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Recrystallization and Provenance History of the Upper Kaimur Group Siliciclastics, Son Valley, India: Coupled Petrographic and Fluid inclusion Proxy

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ABSTRACT

The Mesoproterozoic Kaimur Group belonging to upper part of Vindhyan Supergroup, conformably overlies the carbonate sequence of Semri Group (Lower Vindhyan) in the Son Valley, central India. The Upper Kaimur Group consists of Dhandraul sandstone, Scarp sandstone and Bijaigarh shale. The detrital contents of the Dhandraul and Scarp sandstones are mainly composed of several varieties of quartz followed by feldspar, rock fragments, micas and heavy minerals. Fluid inclusion studies are carried out on the detrital and recrystallized quartz grains of the Dhandraul and Scarp sandstone to know about the fluid phases already present in the source rock and / or introduced in the recrystallisation process. Fluid micro-thermometry reveals the presence of two types of fluids: (i) bi-phase low saline aqueous inclusions, (ii) bi-phase high saline aqueous inclusion. These fluids were trapped during the development of grain and recrystallization processes. The salinity of these inclusions in the quartz grain is in the range of 5.7 to 13.4% suggests that initially there was good proportion of marine water during the initiation of sedimentation. The provenance of these rocks may be granite/metamorphic rocks of Mahakoshal Group and Chhotanagpur granite-gneisses and minor input from Bundelkhand granite complex.

INTRODUCTION

The fluid composition of sandstone has been used in appraising the nature of their protolith and identification of fluid events during sedimentation process. Rocks of the Vindhyan Supergroup have been extensively studied for various aspects relating to stratigraphy, physical sedimentary structures (Misra et al., 1972; Sarkar, 1980), micro-and mega fossils (Kumar and Srivastava , 1992; Anbarasu, 2001; Kumar, 2001, 2009), stromatolites (Kumar, 1976), isotopic studies (Kumar et al., 2002; Chakrabarty et al., 2007; Gopalan et al., 2013). Mathur and Srivastava (1962) and Misra and Awasthi (1962) have studied the Vindhyan rocks of Son Valley from sedimentological point of view, and suggested a shallow water environment for their deposition. Banerjee (1964, 1974) and Singh (1976) have interpreted depositional environments as varying from beach to barrier bar or shoal through tidal flat and lagoon.

Fluid inclusions within authigenic overgrowths and diagenetic cements reflect conditions during thermal evolution of sediments. Fluid inclusions are assumed to have retained a constant composition and volume since the time of trapping, with each inclusion containing a representative sample of fluids present in the rock at a specific time. Detrital and authigenic quartz best preserve the original chemical and physical properties of a particular fluid. Although, Modard et al. (1991) carried out preliminary fluid inclusion study on the Upper Kaimur Group sandstone and proposed the involvement of meteoric water in diagenetic history. Despite the above mentioned studies, little attention has been paid on the problem of provenance and recrystallization history based on coupled fluid inclusion and petrographic study. In this paper, an attempt is made to discuss the processes of recrystallization history and provenance and behavior of fluid involved during the formation of the Upper Kaimur Group sandstones.

GEOLOGICAL SETTING

Precambrian Vindhyan basin is the largest intracratonic basin is exposed in the Son Valley of central India covering more than 1, 00,000 km^2 area and considered to be the largest sedimentary basin exposing about 6 km thick succession. The Vindhyan Supergroup in central India is entirely unmetamorphosed and insignificantly deformed overlies deformed metasediments of either the Bijawaror or the Mahakoshal Group, and Archaean granitic basement. Developed in an intracratonic and dominantly marine setting, the supergroup is divided into two sequences separated by an unconformity and a laterally correlatable conformity (Bose et al., 2001). A sharp upward transition from carbonates to siliciclastics everywhere across the surface reflects a basin-wide regression of the sea (Bose et al., 2001). The base of the Supergroup is of Palaeoproterozoic age (Rasmussen et al., 2002; Ray et al., 2002; Bengtson et al., 2009). The upper age limit of the Supergroup is more controversial; the previous general consensus was 600 Ma (Ray, 2006), while some recent workers suggest that it could be 900–1000 Ma (Malone et al., 2008; Gopalan et al., 2013). The fossil record of Vindhyan indicates an age ranging between 1400-400 Ma (De, 2003). Kaimur Group of Upper Vindhyan acts as the marker horizon not younger than 1070 Ma (Gopalan et al., 2013). Chakrabarty et al. (2007) confirms that sediments from Kaimur and Bhander Groups have been derived from more juvenile sediments compared to Semri and Rewa groups. The age of Scarp sandstone was determined to be 940 Ma by K-Ar dating (Vinogradov et al., 1964), intruded by Majhgawan kimberlite which has been dated at 1140±12 Ma (Crawford and Compston, 1970).

Different ideas have been proposed about the tectonic setting for the Vindhyan sedimentation based on piecemeal observations. Sedimentation in a foreland basin verging northward (Chakraborty and Bhattacharyya, 1996) or southward (Chakrabarti et al., 2007) was suggested. Some workers envisaged the Vindhyan basin as a strike-slip fault basin (Crawford and Compston, 1970; Crawford, 1978). However, the general fine grain size, and high textural and mineralogical maturity of sandstones, confront rapid sedimentation from supracrustal source and do not comply with the above mentioned

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propositions. Extensive studies on multiple fronts later reveal intracratonic north–south rifting with a dextral shear at the initial stage (Bose et al., 1997, 2001) and sag at a subsequent stage (Sarkar et al., 2002). Consequently the east–west elongated main Vindhyan basin had initially been divided into several sub-basins by a number of NW–SE oriented ridges (Bose et al., 1997), but during the Upper Vindhyan sag stage this segmentation was largely removed (Bose et al., 2001). According to Chanda and Bhattacharyya (1982) and Sarkar et al. (2004) that Vindhyan basin was east–west elongated and opening westward.

The entire basinal sequence of the basin belongs to two distinct depositional cycles. The first one dominantly calcareous and argillaceous and is characteristically developed in the lower part (Lower Vindhyan). The second arenaceous and argillaceous sequence developed in the upper part (Upper Vindhyan). The Vindhyan Supergroup has been divided into four groups in Son Valley namely Semri, Kaimur, Rewa and Bhander. The Kaimur Group is the lowermost unit of the Upper Vindhyan is differentiated into Lower and Upper Kaimur. The Upper Kaimur includes three formations *viz.,* the Bijaigarh shale at the base, overlain by Scarp sandstone Formation which is further overlain by the Dhandraul sandstone Formation (Fig. 1). The focus of the present study has been the Dhandraul and Scarp sandstone formations of the Upper Kaimur Group of the Vindhyan Supergroup which is mainly arenaceous in nature and lack fine-grained horizons.

The study is based on samples representing different levels of the measured litho-sections along the Markundi-Ghat and Churk-Markundi road (Fig. 2). The traverses were taken along Markundi-Ghat, Churk-Markundi road is located in Sonbhadra district. In this section the Upper Kaimur Group (Dhandraul sandstone, Scarp sandstone and Bijaigarh shale) is exposed and Lower Kaimur Group dislocated by the Markundi-Jamwal fault (Prakash and Dalela, 1982). Thus Bijaigarh Formation directly rests over the Semri Group. The field characteristics of studied lithounits are as follows.

Dhandraul sandstone characterized by mostly tabular and laterally persistent (for tens to hundreds of meters) white, coarse-grained quartzose sandstone beds with sharp boundaries and exhibits sedimentary structures like large scale cross bedding with long, low-angle foresets alternate with co-sets of parallel laminated sandstone, trough bedding and ripple marks.

Scarp sandstone characterized by trough- and planar- cross stratified variegated medium-grained sandstone. It shows planar, laterally impersistent erosion surfaces invariably carpeted by lensoid bodies of conglomerates, consisting of flattened and angular red shale pebbles of intraformational origin.

PETROGRAPHY

The detrital contents of the studied sandstones are mainly composed of several varieties of quartz followed by rock fragments, feldspar, micas and heavy minerals. The average composition of detrital minerals in Dhandraul Sandstone are: monocrystalline quartz (91.49 percent), polycrystalline recrystallized metamorphic quartz (1.20 percent), stretched metamorphic quartz (4.89 percent), feldspar (0.12 percent), rock fragment (0.36 percent) chert (0.32 percent), mica (1.44 percent), and heavy minerals (0.19 percent) (Table 1) and the average composition of detrital minerals in Scarp Sandstone are: monocrystalline quartz (90.88 percent), polycrystalline recrystallized metamorphic quartz (0.60 percent), stretched metamorphic quartz (6.16 percent), feldspar (0.16 percent), rock fragment (0.05 percent), mica (1.34 percent), chert (0.72 percent) and heavy minerals (4.5 percent).

Quartz is the most dominant detrital constituent of the Dhandraul and Scarp Sandstones. The monocrystalline quartz generally shows undulose extinction. Polycrystalline quartz grains possess both sharp and sutured intercrystalline boundaries. The quartz mostly occurs as subangular to subrounded grains having few inclusions of mica, zircon and tourmaline. The interlocking mosaic texture with two generations of growth is observed in the quartz grains. The first generation of

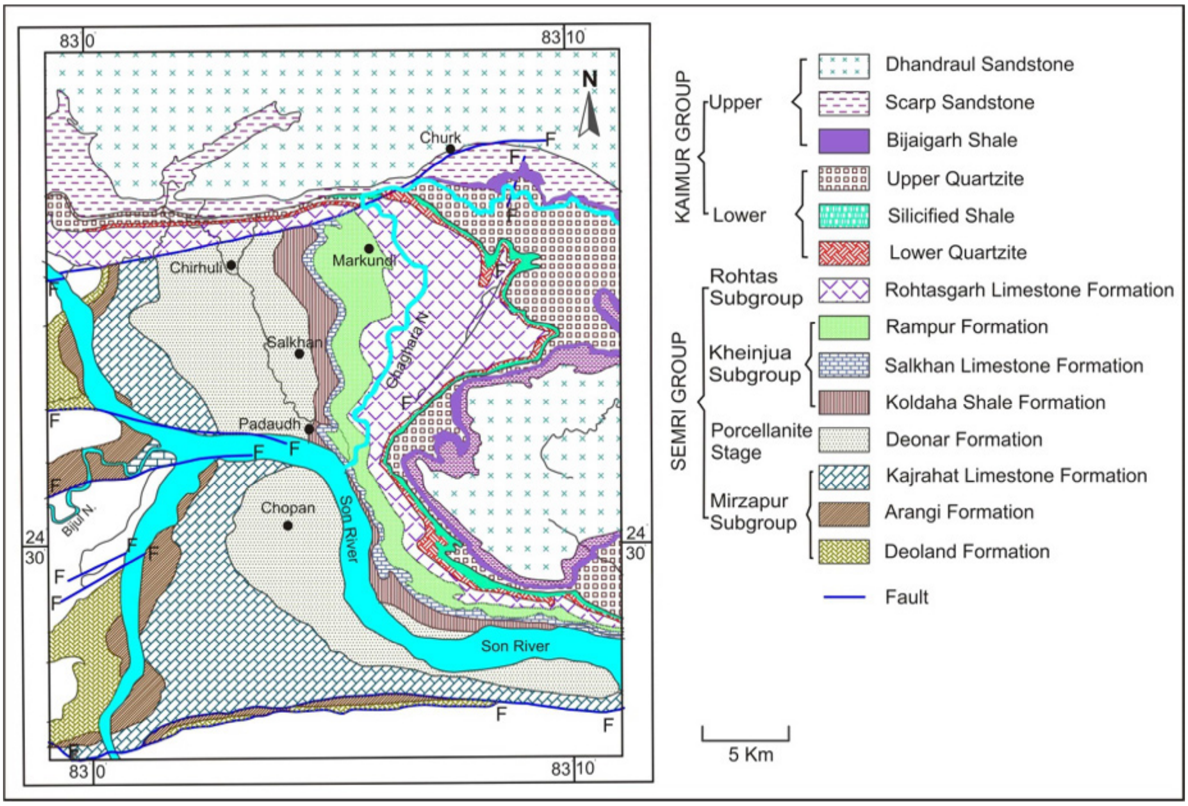

Fig. 1. Detailed geological map of Vindhyan Supergroup in and around Sonbhadra and Mirzapur districts, UP, India (after Auden, 1933; Sastry and Moitra, 1984).

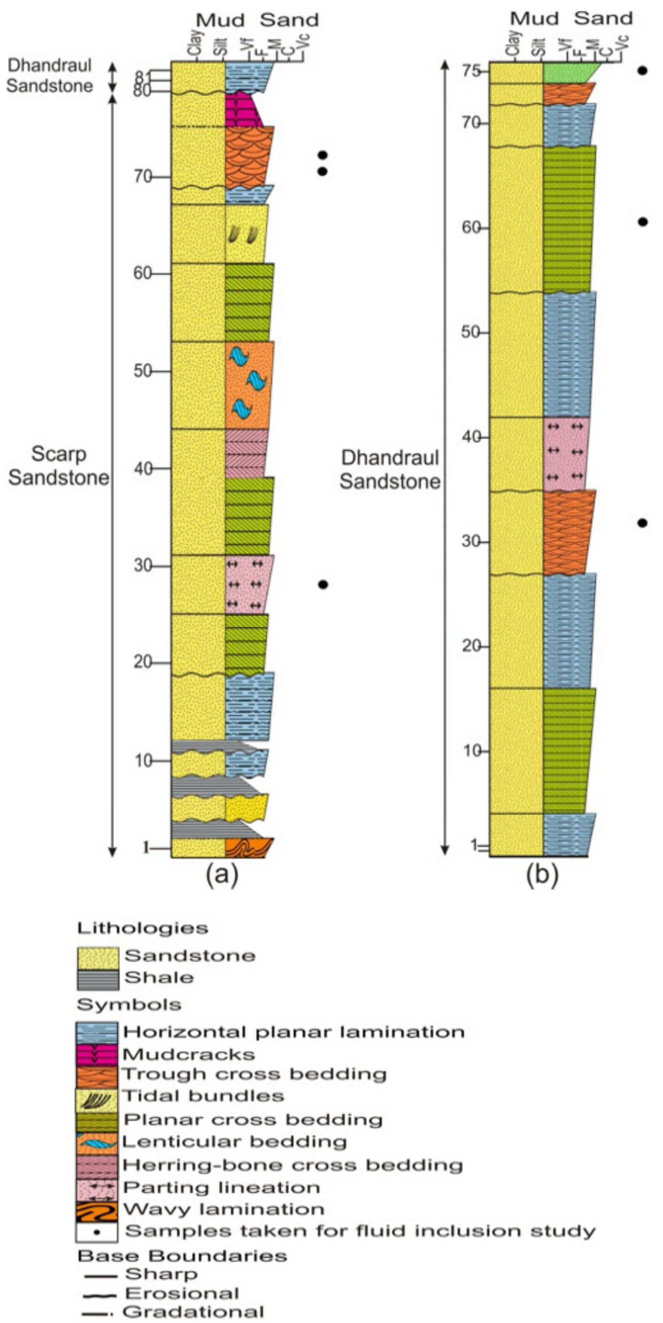

Fig.2. Lithostratigraphic columnar sections of the Dhandraul Sandstone and Scarp Sandstone at **(a)** Markundi-Ghat section and **(b)** Churk-Markundi road section, respectively.

quartz is primary in origin and represented by rounded margins (Fig. 3a), and the second generation is represented by sharp grain boundaries indicating a recrystallization event in these rocks (Fig. 3b). In some of the quartz grains, partial recrystallization is observed, such grains display mellow grain boundaries with development of sub-grains, with the centre unchanged. Small bulges were formed along the old grain boundaries that lead to elongation and endomorphism of grains (Fig. 3c and d) at some places bimodality is also developed (Fig. 3e). The irregular shaped coarser grains shows ragged boundaries and undulose extinction. Bulges are observed along sutured grain boundary with triple junction (Fig. 3f). Growth of the recrystallized grain and sutured grain boundaries with bulges advocate dominant bulging recrystallization (Fig. 3g). Isolated sub-grains are also witnessed around the rim of porphyroclasts (Fig. 3h). This bulging phenomena along with minor sub-grain rotation reveals that recrystallization took place in between 290° to 390°C (Stipp et al., 2004; Stipp and Kunze, 2008). In the studied sandstones noticeable presence of quartz overgrowth (Fig. 4a and b), numerous long intergranular concavo-convex contacts and some suture contacts has been observed (Fig. 4c and d). The presence of quartz cement as a syntaxial overgrowth near the sites of intergranular dissolution and around tightly packed detrital quartz grains indicates a mesogenetic origin (Worden and Morad, 2000). Worden and Morad (2000) proposed various internal sources of silica, including intergranular pressure, the dissolution/transformation of smectite to illite and the solution reaction of detrital feldspars.

FLUID INCLUSIONS

Fluid inclusion study and micro-thermometry has been conducted on the quartz grains. For the micro-thermometry, Linkam THMSG 600 heating/cooling stage was used in Wadia Institute of Himalayan Geology (WIHG). Heating temperatures were found to be correct to ±3°C and the cooling temperatures were precise to ±0.2 to 0.3°C. Density estimates and isochors were made using the FLINCOR computer program of Brown (1989). The equations of Zhangand Frantz (1987) and Brown and Lamb (1989) were used for the estimation of aqueous fluid inclusions

Fluid Inclusion Petrography

Majority of the fluid inclusions are bi-phase aqueous and rarely mono-phase inclusions are also observed. In the case of quartz overgrowths, the fluid inclusions are located near the boundaries with the detrital grains and also within the overgrowths. The fluid inclusions are classified into two categories, viz. (i) primary, and (ii) secondary. The primary fluid inclusions were of 10 to 3 μm in sizes whereas the secondary fluid inclusions are generally ≥5 μm in size. The detailed fluid inclusion petrography is summarized in the respective sections below (Fig. 5).

Table 1. Range and average of mineralogical composition of sandstones of the Upper Kaimur Group, Son Valley

	Mono-crystalline quartz Common quartz	Polycrystalline quartz		Feldspar		Mica		Chert	Rock fragments	Heavy minerals
		Recrystallized metamorphic quartz	Stretched metamorphic quartz	Plagioclase	Microcline	Muscovite	Biotite			
Dhandraul Sandstone										
Range	83.02-97.46	0.00-4.17	0.87-13.27	0.00-0.39	0.00-1.06	0.00-10.46	0.00-0.87	0.00-1.47	0.00-2.77	0.00-1.11
Average	91.49	1.2	4.88	0.02	0.1	1.37	0.07	0.32	0.36	0.19
Scarp Sandstone										
Range	82.22-96.71	0.00-2.80	1.35-17.04	0.00-0.35	0.00-1.93	0.00-2.64	0.00-0.61	0.00-1.70	0.00-0.62	0.00-0.54
Average	90.88	0.6	6.16	0.03	0.13	0.08	1.26	0.72	0.05	0.09

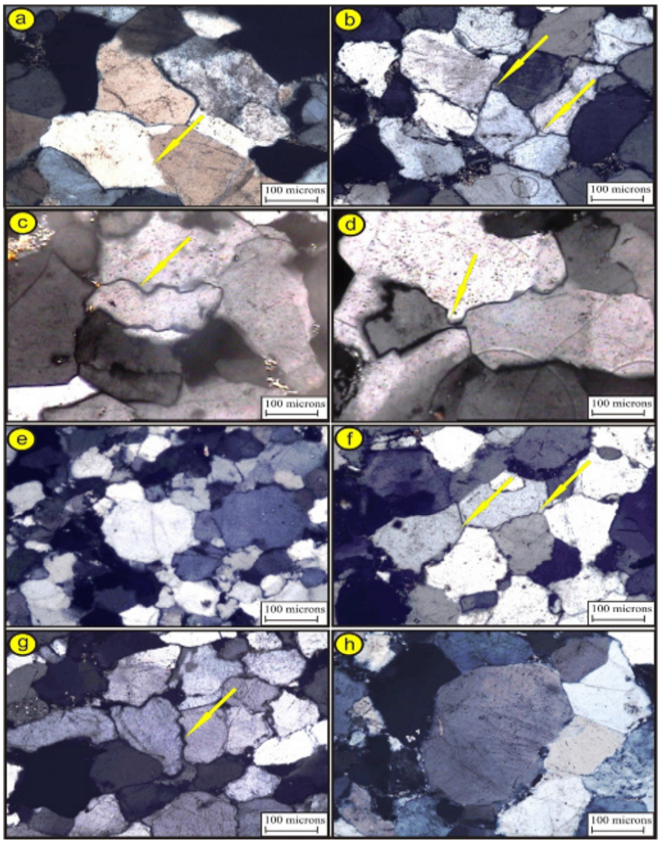

Fig. 3. Photomicrographs showing **(a)** primary quartz with rounded boundary **(b)** Secondary origin quartz represented by the sharp boundaries **(c, d)** Sutured grain boundary with developed bulges in quartz grains **(e)** Bimodal quartz grain **(f)** Triple junction boundaries between quartz grain **(g)** Sutured quartz grain **(h)** Phynocryst surrounded by the smaller grain.

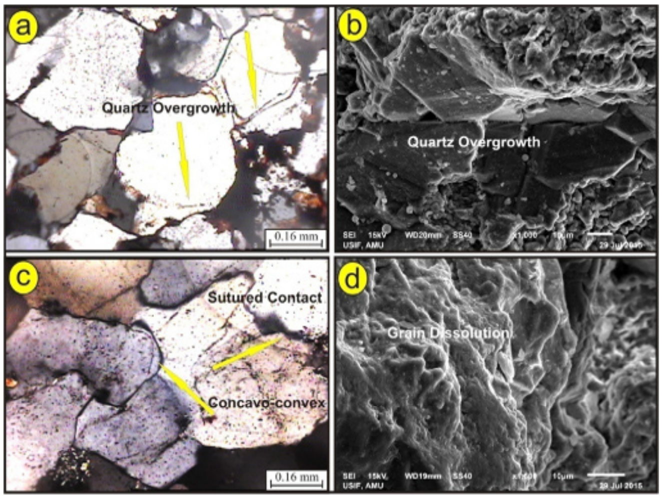

Fig. 4. (a) Photomicrographs showing the quartz overgrowth **(b)** Scanning electron microscopic (SEM) images of quartz overgrowth in the Upper Kaimur Group sandstone **(c)** Evidence for pressure dissolution including sutured and convex-concave contacts (yellow arrows) **(d)** Scanning electron microscopic (SEM) images showing the pressure dissolution effect.

The more predominant inclusions are two phase aqueous inclusions, with the vapour phase representing around 30% area. Inclusions size varies from 10 to 20 µm, generally colourless, with irregular shapes, commonly showing necking-down features. These inclusions are further categorised into two types on the basis of salinity.

Fluid Chronology

Two inclusion associations have been marked on the basis of their distribution within the authigenic overgrowths and grains. These are interpreted as representing distinct stages or generations of fluid. A 'hazy' rim marks the boundary between detrital quartz grains and their authigenic overgrowths. This rim hosts abundant sub-microscopic inclusion bunching, with lesser numbers of larger (3-8 µm) inclusions. The variation in inclusion morphology is supposed to be primarily determined by the roughness of the detrital grain, because highly irregular inclusions occur along side those that have formed in a euhedral crystal termination. The inclusions that were analysed from this generation were those that are from 5-8 µm across. These inclusions less then 8µm were too small to permit determination of homogenisation temperatures.

The inclusions which have formed within authigenic overgrowths are clearly younger than those which formed at the dust rim. Their generally euhedral morphologies indicate active growth of the authigenic quartz. Inclusions are mostly in the 5-8 µm range, and occur either in small trails or singly, and are interpreted as having formed in crystal impurities isolated during the growth phase (Roedder, 1984).

Type 1 inclusions occur in all settings, and hence are inferred to have formed during each period inclusions were generated. Numerically, hazy rim inclusions are most common, with approximately equal numbers generated in overgrowth and fracture settings. Type 2 inclusions are occurring in the centre of quartz. Type 2 inclusions are the earliest inclusions trapped in this environment whereas Type 1 inclusions formed later. Type 1 inclusions entrapped during diagenesis and Type 2 inclusion trapped during the formation of grain.

RESULTS

Homogenization Temperature

The homogenisation temperatures (Th) was collected on 115 inclusions in quartz overgrowth and on 113 inclusions in quartz grain from 6 samples. Total homogenisation results are presented in figures (Fig.6). The bi-phase aqueous inclusion homogenized in quartz overgrowth or hazy rim in the range of 90 to 130°C whereas the aqueous inclusions present inside the quartz grain homogenized in between 130 to 175°C. The majority of homogenisations (in quartz overgrowth or in hazy rim) occurred between 90°C and 120°C (Fig. 6a and b). This data is very much similar to the inclusions observed in diagenetic mineral phases (Wilkinson et al., 1990), The homogenization temperature shown by the inclusions present inside the quartz grain is much higher up to 175°C. Although most of the inclusions present in this category homogenized in between 140 to 160°C which is much more alike the maximum diagenetically produced homogenization temperature of 160°C as exemplified by Visser (1982). However these homogenization temperatures are not linked to diagenetic phenomena. The summary of micro-thermometric data is given in Table 2.

Melting Temperature

The freezing data (Tim and Tfm) was collected on 65 inclusions from quartz overgrowth and 44 inclusions inside quartz grain from 6 samples. The initial melt temperatures (Tim) range from -24°C to -21.2°C. This initial melting temperature indicates the composition of fluid is essentially NaCl-H_2O (Sheapard et al., 1985). The final melting temperature (Tfm) in quartz overgrowth (hazy rim) range from -0.5 to -3°C whereas inside the quartz grain it varied in between -3.5 to -9.5°C (Fig. 7a and b). Tfm can be used to derive the salinity of a given fluid, expressed as equivalent weight percent NaCl (Roedder, 1984). Most inclusions reached Tfm between -1.0°C and -2°C, yielding

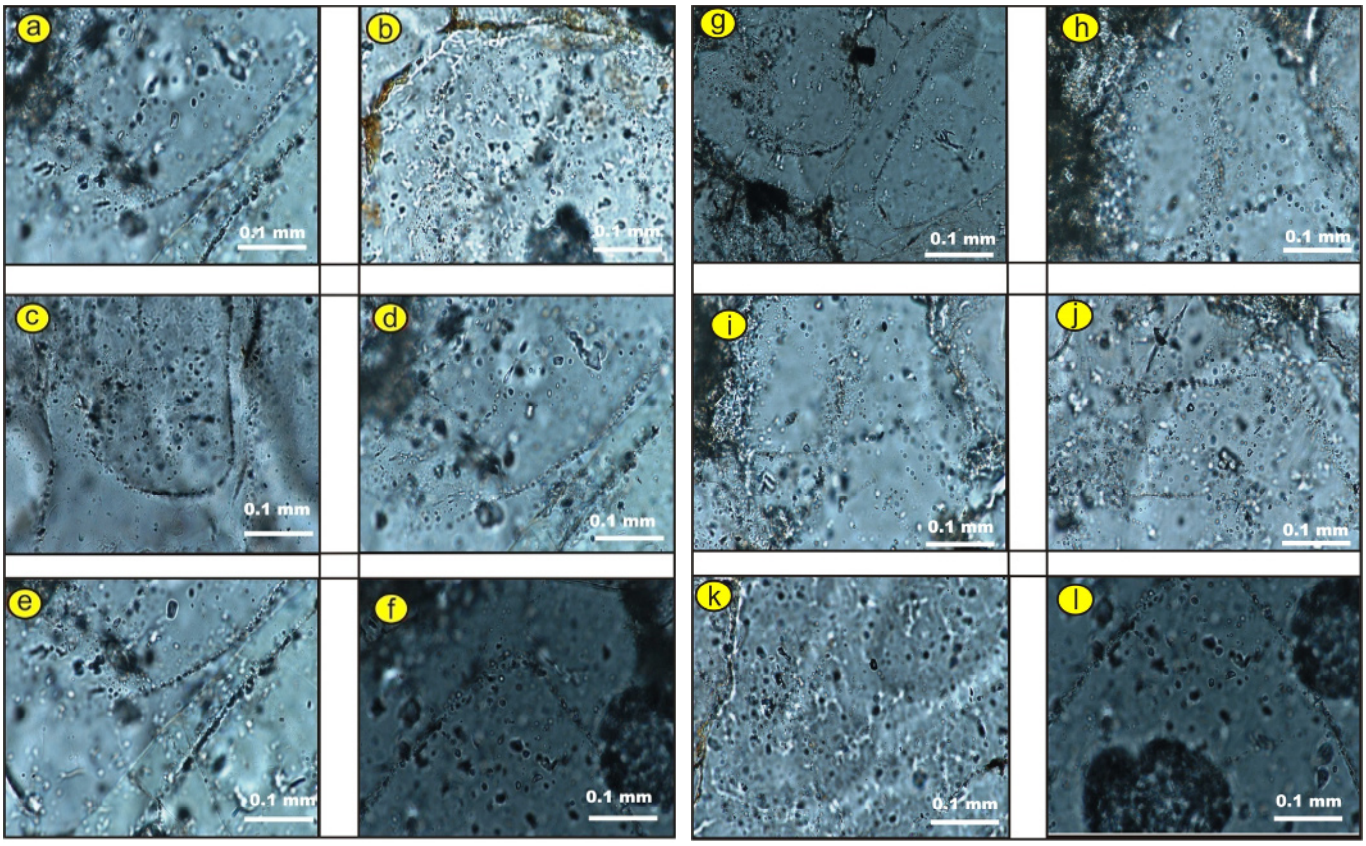

Fig. 5. Photomicrograph of fluid inclusions present in the quartz grains of studied samples. **(a)** Random presence of bi-phase aqueous inclusion along with trails of inclusion present at boundary of the grain. **(b)** Primary bi-phase aqueous inclusion. **(c-l)** Random presence of bi-phase aqueous inclusion (primary) along with pseudo-secondary trails of inclusion present at boundary of the grain.

NaCl equivalent salinities in the range 1.7% to 3.4%. The range of interpreted salinities is from a large cluster of results around -1.5°C, indicating salinity of 2.5%. The salinity variation within the quartz grain is in the range of 5.7 to 13.4%. The implications of the varying salinities of the migrating fluids are discussed.

DISCUSSION

The cluster of homogenisation temperatures (Th) data points for each studied sample characterizes the maximum burial temperature for that sample, and this may involve the heating and thermal resetting of early inclusions. The inclusion presents in quartz overgrowth homogenize between 90-120°C whereas the inclusions present in core of quartz grain shows higher homogenization temperature upto 180°C. These higher values may be the resultant of necking-down or leakage (Roedder, 1984) of inclusions during formation, although no direct evidence of these phenomena (such as increased vapour/fluid ratios) could be observed because of their small size.

Tifm results should represent the eutectic melting point of the salt system of the fluid inclusion (Aulstead and Spencer, 1985). The **Tifm** measurements indicate that the Vindhyan basin inclusions contain dilute aqueous solutions of Na-Chloride system (T. Eutectic = -21.2°C). The range of salinities is from a large cluster of results around -1.5°C, indicating salinity of 2.5% for the inclusions present in the quartz overgrowth reveal that the solution was very dilute and having meteoric or connate water was involved during the formation of quartz overgrowth whereas the salinity estimated for the inclusions variation within the quartz grain is in the range of 5.7 to 13.4%. The high salinity of these inclusions suggest that initially there was lot of marine water when sedimentation process was started which is evidenced by the presence of higher saline inclusions but later on the marine water was replaced by flushing of meteoric or connate water implications of the varying salinities of the migrating fluids.

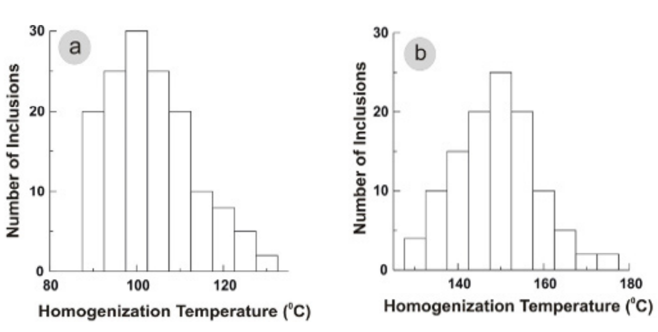

Fig. 6. Histogram of homogenization temperature (^{0}C) of bi-phase aqueous inclusion present **(a)** in the quartz overgrowth (Hazy rim). **(b)** inside the quartz grain.

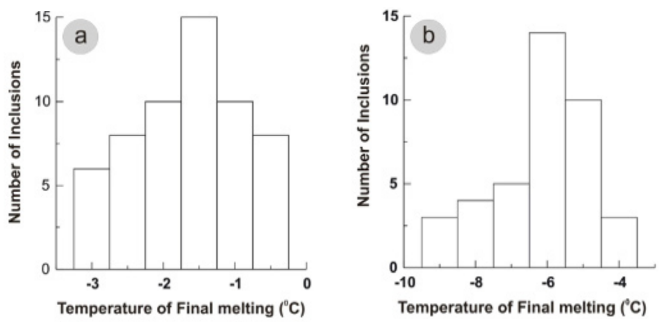

Fig.7. Histogram of melting temperature (^{0}C) of bi-phase aqueous inclusion present **(a)** in the quartz overgrowth (Hazy rim). **(b)** inside the quartz grains.

Table 2. Summary of micro-thermometric measurements of fluid inclusions in the Upper Kaimur Group sandstones from Son Valley

Sample No.	Host Mineral	Type of Inclusion	Tim(⁰C)	Tfm(⁰C) Minimum	Tfm (⁰C) Maximum	Th(⁰C) Minimum	Th(⁰C) Maximum	Salinity (NaCl Equiv wt. %)	Mode of occurrence of Inclusion
Dhandraul Sanstone	Quartz	Biphase-aqueous	-21.2 to -22.3	-3.5	-9.5	130	175	5.7 to 13.4	Inside quartz grain
Dhandraul Sandstone	Quartz	Biphase-aqueous	-21.2 to -22.8	-0.5	-3	90	130	1.7 to 3.4	In quartz overgrowth
Dhandraul Sandstone	Quartz	Biphase-aqueous	-22.3 to -22.8	-4.2	-7	140	160	6.6 to 10.4	Inside quartz grain
Dhandraul Sandstone	Quartz	Biphase-aqueous	-21.2 to -23.3	-1	-2	95	120	1.65 to 3.27	In quartz overgrowth
Scrap Sandstone	Quartz	Biphase-aqueous	-21.2 to -23.8	-5	-6	145	155	7.81 to 9.18	Inside quartz grain
Scrap Sandstone	Quartz	Biphase-aqueous	-21.2 to -23.9	-1.3	-1.8	100	125	2.14 to 2.95	In quartz overgrowth

Recrystallization and Provenance History

Coupled petrography and fluid inclusion study becomes extremely valued in the restoration of the provenance and recrystallization history of sedimentary rocks (Burruss, 1987; Goldstein and Reynolds, 1994). Fluid inclusions trapped, therein, can divulge the details of fluid system present in the region of provenance, and the recrystallisation account of these rocks. In order to constrain the P-T condition of entrapment of inclusion, the isochores of different generation and composition of bi-phase aqueous fluid inclusions were plotted in Fig. 9. The isochores of inclusions present in the quartz overgrowth are positioned on the higher side of the plot representing peak recrystallization side of the P-T plot followed by steeply dipping isochores of inclusions present within quartz grains. The isochores of both type of H_2O-NaCl inclusions intersect the temperature range of observed recrystallization features in quartz microstructures (Stippet al., 2002) from 290-390°C and 6.8 to 4.2K bars (Fig. 9) indicating the range of deformation and recrystallization P-T conditions undergone by the Upper Kaimur Group sandstone.

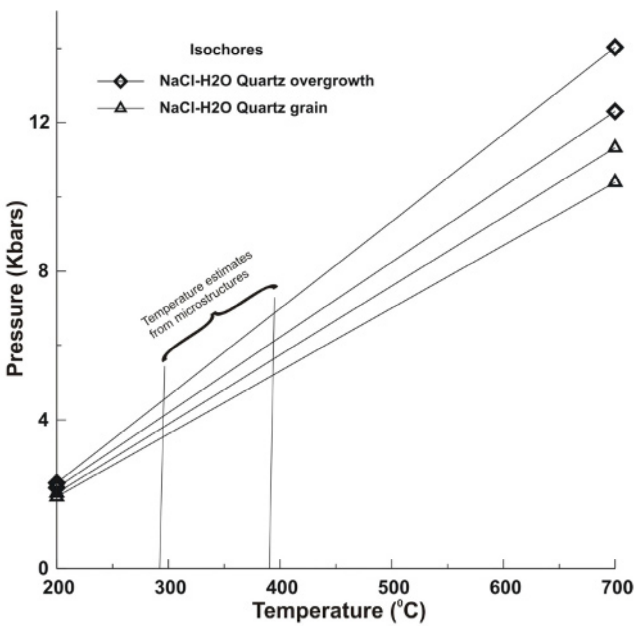

Fig.9. Schematic representation of fluid entrapment stages in the wide range of P–T conditions recorded by the Upper Kaimur Group of rocks. Two vertical thin lines are showing temperature estimates as per observed quartz microstructures and are interpreted in terms of temperature (after Stipp et al., 2002; Stipp and Kunze, 2008). Two sets of isochores recovered from micro-thermometry are shown for individual fluid inclusions of NaCl–H_2O (Quartz Overgrowth) and NaCl–H_2O (Quartz grain) phases.

The petrographic characteristics of studied lithologies give the indications of provenance. The presence of moderate to strongly undulose, monocrystalline quartz grains in the Upper Kaimur Group sandstone suggests a medium to high grade metamorphic source (Quasim et al., 2017A, 2017B). The presence of alkali feldspars indicates their source as plutonic and metamorphic rocks (Trevena and Nash, 1981). However in the Upper Kaimur Group sandstone the feldspar is very rare indicating multi-cyclic weathering from distance granitic craton. The rocks of the Upper Kaimur Group were formed from the same Proterozoic felsic source and the provenance is dominantly granitic with a minor contribution of granodioritic source. The collective petrographic and geochemical data strongly suggest that source and the provenance is dominantly granitic with a minor contribution of granodioritic source (Quasim et al., 2017A, 2017B) from Mahakoshal Supracrustal-Chotanagpur-Bundelkhand Gneissic Complex. Mishra and Sen (2010, 2012) also argued for same provenance based on geochemical proxy. Sen (2010) indicated Bundelkhand granite as the source of these sediments using mixing modelling calculations.

Fluid inclusions with higher salinity in the quartz grain than in the diagenetic quartz overgrowth indicate that the sedimentation processes started with in the shallow marine regime to landwards. This is also evident by the previous works that the deposition of the Scarp and Dhandraul Sandstone is taken place in the shallow marine environment (Banerjee 1964, 1974; Singh 1976; Sachan and Ghosh, 1996). Fluid inclusions having high salinities range 5.7 to 13.4% observed in the quartz grain suggest that the protoliths of theses rocks could have a strong affinity with the granite/metamorphic rocks which is also coherent with the petrography. It is envisaged that the Paleo- and Mesoproterozoic granite, granodiorite, gneiss and meta-sedimentary rocks of Mahakoshal Group and Chhotanagpur granite–gneiss present in the western and northwestern direction as well as Bundelkhand granite may be the possible source rocks for the Upper Kaimur Group in the Son Valley. The homogenization temperatures (Th) values of the studied fluid inclusions in the core of quartz grain are above the expected sedimentary to diagenetic range and might be explained by this sedimentation may have sourced from Bundelkhand granite complex or Chhotanagpur granite-gneisses. The present geothermal gradients vary from 12 to 27°C and heat flow 46 to 61 W m^{-2}, in Vindhyan basin (Nagrajuet al., 2012). The anomalous high paleogeothermal gradient of 67°C/Km recorded by Srivastava and Sahai (2003) whereas current geothermal gradient is 27°C indicate that the sediments in Vindhayan Basin were buried at maximum depth of 6 to 2.7 Km. The high anomalous geothermal gradient deduced by Srivastava and Sahai (2003) gave the reason for such high geothermal gradient which is attributed to the continental rifting during the Proterozoic era, and the occurrence of additional heat sources, such as basal and intermittent volcanism and high heat-producing basement granite. The higher homogenisation temperatures (Th) values observed in some inclusions are either the result of a higher palaeoheat flow than the currently exists or of greater depth of burial followed by the erosion of an unknown thickness of sediments.

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