

FLUID INCLUSION PETROGRAPHY AND MICROTHERMOMETRY ANALYSIS OF QUARTZITES OF GHATTIHOSAHALLI SCHIST BELT, DHARWAR CRATON, KARNATAKA, INDIA

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Abstract

Fluid inclusions both in quartz of fuchsite quartzite and quartzite rocks from the Ghattihosahalli Schist Belt area were examined with microthermometric methods. The study focuses on analysis of primary and secondary fluid inclusions present in quartz hosted in the quartzites to explore the stress and temperature conditions at the time of formation of metasediment sequences of the study area. The results reveal the two-phase liquid-rich fluid inclusions that indicate that the intrusions of quartz veins in quartzites may have taken place between the temperature from 168.8°C to 256.3°C with an average of 205.55°C from a moderately saline fluid (1.49 to 10.2 wt. % NaCl equiv.). The final ice-melting temperatures ranges from -7.8°C to -2.1°C which indicate that the aqueous fluids are mainly H₂O-NaCl. From the study, it is found that the minimum pressure during the trapping of this fluid inclusion in quartzites were ranging between 1.15 to 2.12 kbar. The study supports epithermal nature of fluid inclusions. The characteristic of fluid inclusions along with lithological and structural peculiarities, nature of structural features may be helpful in understanding the nature of geological formation of quartzites in the study area.

Keywords: Fluid inclusions, Fluid Petrography, Microthermometry, Quartzites.

1. INTRODUCTION

Fluid inclusion studies become an important step in understanding many aspects of the interaction between fluids and rocks. Interest in study of fluid inclusions in the Earth Sciences goes back to works of the founding father of fluid inclusions, Henry Clifton Sorby[1] (1858) whom described samples from ore deposits containing fluid inclusions and drew conclusions concerning ore formation. The modern science of fluids inclusion geochemistry grew principally out of pioneering work on hydrothermal ore deposits more than 50 years ago [2]. Understanding the role of fluids in geologic processes requires knowledge of the P-V-T Properties of fluids over a wide range of conditions [3]. Most fluid inclusions occur along fractures that cross cut the grain boundaries at the time of metamorphism, which was recognized early by Tuttle (1949)[4]. The studies of fluid inclusions in the metamorphic rock help us to understand the nature and type of intergranular fluids during metamorphism [5 & 6]. Thus, the fluid inclusion data not only yields information on the nature and composition of fluid regime, but also about the events

of deformation, recrystallisation and uplift histories which were affecting the fluid inclusion bearing phases [7 & 8]. In the present investigation, fluid inclusions are conspicuously present mainly in quartz grains of Quartzites and fuchsite quartzites.

2. GEOLOGICAL SETTING

The Ghattihosahalli schist belt (GHSB) is located on the western margin of the main Chitradurga schist belt in Karnataka. The supracrustal belt in this area is one of the best preserved in the state. This belt has a northwest trend and is linear. In the north, the belt stretches for over 25 km, and in the south, it extends east of Talya for over 25 km. On the west GHSB, the TTG Peninsular gneisses 3.1 Ga older than the belt [9] are poorly defined, and on the east, the old Chitradurga belt 2.6 Ga older than the belt [10]. Radhakrishna and Sreenivasaiah [11] describe the volcanic-sedimentary sequence as composed of ultramafic komatiites and amphibolites interlayered with fuchsite quartzite and barite. Viswanatha et al [12] reported the first record of spinifex texture in India from the serpentinite of this belt. The idealized upward stratigraphy of amphibolite, ultramafite and fuchsite quartzite visualized for this belt by Narayana and Naqvi [13] is not borne out by field evidences. The gneisses around the belt have abundant enclaves of amphibolites and ultramafic rocks. Two major geological components can be found within the schist belt. It was found in the western part of the area that the older components were found, which belong to the Sargur group. The Bababudan group has younger components on the eastern side of the belt, which make up the lower part of the Dharwar Supergroup.

The Sargur supracrustals within the Ghattihosahalli belt are primarily composed of meta-ultramafics, mafics, and their associated subordinate metasediments arranged without stratigraphic distinction. As part of Ghattihosahalli belt, the Sargur complex exhibits a variety of metasediments associated with mafic and ultramafic rocks. Although the belt is composed of 10-15% metasedimentary rocks, its association with sub-aqueous volcanic rocks is very important for understanding Archaean sedimentation and volcanism [14]. The baryte occurs as thin lenses and bands of conformable but discontinuous structures within the quartzite near the metabasic and metaultramafic rocks underneath. Chromiferous quartzite is the predominant horizon in which barite bands occur. It is clear from the association of the metasediments in the field with the underlying mafic-ultramafic flows as well as their petrographic characteristics that the metasediments are volcanic exhalates [15].

3. ANALYTICAL METHODS

Doubly polished thin wafers of about 100 to 120 μm thickness were prepared for selected rock samples. The study of 60 wafer and doubly polished thin section for petrographic features of fluid inclusions in the quartz samples taken from surface exposures of quartzite, fuchsite quartzite and from quartz vein associated with fuchsite quartzites. Fluid inclusions study was carried out with an Olympus-BX51 microscope with a 50X objective. Microthermometric studies were carried out using the LINKAM-THMS-600 heating and freezing stage, by passing a nitrogen gas with the help of copper coil immersed in a Dewar flask filled with liquid nitrogen. This work was carried out in the fluid inclusion lab,

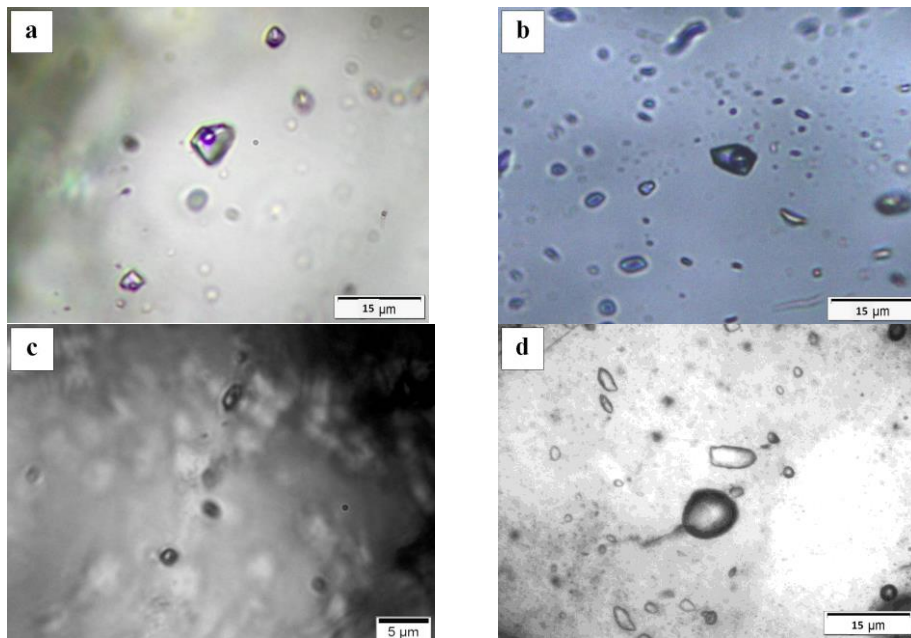
Department of Earth Science, Indian Institute of Science (IISc), Bangalore. Microthermometric data reported are within the error of $\pm 0.2^\circ\text{C}$. By using the equations of state available for different systems, the salinity and density was calculated for the different types of inclusions. The available resource (PVTX tool "HOKIEFLINCS_H2O-NACL" of Steele-MacInnis (2012) [17], program AqSo of Bakker, 2003[18]) have been used to calculate the salinity and density. Also the equations of Zhang and Frantz (1987) [19] and Brown and Lamb (1989) [20] were used for the estimation of aqueous fluid inclusions and the equation of Bower and Helgeson (1985) was used for the calculation of $\text{CO}_2\text{-H}_2\text{O}$ inclusions. The microthermometric studies have been performed for only selected fluid inclusions present in the quartz grains. The purpose of microthermometric analysis is to observe the different phase transitions within the fluid inclusions in response to temperature changes.

4. FLUID INCLUSIONS CHARACTERISTICS

Double polished sections were prepared for fluid inclusion studies and fluid petrographic studies have been carried out for the selected quartzite samples. Based on the observations indicates all fluid inclusions are restricted to quartz mineral of the quartzite and fuchsite quartzite rocks of the study area. Eleven quartzite samples were selected for fluid inclusion studies, five from the quartzites, three from fuchsite quartzite and three from quartz vein associated with fuchsite quartzite. The fluid inclusion present within the individual quartz grains occur as isolated, cluster and some are intragranular and also along the grain boundaries. Based on the phases present in the inclusions are distinguished as monophasic liquid rich and vapour rich biphasic at room temperature. The monophasic fluid inclusions are common and are contain H_2O and few of CO_2 phase. The liquid rich biphasic inclusions abundant and contain vapour of H_2O with liquid H_2O . The vapour rich biphasic inclusions are rare and mostly contain CO_2 which is surrounded by liquid H_2O and $\pm\text{NaCl}$. The intra-granular and trans-granular trails are generally observed and contain extremely small and highly distorted monophasic and biphasic inclusions. The quartz grains contain four types of fluid inclusions, distinguished on the basis of their textural/phase relationships at room temperature, homogenization behavior and fluid type. Primary inclusions are randomly distributed towards the centre, mostly isolated in appearance. Secondary inclusions occur in the form of trails that cut across the grains. The inclusions are observed in the quartz grains, that are filled with H_2O - NaCl , $\text{CO}_2\text{-H}_2\text{O}$, pure CO_2 and H_2O . They are grouped into four types: type-I aqueous carbonic inclusions, type-II carbonic monophasic inclusions, type-III aqueous bi-phase inclusions and type-IV Monophasic H_2O aqueous inclusions. The detailed fluid inclusion petrography is carried out and description is summarized in the respective sections below. Type I inclusions are primary biphasic, liquid+vapour (L+V) aqueous-carbonic fluid ($\text{CO}_2\text{-H}_2\text{O}$) inclusions and homogenize to the liquid phase. They are present in both quartzite and fuchsite quartzite samples. The CO_2 vapour is circular and spherical and are homogenized into the liquid phase. These inclusions occur as isolated inclusions (Fig. 1a) and as mixed clusters with aqueous monophasic inclusion at the grain cores (Fig. 1b) of both quartzite & fuchsite quartzite samples; they can be considered primary in origin

following the criteria of Roedder (1984) [16], i.e. they were entrapped during quartz crystallization.

The aqueous carbonic inclusions often show varying degrees of fill. These inclusion ranges in size from 4 to 15 μm . Type II inclusions are primary monophase CO_2 inclusions were noted (Fig.1c & d) to coexist with type-IV inclusions in quartz of quartzite and quartz vein. They are isolated rounded to sub rounded in shape. These inclusions vary in size from 3 to 15 μm . Type III inclusions are comparatively more abundant than any other inclusions and these inclusions occur as isolated tabular, arrayed and sub-rounded clustered (Fig.1.e, f & g). They are generally small and rounded as well as irregular and contain two phases, liquid ($\text{H}_2\text{O}+\text{NaCl}$) and a vapour bubble (H_2O), that is homogenized to liquid upon heating. Also they are exhibiting intergranular (fig.1.h) cutting nature of $\text{H}_2\text{O}-\text{NaCl}$ secondary inclusion in quartzite. These inclusions are having range of size from 3 to 20 μm in size. Type IV inclusions are aqueous and are characterized by only a single aqueous (H_2O liquid) phase. On the freezing of Type IV inclusions, these are found to be as pure aqueous, and are most common in all the studied samples. They commonly occur with Type-I and Type-III inclusions. Their shape varies from rounded to irregular, with the size of these inclusions ranging from 2 to 10 μm . Generally, they are seen as clusters and also in the form of randomly distributed in the quartz grains and the later type are trapped after the growth of the host mineral along microfracture. The trails of the secondary inclusions may be seen in several grains having a cross-cutting relationship with the grain boundaries (Fig.1 i & j).



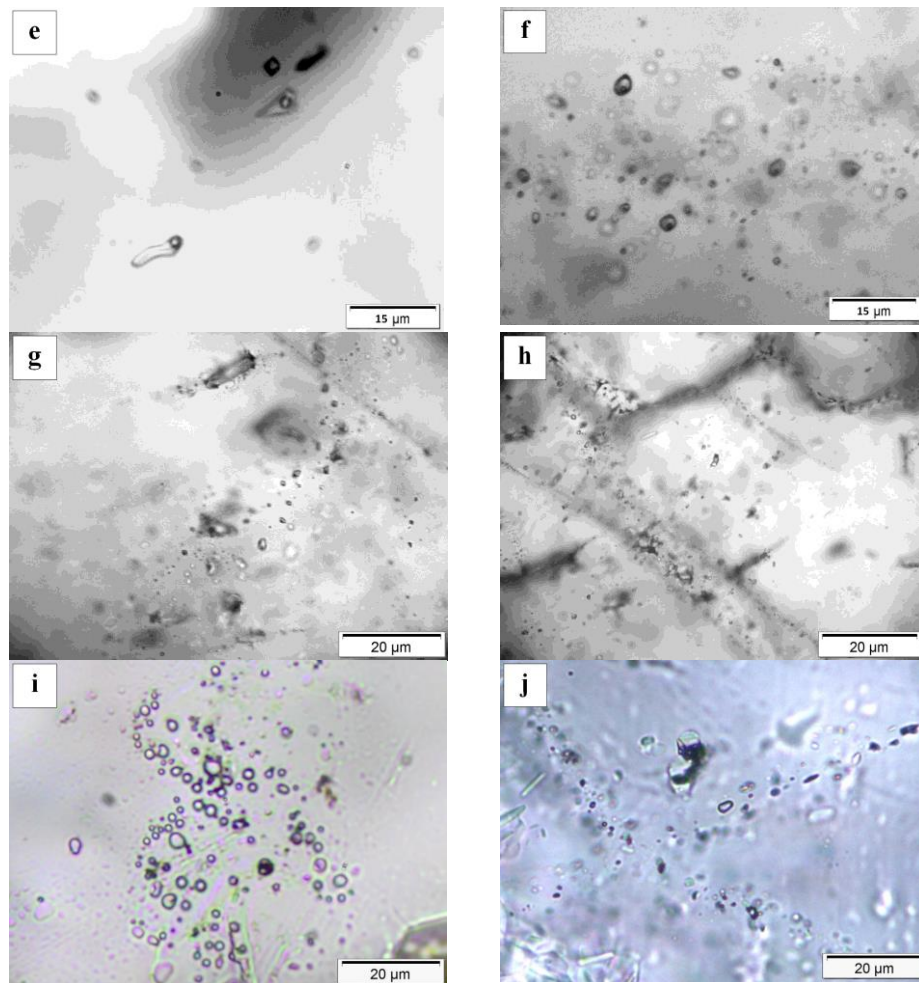


Figure 1: Fluid inclusion photomicrographs: (a) Primary biphase CO₂-H₂O inclusions in the quartz grain. (b) Randomly distributed biphase aqueous-carbonic primary inclusions with monophasic aqueous inclusion in quartzite. Isolated monophasic primary CO₂ inclusions (c & d) and (e & f) primary biphase tabular and subrounded clustered H₂O-NaCl inclusion in the quartz grain. (g & h) Secondary Biphase H₂O-NaCl inclusions in form of planar arrays with cross cutting nature. (i) Rounded to subrounded primary aqueous inclusion. (j) Aqueous inclusion with cross cutting nature.

5. MICROTHERMOMETRY

Microthermometric analyses of fluid inclusions for selected quartzite and fuchsite quartzite samples were carried out and the values are summarized in Table 1. The sizes of all the investigated fluid inclusions vary between 2 and 20 μm. Most of them are found to be monophasic (liquid) and biphase (liquid + vapor). Lesser amounts of monophasic vapor inclusions are also present.

Table 1: Microthermometric data recorded in different fluid phases in quartz grains of different rock types of study area

Rock type	Fl type	N	T _{mCO₂}	Th _{CO₂} (°C)	Te (°C)	T _{mice} (°C)	Th _{total} (°C)	T _{m_{clath}} (°C)	Salinity (wt. % NaCl eq.)	Density g/cm ³
Quartzite	Type-I	36	-55.8 to -57.2	16 to 30	-18 to -32.4	-2.5 to -4.5	200.8 to 302	4 to 8.5	1.49 to 12.3	0.70 to 0.86
	Type-II	15	-56.6 to -57.2	13.8 to 18.3						0.79 to 0.83
	Type-III	23			-20.9 to -24.3	-2.7 to -6.8	112.5 to 287.3		4.49 to 10.24	0.81 to 1.02
Fuchsite Quartzite	Type-I	21	-55.6 to -57.1	18.4 to 28.8	-19.3 to -24.2	-1.8 to -6.4	200 to 262.3	7 to 8.4	4.03 to 9.61	0.69 to 0.96
	Type-III	48			-17.2 to -23.8	-6.3 to -2.1	144.5 to 248.3		3.55 to 9.60	0.83 to 0.97
Quartz vein	Type-I	17	-55.8 to -57.2	15.2 to 29	-18 to -26	-1.8 to -7.5	190 to 286	4 to 7.5	4.80 to 10.50	0.70 to 0.92
	Type-II	9	-56.5 to -57.4	16.4 to 19.2						0.78 to 0.81
	Type-III	35			-20 to -26.3	-2.1 to -6.3	127.6 to 242		3.55 to 9.70	0.85 to 0.97

Type I Inclusions are the biphasic aqueous carbonic inclusion, where liquid is the dominant phase. The homogenization temperature recorded by the disappearance of the tiny bubble. The inclusions have values of T_{m_{ice}} in the range of -4.5° to -2.3°C, -1.8 to -6.4°C and -1.8 to -7.5°C in studied quartzite, fuchsite quartzite and quartz vein respectively (Table I).

Homogenization is always into the liquid state by vapour disappearance (L+V →L) and Th values are in the range of 200.8 to 302°C, 200 to 262.3 °C and 190 to 286 °C for quartzite, fuchsite quartzite and quartz grain from quartz vein respectively. The assemblage of ice, liquid CO₂, clathrate, and vapour observed in inclusions may be a disequilibrium assemblage, resulting from the barrier formed by clathrate between the liquid, aqueous, and carbonic phases, as suggested by Diamond (1994)[21].

Type II inclusions are monophasic inclusions show complete CO₂ melting (T_m (CO₂)) range from -56.6 to -57.2°C and -56.5 to -57.4°C for quartzite and quartz vein respectively (Table 1), and type II inclusions are not found in the studied fuchsite quartzite samples. Temperature of homogenization of CO₂ (Th(CO₂)) varies from 13.8 to 18.3°C in quartzite and 15.2 to 29 °C in quartz vein (Table.1). Homogenization is always into liquid state by vapour disappearance. Although these inclusions are apparently monophasic and are filled with near pure liquid CO₂. These mono-phase carbonic (CO₂) fluid inclusions are dark in colour. They are rounded and anhedral in nature. Carbonic fluid inclusions are less abundant than aqueous carbonic inclusions in these samples. The density of the CO₂ varies from 0.70 to 0.92g/cm³.

Type III inclusions are biphasic liquid-vapour (H₂O+NaCl) are observed in studied quartzite and fuchsite quartzite along with quartz vein. The salinity of aqueous fluid inclusions can be estimated from the melting temperature of ice during a cycle of freezing and heating. The salinities of the fluid inclusions range from 1.49 wt% to 12.3 wt% NaCl equivalent, which are included in the range of the isolated fluid inclusions. The histograms of the salinity and homogenization temperature for type-III fluid inclusions are shown in Figure 2a. The range of the salinity contents in quartzite and fuchsite quartzite is range

from 4.49 to 10.24 wt. % and 3.55 to 9.60 wt. % respectively. The homogenization temperature of the isolated inclusions range from 112.5 °C to 287.3°C in quartzite and 144.5 °C to 248.3 °C in fuchsite quartzite. The results of the microthermometry experiments show that there is light difference between the studied fluid inclusions in terms of the salinity and homogenization temperature. Histograms (Fig.2) showing the different microthermometric parameter of different fluid inclusion, like melting temperature, Homogenization Temperature , salinity frequency and frequency of Density for studied inclusions from quartzitic samples.

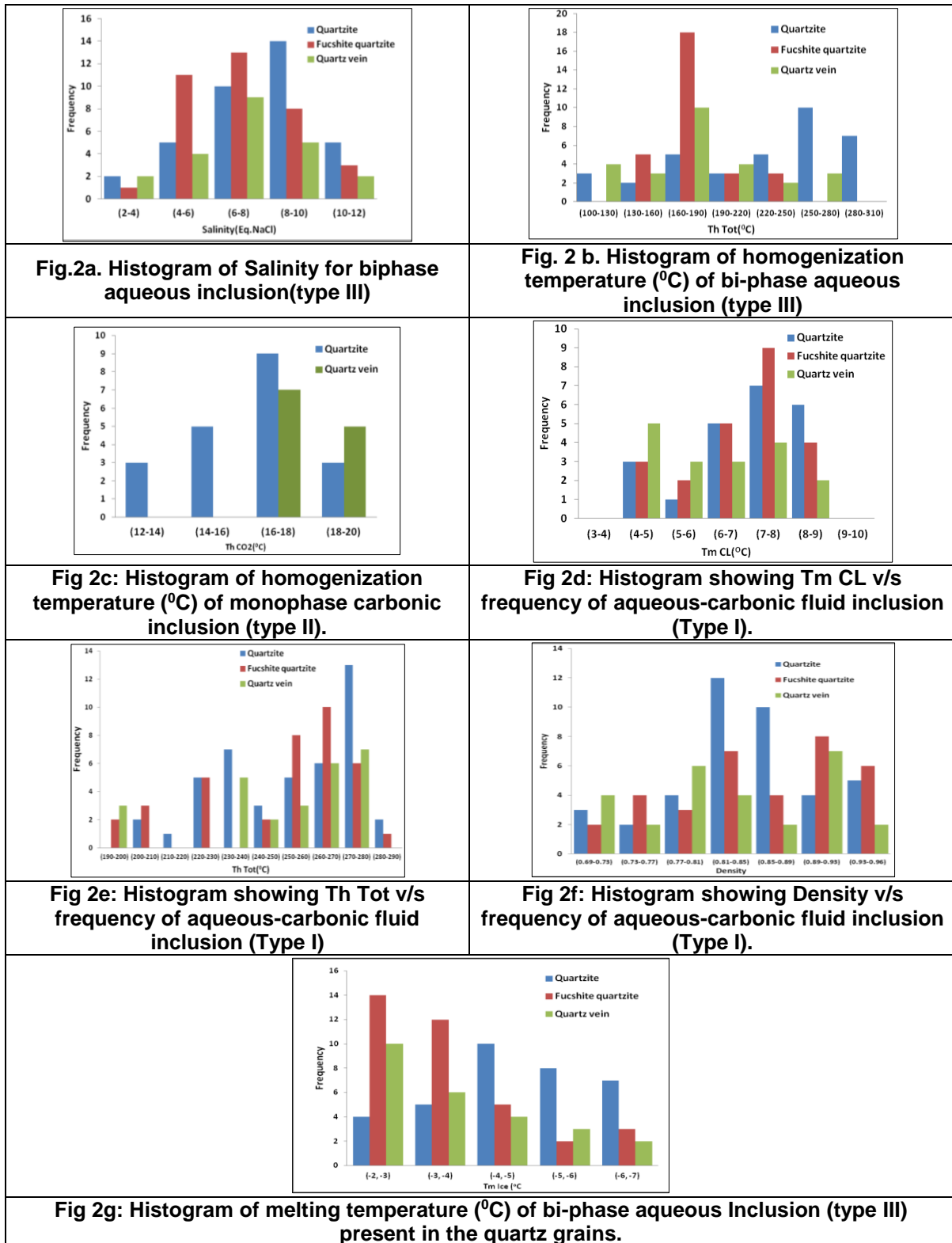
6. RESULTS

6.1 Homogenization Temperature

The homogenisation temperatures (T_h) was recorded from inclusions in quartzitic rocks of the study area. Total homogenisation results are presented in figures (Fig.2). The bi-phase aqueous inclusion homogenized in quartz in the range of 112.5 to 248.3°C (Fig. 2b). This data is very much similar to the inclusions observed in diagenetic mineral phases [22]. The homogenization temperature shown by the inclusions present inside the quartz grain is much higher than 170°C. Although most of the inclusions present in this category homogenized in between 160 to 190°C. Which is much more alike the maximum diagenetically produced homogenization temperature of 160°C as exemplified by Visser [23]. The monophasic carbon inclusion homogenized in quartz in the range of 13.8 to 19.2°C. The histogram of homogenization temperature of these inclusion is shown in fig. 2c majority if inclusion homogenized in the range of 16 to 18°C.

6.2 Melting Temperature

The melting temperature data was recorded from quartz grains during microthermometric studies. The initial melt temperatures of type III inclusions are range from -17.2°C to -26.3°C. This initial melting temperature indicates the composition of fluid is essentially NaCl-H₂O. The final melting temperature in quartz range from -1.8 to -6.8°C, majority of the inclusions are having melting temperature range from -1.0 to -3.0 °C fig.2g . The final melting temperature data can be used to derive the salinity of a given fluid, expressed as equivalent weight percent NaCl [24]. The range of interpreted salinities is from a large cluster of results around -2 to -3°C. The salinity variation within the quartz grain is in the range of 0.7 % to 1.02%.. The implications of the varying of salinities of the migrating fluids.



6.3 Salinity

The calculated salinity of fluid, absence of daughter crystal, low gas content, and the plot between salinity v/s homogenization temperatures suggests that the inclusions in the quartzs are of epithermal in nature (Fig. 3). The epithermal formation of the fluid inclusions also suggest the low trapping pressures and therefore, the temperature of formation of quartz veins can be calculated from the range of homogenization temperatures of inclusions which are the histogram mean of homogenization temperatures [25 & 26]. The trends of inclusion plots indicate the following possibilities [27], Mixing with cooler, less saline fluid, Simple cooling, Boiling with slight cooling.

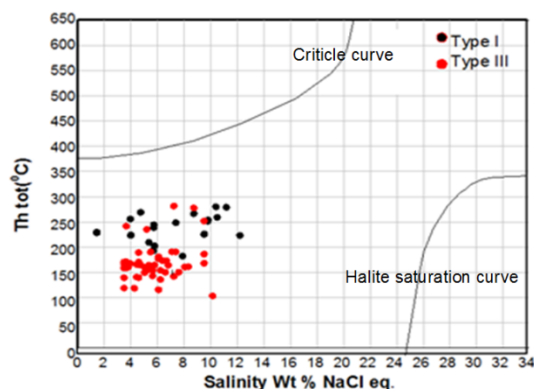


Fig 3: Plot showing Th TOT v/s salinity of type I & type III inclusions.

The trend line of temperature of homogenization vs. Salinity plot is shown in (Fig. 3) which indicates the mixing of fluids with moderate to high salinity at moderate temperature. The possibility for the contrasting fluid composition of type I and type III inclusions is fluid mixing of two different compositions.

7. ESTIMATION OF P-T CONDITIONS OF FLUID ENTRAPMENT

Fluid inclusion studies are the best tools for the estimation of trapping temperature and pressure of the fluids. With the help of necessary data, the interpretation of the trapping condition of fluids can be performed. Trapping pressures of fluid inclusions have been determined using CO₂-rich inclusions in quartz from the quartzites of the study area. The temperatures of CO₂ melting range between -56.5 and -57.4 °C. The temperatures of CO₂ homogenization to liquid phase range between 13.8 and 19.2 °C. The total homogenization temperatures of these inclusions range between 200 and 287 °C. The CO₂ densities range between 0.70 and 0.96 g/cm³. The pressures at temperature of 300 °C are calculated in the range of 1.2–1.6 kbar [28]. The isochores have drawn following the densities determined for the appropriate aqueous and carbonic fluids (Fig. 4). The field of the crosscutting isochors specifies the P-T conditions in which these fluid inclusions trapped. It is found that the minimum pressure during the trapping of this fluid inclusion in studied quartzites were ranging between 1.15 to 2.12 kbar with the corresponding temperature of 287°C to 302°C.

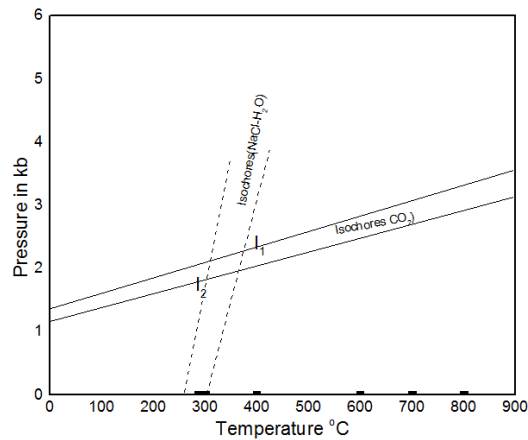


Fig 4: P–T binary diagram with isochors. The I₁&I₂ illustrates the P–T conditions of entrapment of the inclusions. P–T obtained from the aqueous-carbonic inclusions are from the intersection points.

8. CONCLUSION

Fluid Inclusion micro-thermometry, along with petrography, becomes exceedingly valuable in the reconstruction of the thermal and recrystallization history of sedimentary rocks [29; 30]. A wide range of information on the evolution of a sedimentary succession can be derived from the study of diagenetic minerals and their genetic relationships. Fluid inclusions trapped, therein, can reveal the fluid regime in the area of provenance, and the diagenetic and re-crystallisation history of these rocks. The inclusions are filled with two types of fluids viz. an aqueous saline fluid and a mixed aqueous-carbonic fluid. Aqueous saline inclusions, aqueous brine inclusions and aqueous carbonic fluid inclusions occur primarily in the grains, although they were insignificant in the studied samples. It is evident that during the crystallization of detrital quartz grains in the protolith, aqueous brine having salts upto 9.45 wt% NaCl equivalent and a CO₂–H₂O fluid with a CO₂ density of about 0.98gm/cm³ were trapped in the grains. The presence of inclusions with aqueous brine and the aqueous carbonic inclusions in the same grain indicates that H₂O–NaCl– CO₂ fluid was present during the growth of quartz grains.

Petrographic studies indicate the presence of primary and secondary mono-phase/bi-phase inclusions in sample. The characters of the bubble indicate heterogeneous nature of the parent fluid. The highest homogenization temperature of these inclusions (302°C) could therefore provide a minimum temperature of the original trapping conditions. In nature this may result from decompression due to the isothermal exhumation of the rocks. Various re-equilibration textures observed suggest high internal pressure with respect to confining pressure indicating de-compressional exhumation phenomenon for quartzitic rocks. Interpretation of the trapping condition of fluids performed. From the study, it is found that the P-T condition for the trapping of these fluid inclusion in quartzites were ranging between 1.15 to 2.12 kbar.

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