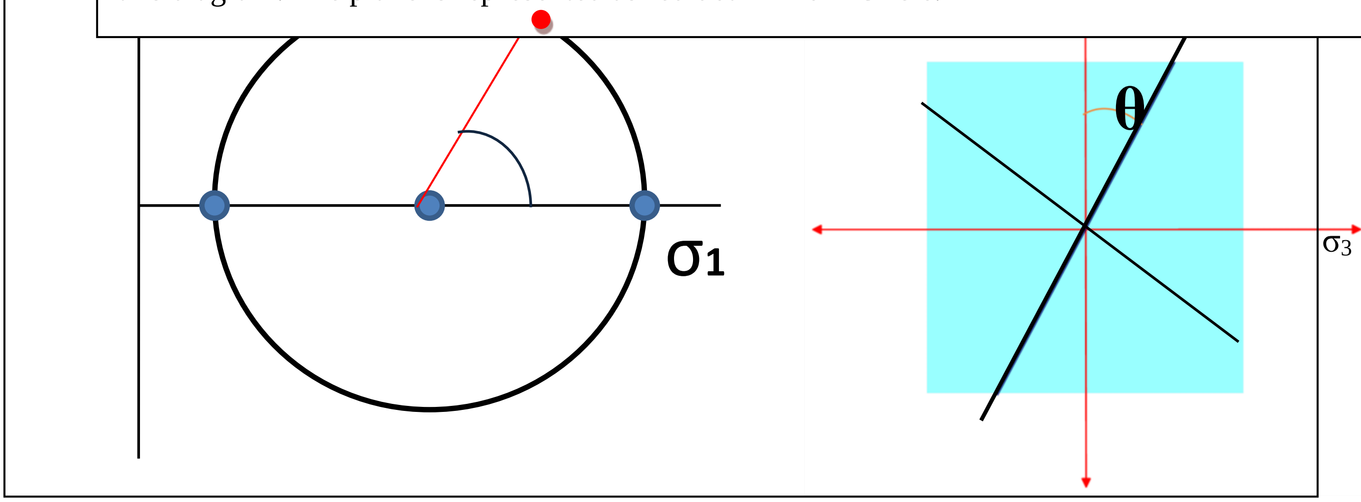
alysis of a

Fig 3.2: Position of a plane in 2D and representation of that plane in Mohr Circle(2D) is shown in this diagram. The plane is represented as red dot in Mohr Circle.



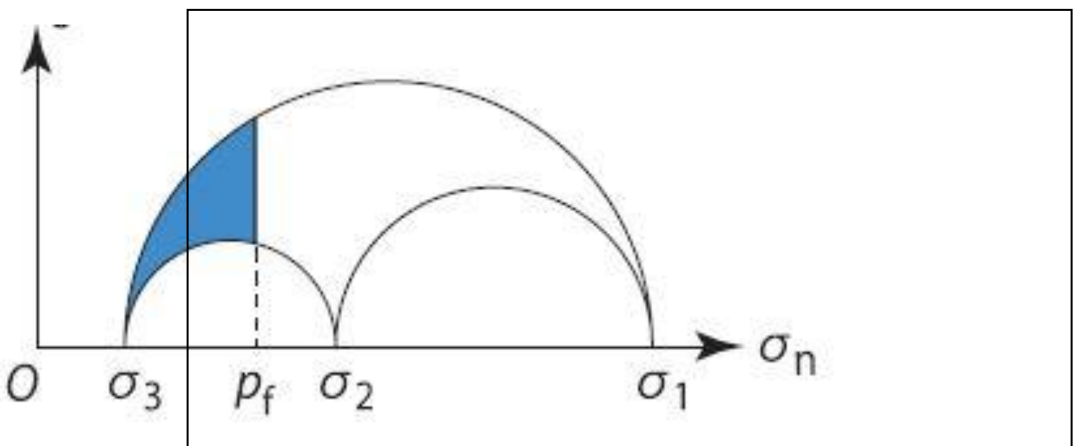


Figure 3.3: An unscaled 3D Mohr Diagram showing fluid pressure(P_f) and the orientations of the dialated veins(region in blue color).

For this condition to be met, the stress on the fracture plane must lie in the shaded area of Fig. 3.3.

So we need to plot the orientations in 3D Mohr diagram. Then we can determine which planes are susceptible during fluid pressure activity.

3.2 Data Collection

For plotting and results we need field observations at first. The set of data that needs to be collected are-

- Strike, dip and dip direction (Orientation of the planes of the dialation veins);
- Vein thickness.

3.3 Method of Analysis

For the analysis, the orientation of the poles from planes of dialation veins should be plotted on the stereonet. The distribution of vein poles in the stereonets should either be categorized as "girdle" or "cluster" type.

A girdle distribution (Fig: 3.4(a)) is characteristic of $P_f > \sigma 2$ when PEFE of varied orientations dilate. In this case, an outline can be drawn around the open space, whose centre defines σ1, and a great circle representing the σ1σ2 plane passes through it. This indicates that the orientations of PEFE that lie outside the open space can be dilated by the fluid (Jolly and Sanderson, 1997). Alternately, if $Pf < \sigma 2$ then a "cluster" distribution (Fig: 3.4(b)) should occur, which implies that only limited range of PEFE orientations were susceptible to reactivation by dilation. In this case, an outline can be drawn around the cluster, whose centre defines σ3. This is the pole of the σ1σ2 plane and therefore the great circles defining σ1σ2 and σ1σ3 planes can be drawn. The PEFE orientations (cluster) that lie inside the outline can be dilated by the fluid (Jolly and Sanderson, 1997). The equal area projection of poles to veins also helps determine the angle (q) between PEFE susceptible to reactivation and principal stresses. Accordingly, θ_1 is the angle between σ2 and poles to range of PEFE susceptible to reactivation lying on the σ2σ3 plane. θ_2 is the angle between σ1 and poles to range of PEFE susceptible to reactivation lying on the σ1σ3 plane. θ_3 is the angle between σ1 and range of poles to PEFE susceptible to reactivation lying on the σ1σ2 plane. Following Baer et al. (1994) and Jolly and

Sanderson (1997), the driving pressure ratio (R') can be calculated using equation (1), and stress ratio (ϕ) can be determined using Eqs. (2) and (3) in case of $P_f < \sigma 2$ (clustered distribution) and $P_f > \sigma 2$ (girdle distribution), respectively.

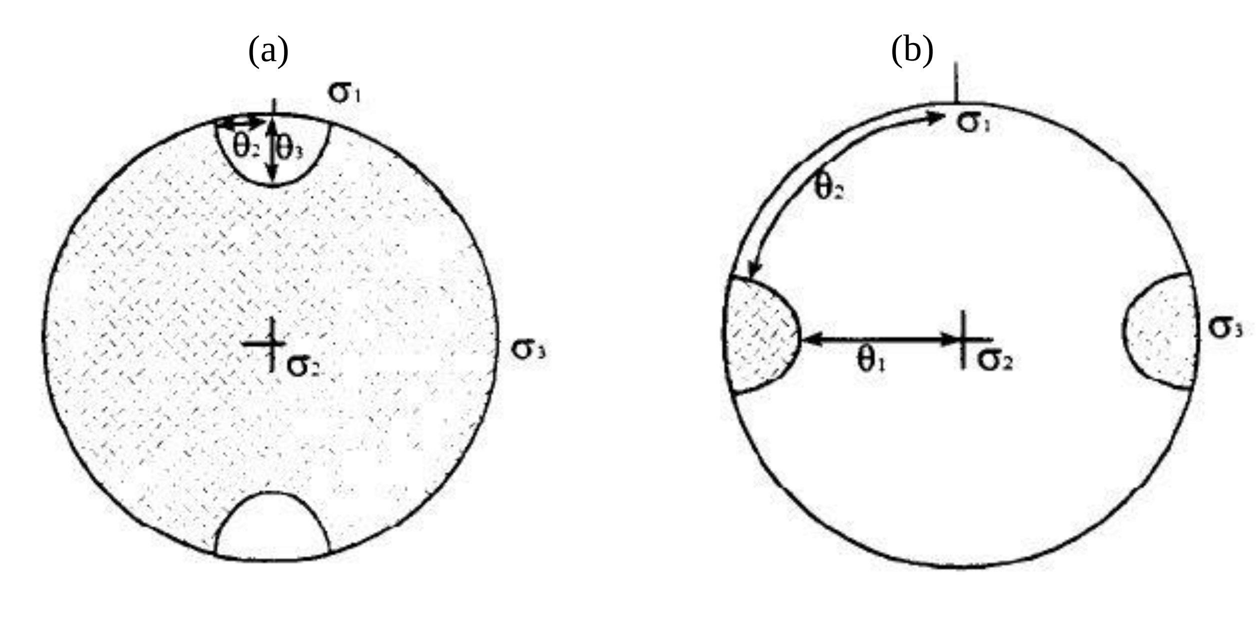


Fig : 3.4: Schematic diagram for girdle(a) and cluster(b) distribution in stereonet

Driving pressure ratio (R') is calculated for both girdle and clustered distribution with the equation 3.1;

$$R' = \frac{P_f - \sigma_3}{\sigma_1 - \sigma_3} = \frac{(1 + \cos 2\theta_2)}{2}$$

For stress condition $P_f < \sigma 2$ (clustered distribution) , stress ratio is calculated with the equation 3.2;

$$\Phi = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} = \frac{1 + \cos 2\theta_2}{1 + \cos 2\theta_1}$$

For stress condition $P_f > \sigma 2$ (girdle distribution) stress ratio is calculated with the equation 3.3;

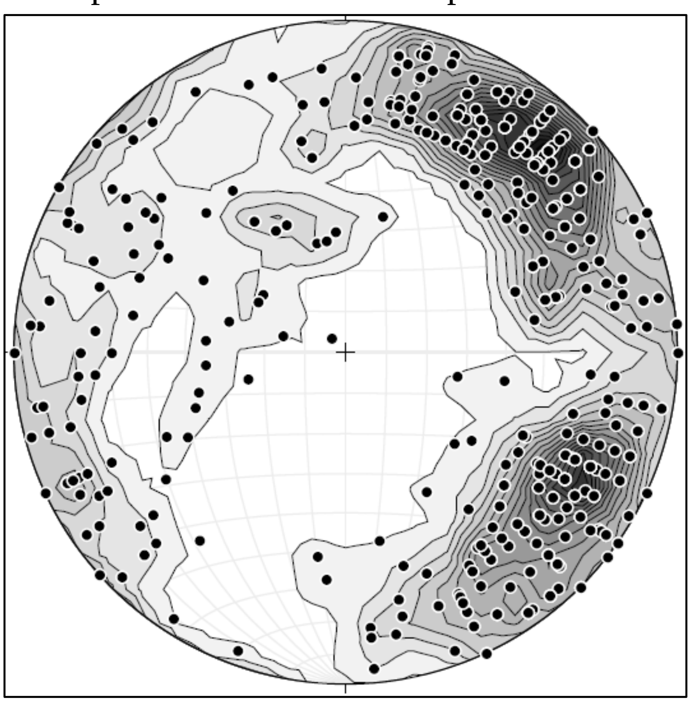
$$\Phi = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} = 1 - \frac{1 - \cos 2\theta_2}{1 - \cos 2\theta_3}$$

So from the stress ratio (ϕ) and driving pressure ratio (R') we get the paleostress of the studied area. From the stereonet plots we can decipher the directional properties of the stress axes and hence can relate the event with regional deformation.

RESULTS& CONCLUSIONS

4.1 Introduction

In the present thesis the fluid pressure conditions of the veins in G.R.Halli region and their variations are studied using their orientations in stereonet plots and with the use of unscaled Mohr diagrams.



Although the overall distribution of poles to veins is of girdletype, there is a significant cluster to the SE and NE (Fig. 4.1). Also, there arelarge number of fractures and veins that cross-cut each other toform a mesh, which indicates repeated cycles of

n G.R Halli region

fluid flow (vein emplacement). Thus the authors envisage that after the initial burping of fluid at high Pf into fractures of various orientations, there was a reduction in P_f, and sealing of several fractures took place.

4.2. Results

The cluster of poles to veins in Fig. 4.1 can be used to comment on the relative stress/fluid pressure conditions that prevailed at low P_f. Following Jolly and Sanderson (1997), an ellipse is drawn around the region of cluster of poles to veins. It may be noted that under reduced Pf, the fractures represented by poles lying

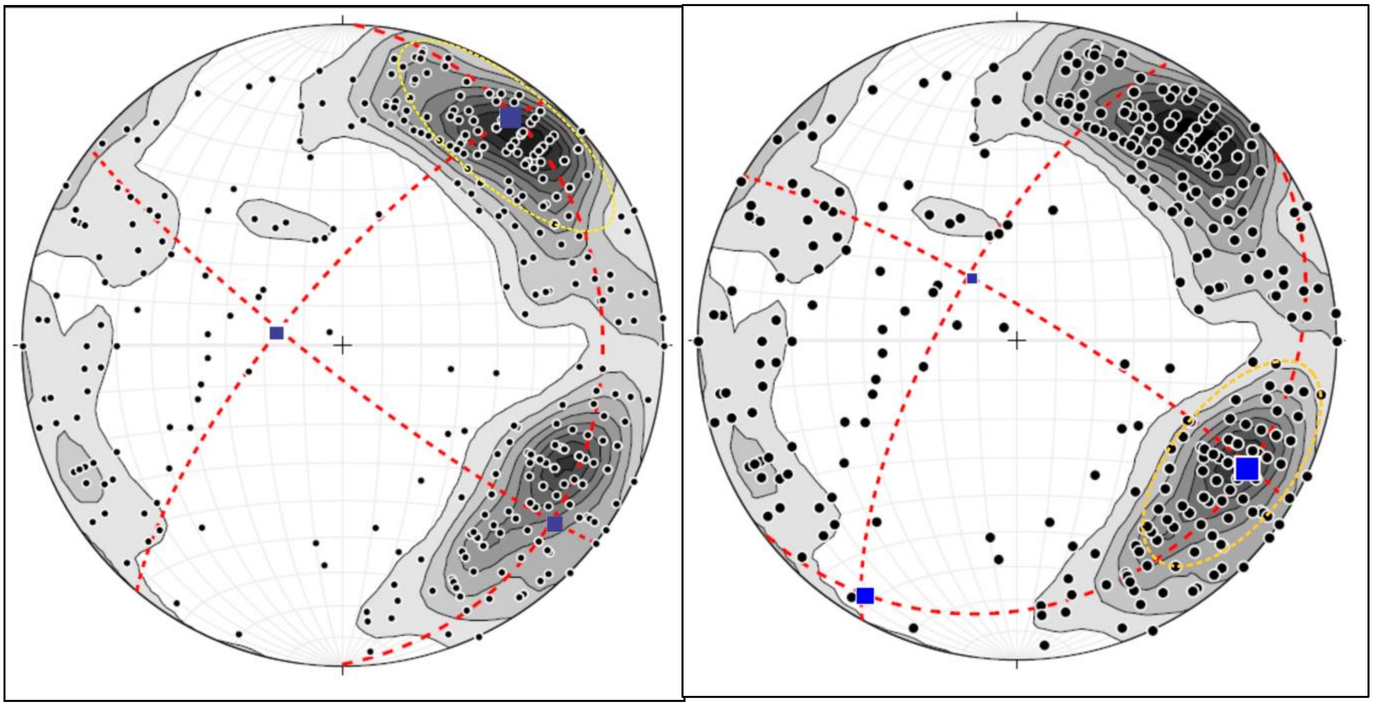


Figure 4.2: In these diagrams stereonet plots of poles to veins is shown. In Fig. 4.2.a. the NE cluster has been shown and an ellipse has been drawn (yellow dotted). Outside this ellipse the poles of veins remained inactive from the low Pf(1). The focus of the ellipse is σ3 and other axes are also shown as blue squares σ1 and σ2. In Fig 4.2.b. the cluster is SE and hence the orientation of the σ3 axis is also SE. σ1 remains in the same position in the stereoplot with minor change in its orientation. Other notations mean the same as in Fig. 4.2.a.

outside this ellipse would be inactive/sealed, and only the fractures represented by poles lying within the ellipse would be susceptible to reactivation/vein emplacement. Therefore, using the ellipse around the cluster in Fig. 4.2 orientation of σ3 (centre of the ellipse), σ1 and σ2, and the angles θ1 and θ2 were determined.

Using the values of the angles from stereonet we calculated the stress ratio(φ) and driving pressure ratio(R′) from equations 3.1, 3.2 and 3.3. The stress ratio and driving pressure ratio determines the shape of Mohr diagram and we can calculate relative values of σ1, σ2, σ3 (principal stresses) and P_f , but we cannot measure the absolute values using this unscaled Mohr diagrams.

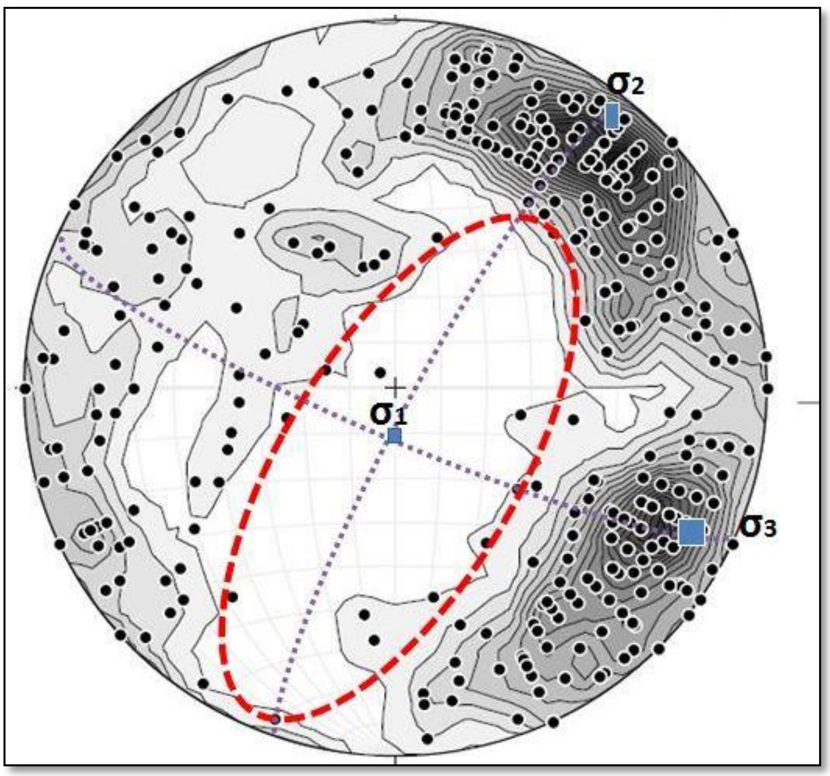
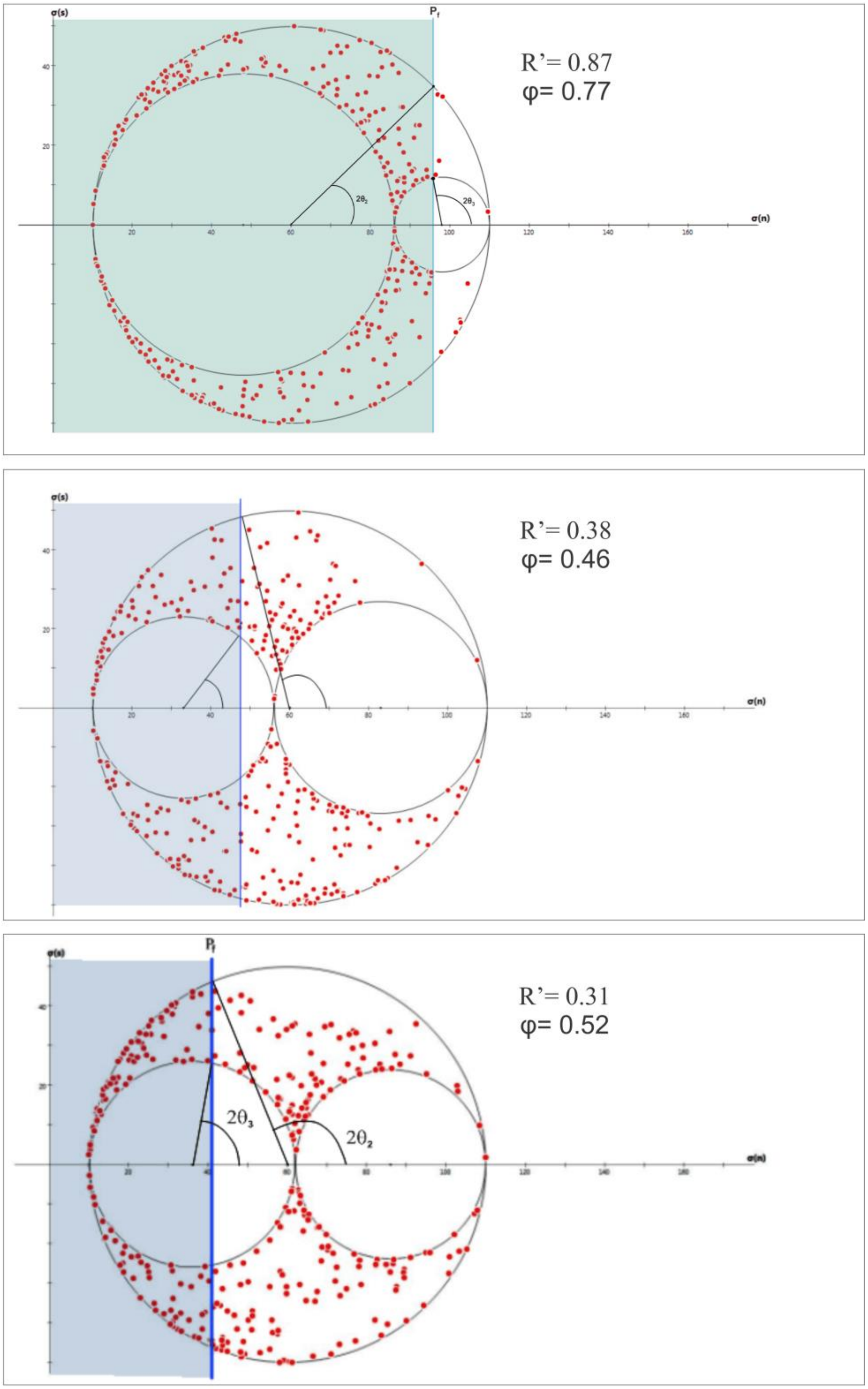


Fig 4.3: In this figure the red ellipse is drawn where no poles are in the stereonet. The plot is shown for girdle distribution and in the focus is σ1 and other blue squares are σ2 and σ3.



he data from stereonet. The three figures
lated in a relative manner it is not a real
alues σ1, σ2, σ3 and Pf can be measured

4.3. Conclusions

The stereoplots of the area shows that there are two prominent clusters in overall girdle distribution of veins to pole. In the figure 4.4 it is shown in also rose diagram showing two prominent directions of veins. The strike v/s no of veins also reveal two dominating strike that has been followed by the veins.

From the calculated ratios we get the idea about the stress conditions and the fluid pressure of the region. In case of multiple fluid expulsion and formation of veins we get different ratios for particular set of veins. In G.R. Halli the studied veins revealed that there were three prominent fluid phases from high to low fluid pressure. The high P_f in the region was generated in a condition where φ = 0.77 and R' = 0.87 and almost all directions of the pre-existing fracture network was filled with fluid. Then the intermediate fluid pressure prevailed where φ = 0.46 and R' = 0.38 and finally the lowest fluid pressure activity occurred with very low stress and driving pressure ratio, φ = 0.52 and R'= 0.31(Figure 4.3).

Fluid Pressure Condition(Pf)	Stress Ratio (φ)	Driving Pressure Ratio(R′)
High	0.77	0.87
Low	0.46	0.38
Low	0.52	0.31

Table 4.1: Different phases of fluid saturation and local stress state in the study area

Thus we get the idea of the role of fluid and relative amount of fluid pressure in earth's crust that results in this type of dilation vein network in the studied area.

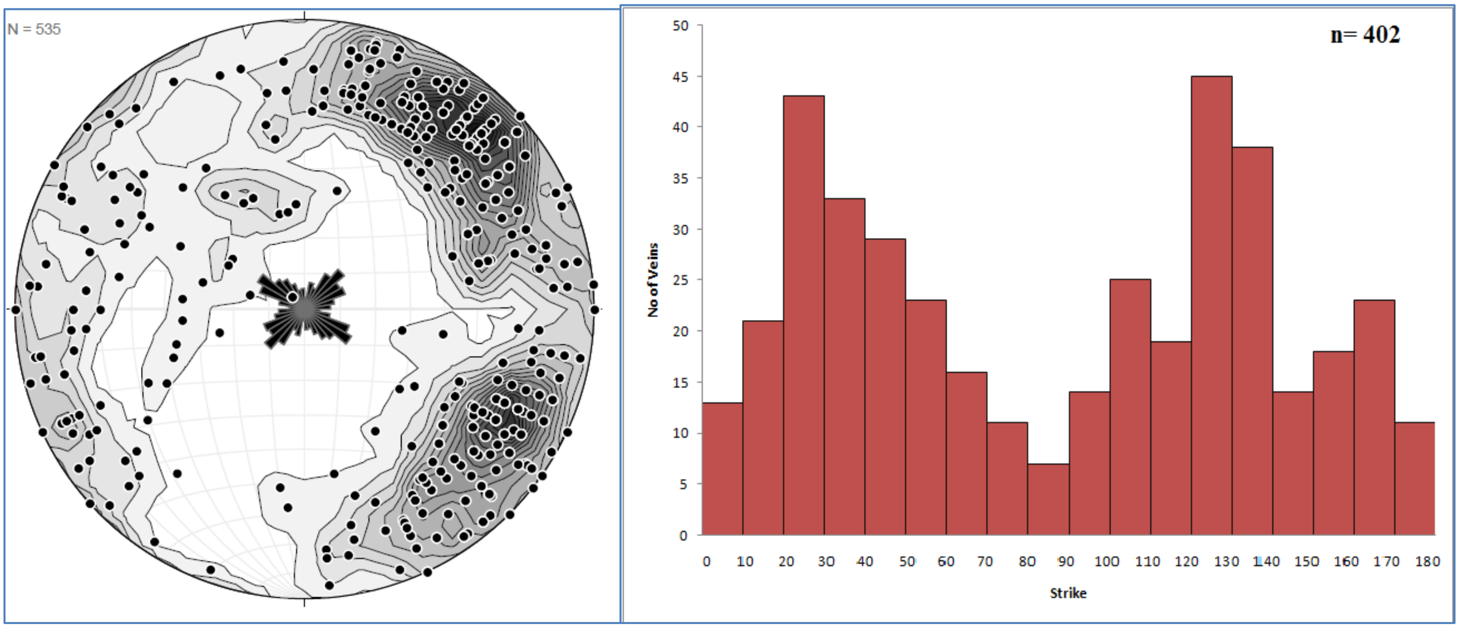


Fig 4.4: (a) Stereonet plot and rose diagram of the veins in G.R. Halli region; (b) variation of number of veins with strike of the veins is shown.

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