PETROLOGY AND FLUID INCLUSION STUDIES OF CORDIERITE BEARING GNEISSES: A CASE STUDY FROM THE KERALA KHONDALITE BELT, INDIA

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ABSTRACT

The petrological, geochemical and fluid inclusion characters of Cordierite bearing gneisses of Kulappara are reported in this study. The common mineral assemblages of the quarry were identified as Garnet + Sillimanite + Cordierite + K-feldspar + Biotite + Quartz + Plagioclase + Rutile with accessory mineral such as Zircon and Monazite.The symplectite and granoblastic textures were obtained from the samples which revealed that the prograde and retrograde metamorphic mineral reaction might have prevailed during partial melting. The parentage material of the Kulappara Khondalitequarry might have been derived from Pelitic rocks. The presence of CO_2 rich fluids were observed entirely in the quarry.

Keyword: *Cordierite bearing gneisses, Kulappara, Petrography, Geochemistry, XRD, XRF, SEM, Fluid inclusion, CO2 and Lazer Raman.*

INTRODUCTION

The linear strip of land, forming the southern tip of the peninsular Achaean gneiss – granulite terrain (Radhakrishna, 1989), constitute one of the oldest regions in the Indian shield and it was undergone multi tectogenesis (Rao, 1978). Kerala state covers an area of 38,864 sq Km and is located in the south western part of the Indian Peninsular shield. Geologically Kerala is composed of Precambrian crystallines, acid to ultra-basic intrusive of Archean to Proterozoic age, Tertiary (Mio-Pliocene) sedimentary rocks and Quaternary sediments of fluvial and marine origin. Both of the crystallines and tertiary sediments have been extensively lateralized (Chacko et al., 1987).

Southern Kerala comprises an assemblage of migmatisedmetasedimentary and metaigneous rocks, khondalite-charnockite assemblages (Chacko et al., 1987 & 1996). Patches of charnockites are associated with this khondalite group of rocks as well. Geochronological domains in the KKB give the aspects of evolution of the crustal structure. Most of the geochronological data are concluding that the time of origin of the KKB is Proterozoic age and the parent material is sedimentary origin (debating). It also belonged to an eastern Gondwana mobile belt that underwent ultra-high temperatures metamorphism at Pan – African rift time. There are evidences from Sri lanka, Madagascar and Antarctica for the Pan - African rift which says that the high grade metamorphism was in action (500-700ma) in the east and west Gondwana, the Proterozoic part of peninsular India. Other than Kerala, khondalites are present in the different part of world like China, Madagascar, Sri lanka and Antarctica. In India, it is also present in Orrisa and Andhra Pradesh. Southern granulite terrain consists of different Blocks. Mainly Nilgiri, Madurai, Trivandrum, Salem and Madras Block; these blocks are divided by major tectonic features called shear zones. P-T estimates of Indian peninsular shield fall in the range of 5-10 kb and 650-950^{o}C. Trivandrum Block (TB) is one of the blocks which present in the Southern tip of Indian peninsular. The Trivandrum Block is divided into subgroups according to the lithological characteristics. The major lithological formation present in the terrain is Khondalite. The Khondalitic rocks are found extensively in the Trivandrum block named as (KKB) Kerala Khondalite Belt. KKBexhibit high grade metamorphic terrain and having a temperature range of 650-800^{o}C at a pressure of 7 – 10kb. The ultra-high temperature (UHT) is also noticed in this terrain, which shows the dynamic evolution of the crustal structure of KKB(Chacko et al., 1987; 1996; Harley, 1998 and Santosh et al., 2005). The dominant lithologies in KKB were found as garnet + plagioclase + k-feldspar + silliminite + biotite + cordierite

+ graphite (khondalites), Calcgranulites, quartzite. Minerals like ilmenite, spinel, monazite and zircon are also present in the khondalitic rock as an accessory (Ravindrakumar and Thomas Chacko, 1988). Scapolite–wollastonite–grossular bearing calc-silicate rocks form the Vellanad area in the Kerala Khondalite Belt (Chetty et al., 1996; Drury et al., 1984. In this manuscript, we are presenting the conclusions derived from results of mineralogical and petrographic characteristics, major element characteristics and fluid inclusion of the cordierite bearing gneisses in Kulappara Quarry.

STUDY AREA

The NW-SE trending Achankovil shear zone (ASZ) was the most prominent geological feature in the southernmost part of Kerala. It is also known as Trivandrum block (TB), (earlier it was known as Kerala Khondalite Belt or KKB). The major rock unit observed in this area were Meta – sedimentary sequence of Khondalite.The Khondalites were well exposed in the different regions of Trivandrum block (TB), Thiruvanadapuram district of Kerala state(Fonvarev et al., 2000). Kerala state bounded by north latitudes 8^0 17’ 30’’ and 12^0 47’ 40” and east longitude $74^0$51’57’’ and $77^0$24’47’’ covers an area of 38,864 sq Km and is located in the south western part of the Indian Peninsular shield.The study area and the sampling sites were shown in Figure 1.

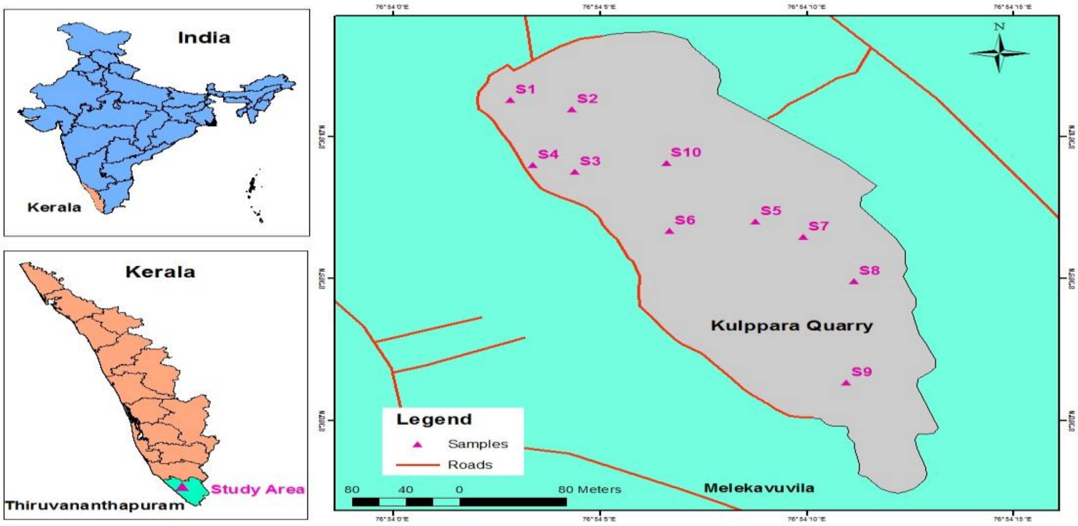


Figure 1 Map showing study area and sampling location in Kulappara Quarry.

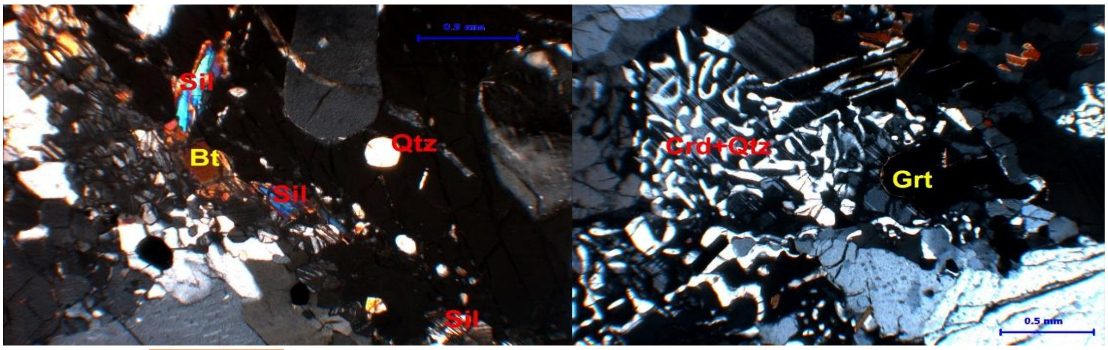
MATERIALS AND METHODOLOGY

All samples were collected only from the fresh surface of the outcrop. The samples are collected manually and made it into different sizes using the geological hammer and chisel. The wet samples were dried at 60°C till the sample turned moisture free condition. The samples have been made into pieces and were powdered according to specification. The coarse fraction of samples where made into very fine and equal grain size using Agate mortar. The powdered fractions were kept under 60°C to remove the wet and free from moisture. X-ray diffract meter (XRD) studies were carried out to establish their mineralogy and by X-ray fluorescence, elemental analyses were done at National Institute of Interdisciplinary Science and Technology, Trivandrum, India. The processed rock fraction samples have been examined under a Leica D-250 binocular microscope for petro graphical assessment. Scanning electron microscopic, analyses were also done for the samples to understand mineral abundance using JEOL JSM 5600 LV microscope. Fluid inclusions studies were subjected to microscopic analyses using Leica Microscope, LAS V3.8.The LASER Raman micro spectrometer is used to analyses the systems contain in the fluid inclusions.

RESULTS AND DISCUSIONS

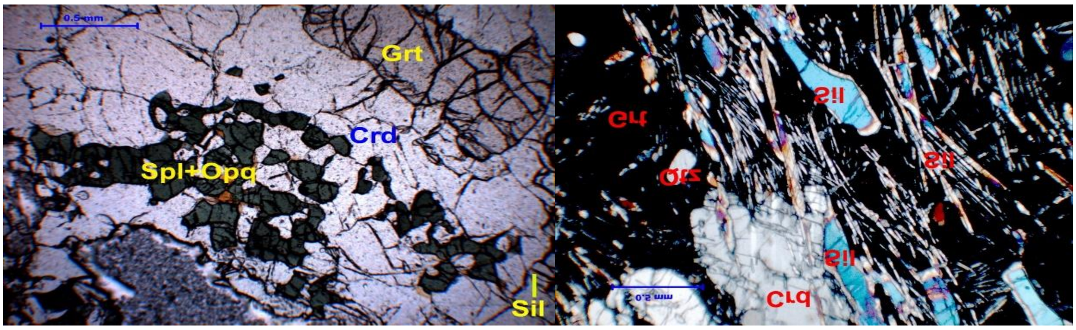
Petrographical analysis of the sample from the Kulapparaquarryexhibits textures indicative of prograde metamorphism. The garnet is seen as porphyroblasts(Figure 2) of 1-1.8 mm surrounded by cordierite, spinel,biotite and quartz in sample KPA6 (Figure 3). Harley and Nandakumar(2014), were stated that the dominant rock types in the central Trivandrum Block have been found as quartzo-feldspathic garnet-biotite gneisses, garnet- cordierite-sillimanite-ilmenitebearing migmatiticpelites with or without spinel, and minor orthopyroxene-bearing garnet – cordierite - ilmenite -(magnetite) - spinel aluminous magnesian gneiss. The results obtained from the current study were strongly corresponding with Harley and Nadakumar findings. Cordierite forms some symplectite intergrowth with quartz, which are mostly concentrated at the rim of the garnet. Cordierites were found anhedral and fine grained. This texture gives an idea of garnet breakdown during some retrograde process at corona of cordierite – quartzsymplectite along grain boundary. Cordierite + quartz symplectite around garnet suggests the prograde metamorphism (Figure 2). This represent a melt involved reaction,

Grt + Melt ⇄Crd + Qtz (equation 1; Cenki et al., 2002)



KPA1 KPA3

Figure2 Photomicrograph of sample KPA1 show, poikiloblastic garnet with inclusions of sillimanite, quartz and biotite. Sample KPA3, show Cordierite + quartz symplectite around garnet suggesting the progressive metamorphism (Right Upper).



KPA6 KPA7

Figure 3 Photomicrograph of sample KPA6, showed, Fine-grained aggregate of spinel + cordierite + opaque minerals (Left bottom) and sample KPA7 showed aggregates of cordierite mantling anhedral garnet suggesting the progress of garnet breakdown reaction to form cordierite (Right Bottom).

Bulk Mineralogy of the samples has been determined using XRD and XRF analysis. Geochemistry of the samples was determined using the X- Ray fluorescence Pan – Analytical Instrument. Based on the bulk mineralogy, the minerals obtained from samples were, quartz (major phase), followed by garnet (almandine, pyrope), cordierite

(Figure 4 b-c), biotite, sillimanite and spinel as the other major minerals and zircon, monazite and ilmenite (Figure 4c) were the accessory minerals which have been shown in figures 4a-4c. Wollastonite, diopside and clino-pyroxene (Figure 4a) were found very less in abundance and were not well distributed in the quarry. Cordierite, Sillimanite (6 c-d) and Garnet are moderately distributed in the quarry.

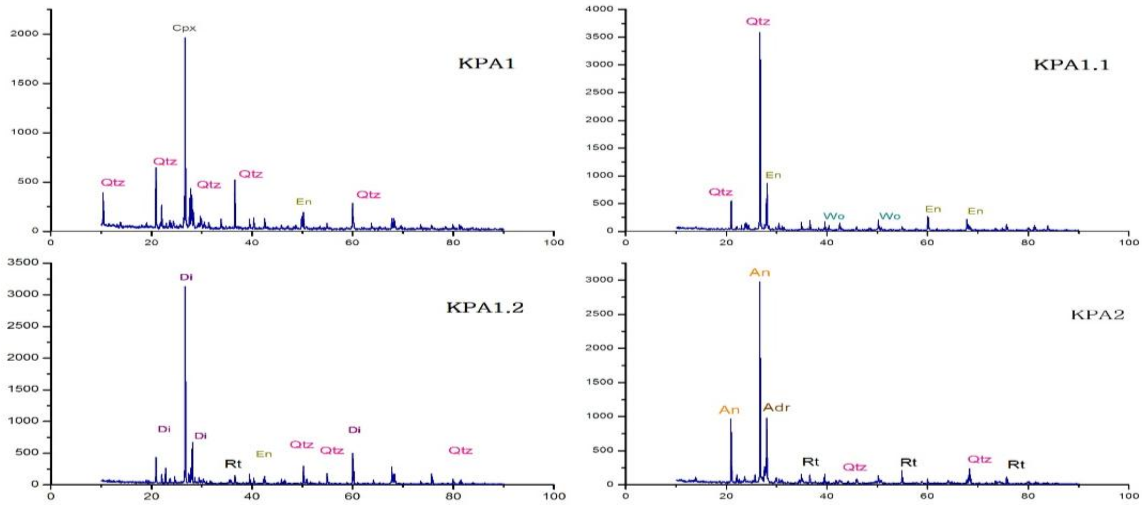


Figure 4a XRD pattern showed peaks of Quartz (Qtz), Clino-pyroxene (Cpx), Garnet (Adr) Rutile (Rt), Enstatite (En), Wollastonite and Diopside (Di). Note that X-axis denote 2 ° Theta and Y-axis denote count %.

X-Ray Fluorescenceanalyses were revealed the presence of major element representation in the samples. The results shown that, the SiO_2 (wt %) marks the highest weight percentage among all other major oxides, in the sample which is followed by Al_2O_3, Fe_2O_3, K_2O,CaO, MgO,TiO_2, P_2O_5 and Na_2O as the major oxides. The elemental ratio found increasing in the order of Si >Al > Fe> K>Ca> Mg> Ti > PO> Na. The Major oxides were plotted in the ACF diagram in order to get the rock parentage of the Kulappara Quarry. Alkaline, Silica and Ferro magnesium and calcic oxides weight % were plotted in the ternary diagram (Figure 5). The pelitic rocks are the parentage of the Kerala Khondalite Belt (Cenki et al., 2002, Ravindrakumar and Chacko, 1994;Radhika and Santosh, 1996). The parentage of kulappara quarry is also found to be falling under the same source by ACF analysis.

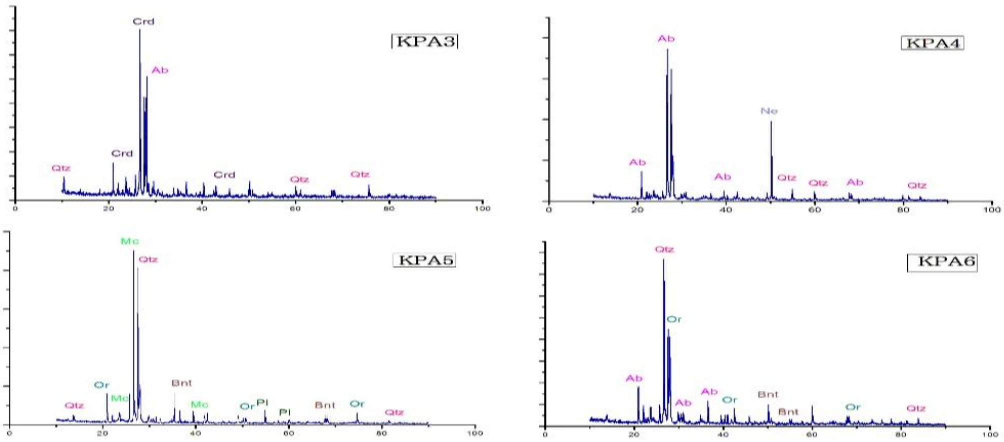


Figure 4b XRD pattern showing peaks of Quartz (Qz), Garnet (almandine, pyrope), Cordierite (Crd), Biotite (Bnt), and K-Feldspar (Ab, Or and Mc). Note that X-axis denote 2 ° Theta and Y-axis denote count %.

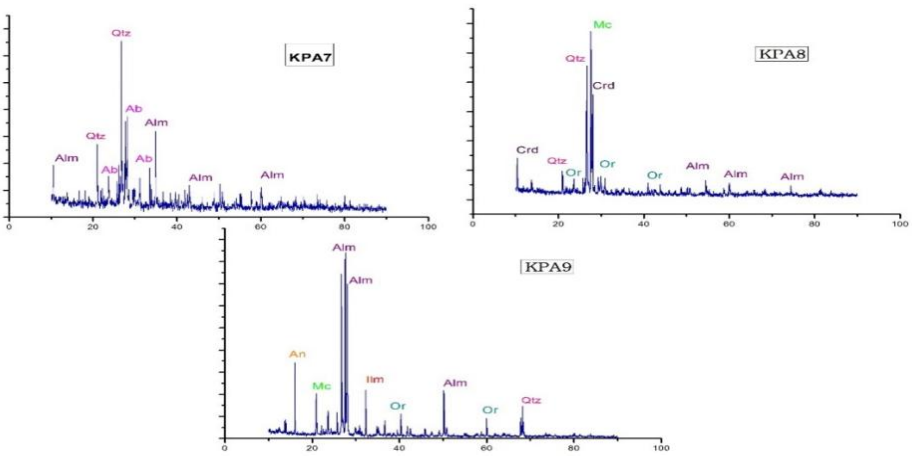


Figure 4c XRD pattern showed peaks of Quartz (Qtz), Cordierite (Crd), Garnet (Alm), Ilmenite (Ilm) and Feldspars (Mc, Or and An).Note that X-axis denote 2 ° Theta and Y-axis denote count %.

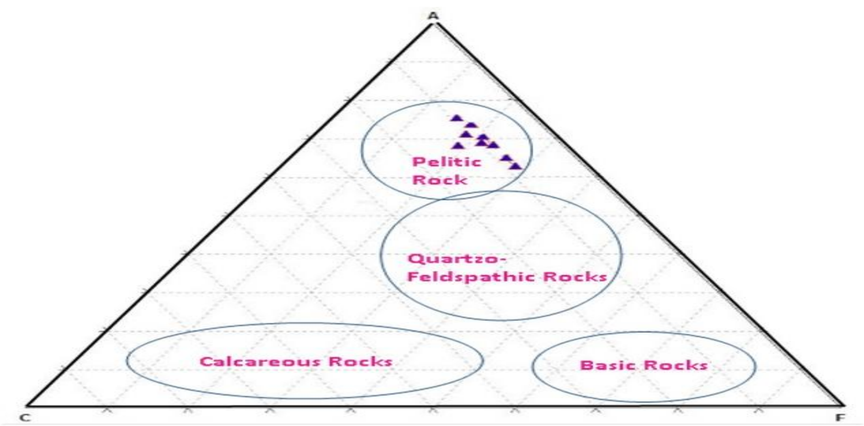


Figure 5 ACF diagram showing the parentage rock type and the samples from the study area were belongs to Pelitic type of Rock

The micro morphology of the rock was identified with the help of SEM (Figure 6). The individual mineral sample and its micro morphology are revealed with the SEM images. Flaky nature of biotite (Figure 6 a-b) was preserved at its micro level and prismatic shape of sillimanite(Figure c-d) was also visible. The conchoidal fracture or shape of quartz mineral, hexagonal shape of garnet is identified from the SEM image (Figure 6 d).Vermicular biotite with the flaky nature, prismatic sillimanite, and lamelle of plagioclase minerals were also identified in the SEM image. We could alsoobservethe initial stage of weathering and alteration of the samples from the Kulappar quarry (Figure 6 a-d).

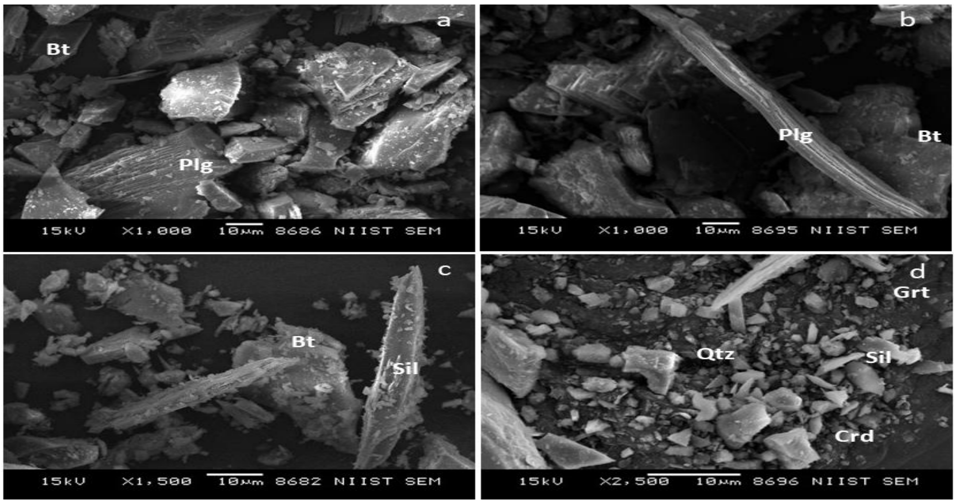


Figure 6 Scanning Electron Microscope Images of the samples of the study area. a) Lamelle of plagioclase and flaky appearance of biotite (KPA2), b) flaky sheets of biotite are arranged and lamellas packing in plagioclase (KPA4), c) prismatic sillimanite and flaky downside dip of biotite (KPA5) and d) conchoidal fracture in quartz, needle shape of sillimanite, hexagonal shape of garnet (KPA-8).

Fluid inclusions may occur in almost all minerals but in metamorphic rocks, fluid inclusions are present mostly in quartz or calcite. More than 90% of fluid inclusion studies of metamorphic rocks were carried out from quartz since it is a principal phase of the peak metamorphic assemblage with high viability for heating freezing experiments.

Textural relationships between fluid inclusions and the host mineral are very important when interpretation of fluid inclusions were done. The fluid inclusion petrography of the samples is observed at a room temperature of 26-28°C. The most common type of fluid inclusions is monophase gas rich which are inferred to be of CO_2. These inclusions are found as solitary negative crystal type inclusions or in isolated groups, which can be considered of primary origin, compared to those occurring as arrays along healed or fresh fractures (pseudo secondary and secondary). Brief descriptions of the samples from the three localities were studied and the natures of inclusions seen in them were discussed in detail. The samples which were collected from the Kulappara Quarry showed some inclusions, KPA1 sample showed primary and secondary inclusions (Figure 7). The primary and secondary inclusions are present within the mineral and pseudo secondary trails are passing through the mineral boundary and cut the boundary. Aqueous inclusion were also present with adjacent to the primary fluid inclusions (Figure 7).

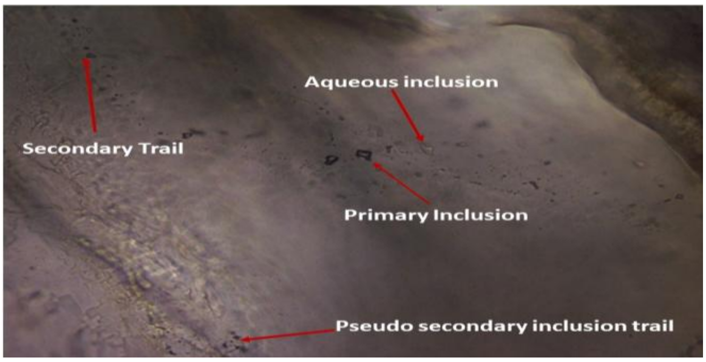


Figure 7 Photomicrograph showing various type fluid inclusions in a cordierite mineral of KPA1 sample.

The sample KPA2 showed both primary and secondary inclusions along with aqueous inclusion (Figure 8), but cordierite minerals which were also presented not showed any pseudo secondary inclusions**.** The KPA3 sample were also showed similar fluid type (Figure 8) but the secondary inclusion were absent in the sample. Primary and pseudo-secondary inclusions were also found along the cleavage phase or fracture plain in this sample.We also noticed that many mineral inclusion mostly zircons and aqueous inclusion were completely absent in the sample**.** Primary inclusions were highly visible in this sample (KPA4), which were present across the fracture plain or grain boundary (Figure 8).

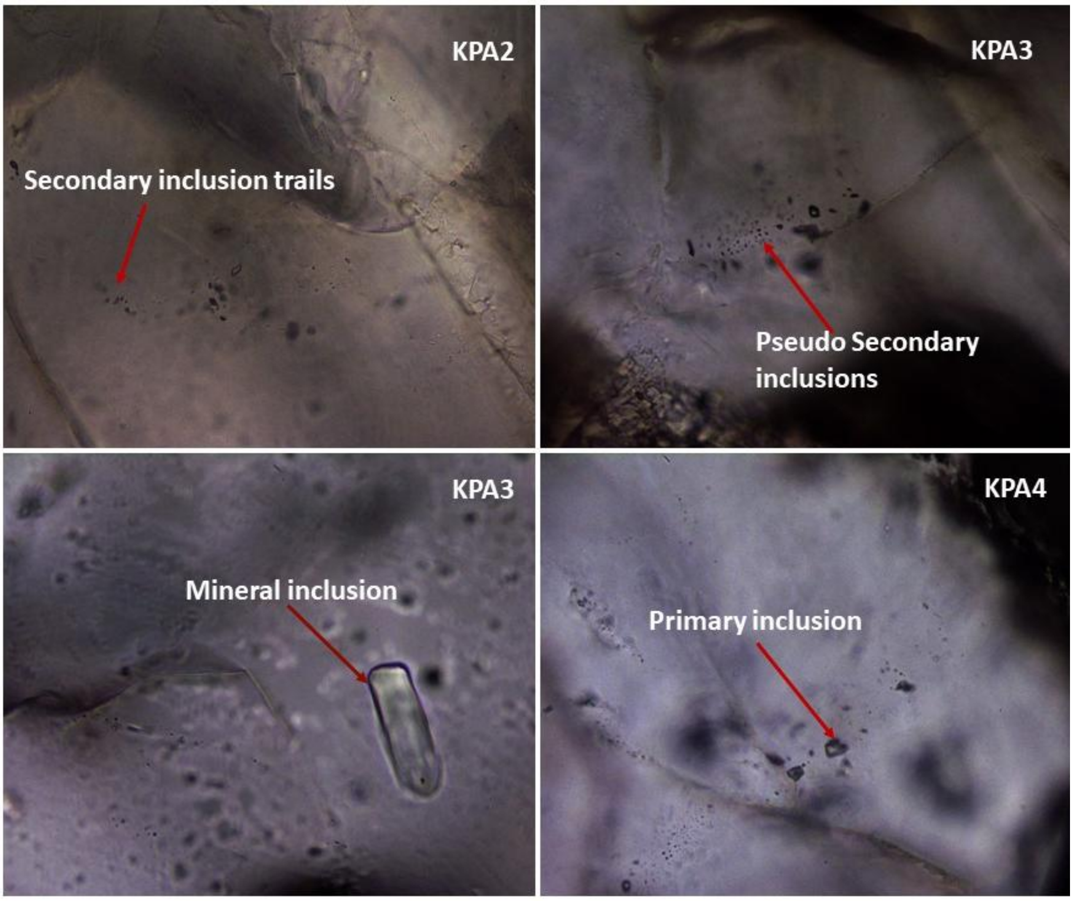


Figure 8 Photomicrograph showing different type of fluid inclusion (Primary, Secondary and Pseudo Secondary) in KPA2-KPA4 samples.

The LASER Raman micro spectrometer is used to analyse the systems contain in the fluid inclusions (Dubessy et al., 2012, Frezzotti et al., 2012). The Micro-Laser Raman examinations were carried out for the samplesKPA1, KPA2 and KPA3, and the characterization of the fluid inclusions have been studied using the spectrogram and the result has been given in Table 1 and Figure 9.Most of the samples showed the presence of inclusions i.e. gas especially, CO_2enriched, with peak around 1238 - 1386 cm^{-1}.The Inference have been derived from this result showed an indicative of the condition of past history of mineral formation and time of tectonic upliftment of the crustal blocks.

Table 1 Raman shift and different spices identification.

Sample No.	Raman Shift (Cm-1)	Compound
KPA1	500 1380 3380	Quartz Co_2 H_2O
KPA2	1380 1645 3380	Co_2 Co_2 H_2O
KPA3	500 1380	Quartz Co_2

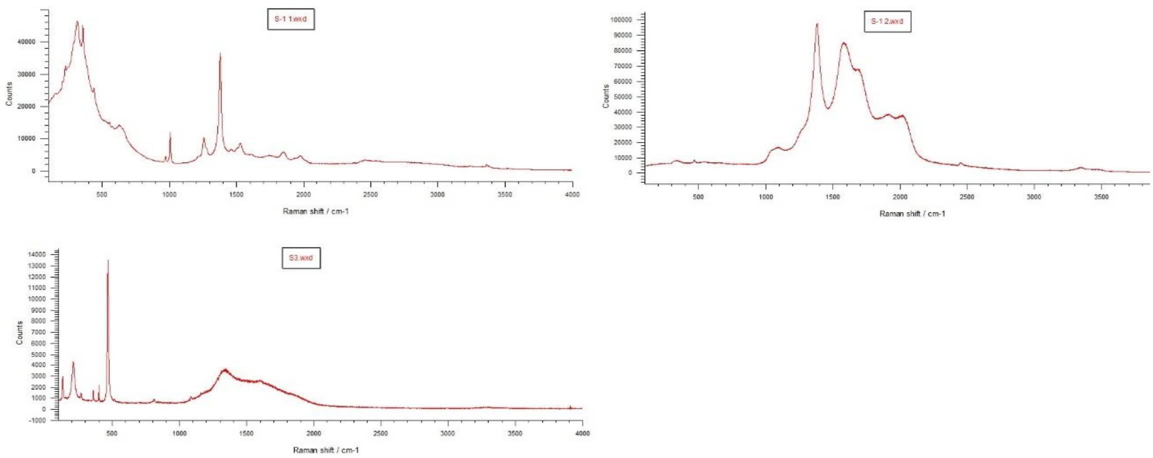


Figure 9 Raman shift of selected samples and the peaks showed the different fluid spices in the minerals (CO_2 and Aqueous).

CONCLUSIONS

The following inferences have been drawn based on geochemical, mineralogical and fluid inclusion studies. The common mineral assemblages of the quarry were identified as Garnet + Sillimanite + Cordierite + Kfs+ Biotite + Quartz + Pl + Rt with accessory mineral such as Zircon and Monazite. The major mineral phases obtained were quartz, but, cordierite, microcline, garnet and sillimanite phases have also been present as minor mineral. This mineral assemblage clearly enlightens the dominant Khondalite rocks in the Kulapparaquarry, whereas Calc- granulites and quartzite have also been found. The parentage material of the Kulappara quarry and Khondalite rock might have been

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derived from Pelitic rocks, which is inferred from ACF diagram. Primary, Secondary and Monophase inclusions were found in the samples along with secondary and pseudo secondary inclusion. The monophase inclusions which were obtained in the minerals show low and high density of CO_2 fluid. CO_2 rich fluid inclusion indicates a degassing phase towards the lighter phase of metamorphic activity. Raman peaks revealed that the fluidofhigh to low CO_2 rich in composition was found plenty in the Kerala KhondaliteBelt.

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