Felsic Xenocryst in the Bedded Porcellanite (Mesoproterozoic) of the Central India: An Evidence Suggesting the Rhyolitic Source of Silica

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Abstract: The Mesoproterozoic porcellanite of the Vindhyan Super group is the oldest porcellanite deposit of India. Its origin is poorly understood in the absence of silica secreting organisms during Proterozoic times and earlier. Here, we interpret the origin and possible source of silica based on sedimentary structures and xenocryst occurring in these porcellanites. Lithofacies and related sedimentary structures suggest that the studied porcellanite precipitated in a shallow marine condition in the intracratonic Vindhyan basin. Four different facies types are recognised within the porcellanite; these are yellow, black, white and green chert / porcellanite. Based on physical characteristics, it is suggested that the black and green porcellanites are chert and yellow and white porcellanites are either rhyolite or porcellanie. The presence of felsic xenocryst, including sanidine, encased within the microcrystalline and cryptocrystalline quartz suggests that the source of silica was ~~a~~ rhyolite. The quartz of the felsic volcanic rock (rhyolite) was dissolved in the seawater during alkaline pH created by the presence of phytoplanktons and the dissolved silica got precipitated in the form of bedded chert and porcellanite during lowering of the pH coupled with the evaporation of the seawater. The intermittent supply of the clay as impurities in the silica originated true porcellanite in the present case.

Keywords: Felsic xenocryst, porcellanite, Mesoproterozoic, central India, rhyolite.

1. INTRODUCTION

Chert is a hard, compact, cryptocrystalline, varicoloured sedimentary rock with semi vitreous lustre, conchoidal fracture that consists dominantly of silica, while porcellanite is a porous variety of silica that is less hard and less compact than chert [1]. It has a dull lustre and usually consists of either opal and quartz or quartz together with clay, carbonate, zeolite or iron and manganese minerals. Radiolarians and diatoms precipitate silica from seawater in Phanerozoic times. However, the source of silica and origin of chert / porcellanite is enigmatic in Precambrian sedimentary successions those are devoid of these fauna. A major source of silica may be igneous rocks erupting on the oceanic floors. In that case, either it should occur inter-bedded with sedimentary chert or the sedimentary chert/porcellanite should contain xenoliths of the igneous rocks. In the absence of both, it is difficult to ascertain the source of silica. In the present study, we got some felsic minerals as xenocryst in the cryptocrystalline chert/ porcellanite while performing petrography. The X-ray study also supports the petrographic results where quartz shows its abundance along with, microcline, plagioclase and muscovite.

Although it is understood that the Phanerozoic cherts are diagenetic products of biogenous silica, there is still incomplete understanding of the controls of chert formation [2, 3]. In modern deep marine realms, radiolarians precipitate chert from silica derived from the volcanic materials on the ocean floors. Biogenous opal is the silica source for most Phanerozoic cherts, but some cherts associated with volcanic glass, clinoptilolite, and montmorillonite may have a volcanic origin [1]. Felsic volcanic rocks such as rhyolites with high content of silica may be responsible for its (silica) release in oceanic basins facilitating chert precipitation. In cases, they may occur as volcanic plugs and dykes and also as breccias associated with cherts. They (cherts) are also associated with tephra/tuff or ignimbrite. Rhyolite with abundance of quartz, plagioclase, biotite and sanidine minerals account for high amount of silica. These minerals may occur as xenocryst in the sedimentary chert and porcellanite deposits.

The Chopan Porcellanite Formation belonging to Meosproterozoic Semri Group of Vindhyan Supergroup is exposed as a linear belt along the Son River, central India [4] (Figure **1**). It extends in the Palamu District of Bihar in east and the Siddhi District of Madhya Pradesh in west [5-7]. This formation contains bedded chert and porcellanites along with clay layers at some intervals. Three types of porcellanite have been distinguished; banded, spotted and massive porcellanite by Mehrotra and Banerjee [8]. Mehrotra *et al.* [9] described that the Chopan Porcellanite Formation of the Lower Vindhyan represents oldest volcaniclastic formation in India.

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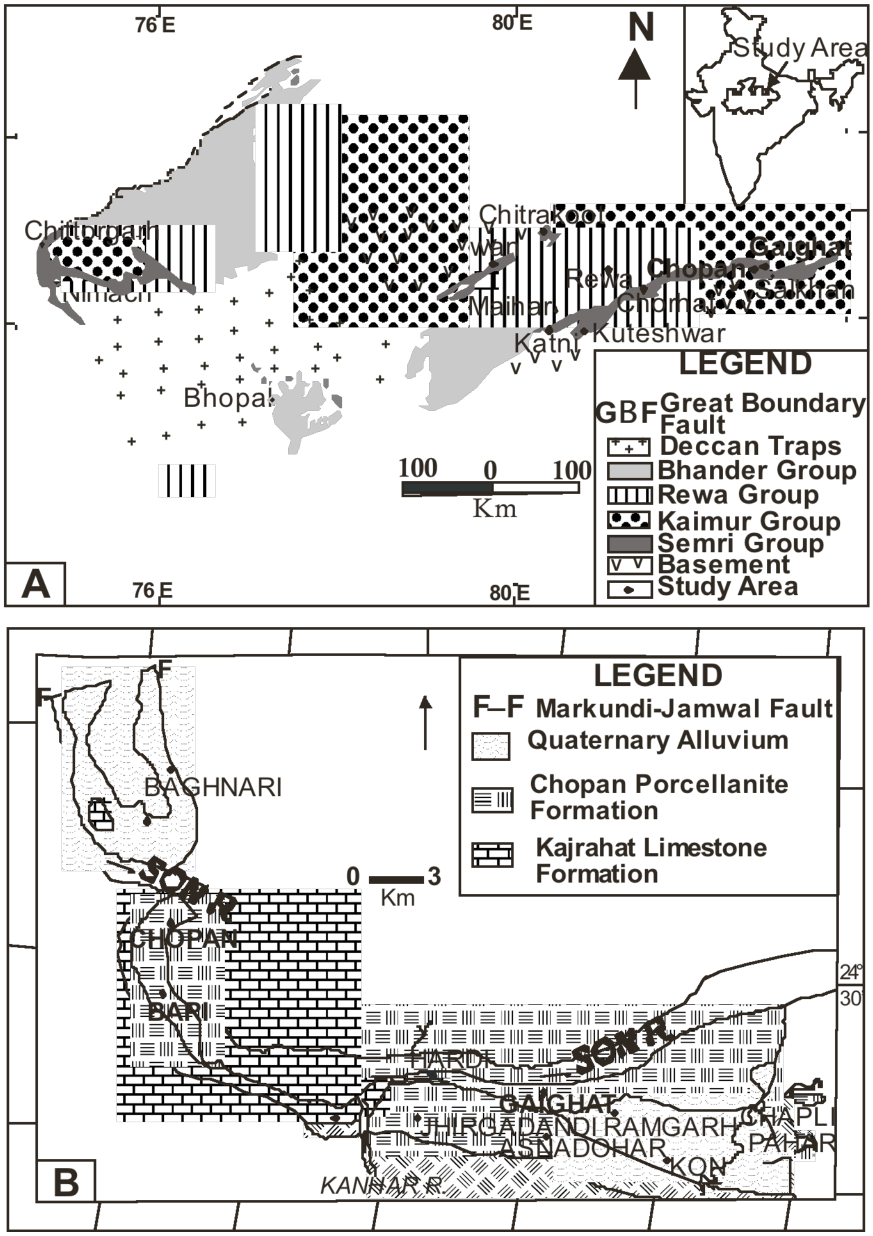

Figure 1: Location and geological maps. (**A**): Geological map of the Vindhyan Supergroup showing disposition of various groups in the central India (modified after Auden [4]. Also shown is the location of Chopan and Gaighat. Inset: Location of the study area in the outline map of India, (**B**): Geological map of the Semri Group, Vindhyan Supergroup showing exposures of the Chopan Porcellanite Formation in the central India.

Srivastava *et al*. [5] and Mishra and Sen [10] have also considered the Chopan Porcellanite Formation as volcanic tuff and ignimbrite. According to Ray *et al*. [11] the Deonar Formation of 1600 Ma age, equivalent to the Chopan Porcellanite Formation, of the Semri Group is composed of silicified volcanic rocks and very fine-grained volcaniclastic sediments. Further, the rocks of the Porcellanite Formation are generally composed of phenocrysts of quartz and relict of feldspar and biotite. Based on composition, they suggested that the rocks are rhyolite. However, Proterozoic tuff beds are difficult to distinguish in the field especially if they have been silicified [4]. The basic question remains to be unresolved related to the Chopan Porcellanite Formation i.e. "Whether the Chopan Porcellanite Formation is a sedimentary deposit or it is a volcanic rock of felsic composition?" This paper highlights the variety of xenocrysts found in the bedded Chopan Porcellanite Formation and presents evidence for the felsic volcanic source as the source of silica here.

2. METHODS

Individual lithofacies were demarcated in the field and lithologs were prepared. Unaltered samples of the

Mesoproterozoic porcellanite were collected from exposed sections. Thin sections were prepared using standard technique of thin section preparation. They were studied on a LEICA petrological microscope. Xenocrysts were identified based on their mineralogical properties. The samples were further studied on a X-ray Defractometer for ascertaining mineral composition. The diffraction pattern was obtained on a PANalytical X'Pert Pro diffractometer fitted with a copper tube (CuK-Alpha) and xenon detector at the Department of Geology, Banaras Hindu University, Varanasi. The samples were individually scanned over a range 5-40° 2Theta using a 0.4354 fixed divergence slit and 0.3800mm in size receiving slit with a step size of 0.0250. 1.20 sec/step and a total run time of 28.02 min at 40 mA and 45 kV. The instrument was calibrated using a silica calibration standard and the mineral identification was carried out comparing the measured data to a reference database, *viz*., Inorganic Crystal Structure Database (ICSD) in PANalytical X'Pert High Score (Plus) v3.X database.

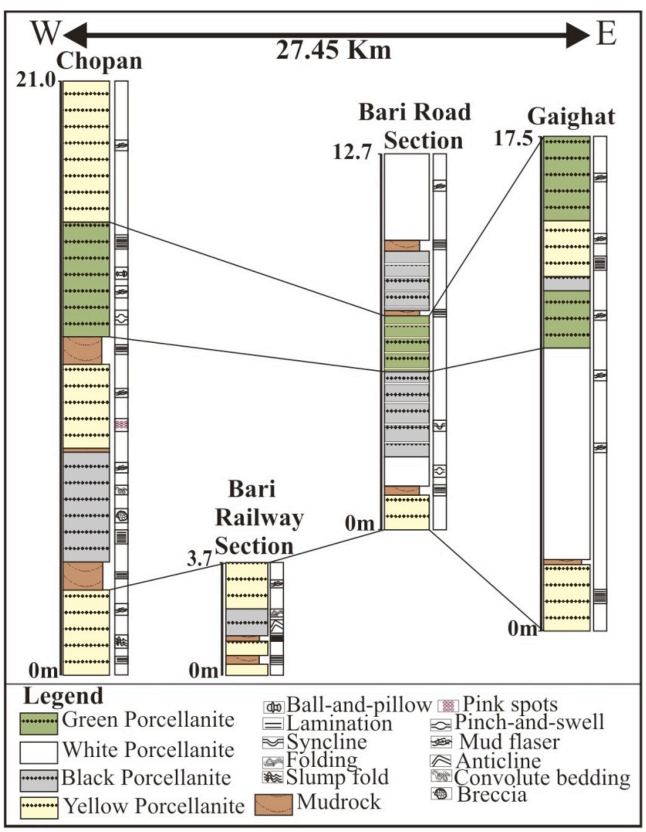

Figure 2: Lithological profile along the measured sections in the Chopan Porcellanite Formation in the type-area, Bari and Gaighat, District Sonbhdra, central India.

3. RESULTS

3.1. Field Observations

All the Mesoproterozoic porcellanite of the central India occur in bedded form. Colour is used as a criterion for erecting facies in them further. Four main varieties are distinguished in the present case based on dominant colours. They are yellow porcellanite, black porcellanite, white porcellanite, and green porcellanite. The porcellanites of different varieties are separated from each other by a thin layer of laminated mud. The stratigraphic architecture of the different facies of the porcellanite is shown in figure **2**.

Yellow Porcellanite is thickly bedded, hard, porous and fine-grained in nature. Bed thicknesses vary from tens of centimetre to a meter (Figure **3A**). At places, it is spotted with white and pink spots of pea size. This lithofacies also contains small folds, with narrow anticlines and broad synclines, confined within planar underlying and overlying beds at few levels (Figure **3A**). It is overlain by the black porcellanite.

Black Porcellanite is dark grey to black coloured, hard and compact and occurs in a bedded form. This variety of porcellanite contains alternate beds of grey to black coloured chert and white coloured porcellanite (Figure **3B** and **C**). The grey to balck coloured beds are few centimetre thick and white coloured beds are millimetre to centimetre thick. The white coloured beds are porous in nature. SSD structures such as convolute bedding, slump breccias, slump folds, dykes, and pinch-and-swell structure occur in this lithofacies (**3B** and **D**). Quartz veins are also identified in this lithofacies.

The white Porcellanite is white or creamy white in colour. It is also thickly bedded, fine-grained, hard and porous. The thicknesses of the beds are tens of centimetres. This porcellanite contains convolute beddings as SSD structures.

The green porcellanite facies forms the top-most part of the Chopan Porcellanite Formation. It is thinly bedded and contains alternate beds of green and white porcellanite. The green beds are a few millimeter thick and white beds are less than a millimetre thick (Figure **3E**). The green porcellanite also shows fine-scale laminae those are mostly contorted (Figure **3F**). The green beds are hard and compact and white beds are porous. SSD structures such as dykes, pinch-and-swell structure, ball-and-pillow structures occur within the

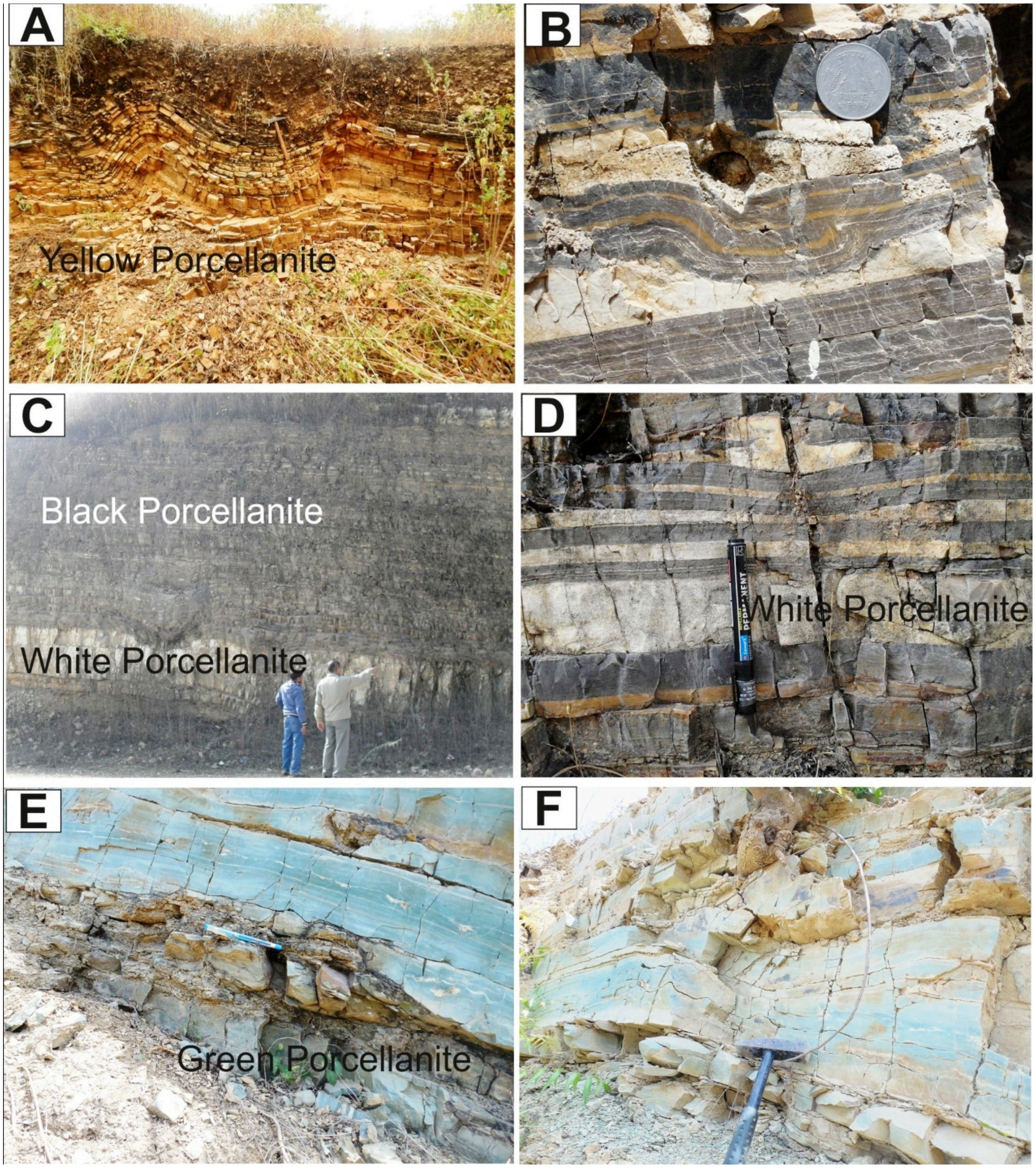

Figure 3: Field photographs of the Mesoproterozoic porcellanite, (**A**): Bedded yellow porcellanite showing contorted bedding. Locality: Chopan town. Length of the hammer used as scale is 30 cm, (**B**): Alternation of white and black porcellanite displaying convolute beddings. Diameter of the coin is 2.5 cm, (**C**): Bedded occurrence of black porcellanite alternate with white porcellanite. Locality: Bari village. Length of the longer man is 175 cm, (**D**): Intercalation of white and black porcellanite showing pinching and swelling structures. Length of the marker pen is 12.0 cm, (**E**): Green porcellanite exhibiting pinching and swelling structures. Length of the pen is 13 cm, (**F**): Green porcellanite showing contorted bedding. Lenght of the hammer is 30 cm. Locality Chopan town.

green porcellanite (Figure **3E** and **F**). This lithofacies also contains rhombohedral joint planes at few levels.

3.2. Petrography

Petrography of the rocks is very significant in determining their texture and mineral composition. It is also used in identifying relict features and xenocrysts. In the present study, petrography of the four different facies of the porcellanite has been carried out separately and described below.

Yellow porcellanite contains cryptocrystalline and microcrystalline quartz, and the crystals are oriented in

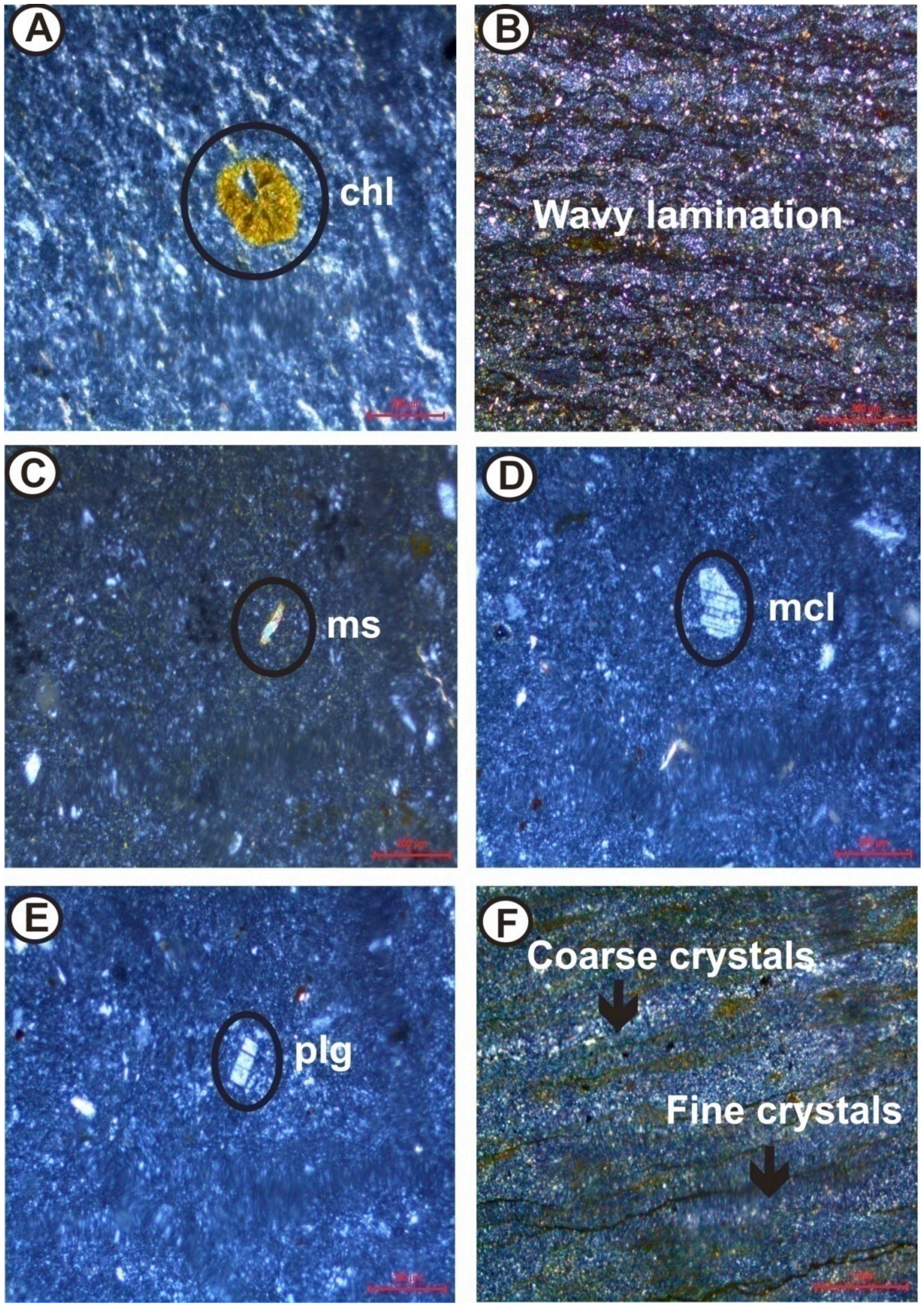

Figure 4: Photomicrogrphs of Mesoproterozoic porcellanite, (**A**): Yellow porcellanite largely composed of cryptocrystalline quartz. Note the occurrence of chalcedony mineral (chl) within the cryptocrystalline quartz, (**B**): Black porcellanite showing wavy laminations in the form of alternate laminae of cryptocrystalline quartz and amorphous silica, (**C**): Black porcellanite composed of microcrystalline quartz. Note the occurrence of muscovite (ms) and a few bigger quartz grains in it, (**D**): White porcellanite containing cryptocrystalline to microcrystalline quartz encasing microcline (mcl) as a xenocryst, (**E**): White porcellanite containing cryptocrystalline to microcrystalline quartz encasing plagioclase feldspar (plg), (**F**): Green porcellanite containing alternate laminae of microcrystalline quartz and cryptocrystalline quartz.

one direction (Figure **4A**). It also shows flow structure in several thin sections. In many thin sections, parallel bands of microcrystalline and cryptocrystalline quartz are present. The bands are mostly grey in colour. The microcrystalline quartz encases euhedral plagioclase and elongated muscovite flakes. The plagioclase shows high relief, lamellar twinning and inclined extinction whereas muscovite is identified based on one set of cleavage and parallel extinction. The occurrence of chalcedony is recorded showing fibrous crystals (Figure **4A**). In some thin sections, three to four quartz and feldspar crystals form patches as xenocryst. The crystals also show alterations along boundaries.

In thin section, black porcellanite shows wavy laminae which are dark grey and light grey alternatively (Figure **4B**). Most common mineral is quartz. It occurs in a cryptocrystalline form. Xenocrysts are plagioclase, microcline and muscovite encased within the cryptocrystalline quartz (Figure **4C**). Plagioclase feldspar shows lamellar twinning, euhedral shape and high relief. Some feldspar crystals have been altered to clay minerals. The microcline occurs with cross-hatched twinning, euhedral shape, medium relief. The muscovite shows needle-like structure and parallel extinction. Quartz veins showing cross cutting relations are also seen in some thin sections.

In white porcellanite, most of the quartz grains are cryptocrystalline in nature. Xenocrysts are plagioclase, microcline and biotite encased within the cryptocrystalline quartz (Figure **4D** and **E**). The plagioclase shows euhedral to subhedral shape, lamellar twining and inclined extinction. The microcline is present with euhedral shape and cross-hatched twinning. The muscovite is colourless and euhedral in shape, and shows one-set of cleavage with parallel extinction.

In green porcellanite, cryptocrystalline to microcrystalline quartz is dominantly present. Wavy laminations are also found and laminae of yellowish green and grey colour occur in bundles (Figure **4F**). These laminae are composed of cryptocrystalline quartz and microcrystalline quartz and organic matter (Figure **4F**). The xenocrysts are plagioclase feldspar and muscovite encased within the crypto crystalline to microcrystalline quartz. Needle-shaped muscovite is also present. Plagioclase feldspar is euhedral in shape and shows lamellar twining and high relief. Needle-shaped muccovite show parallel extinction. Stylolites are common within this type of porcellanite.

3.3. XRD Analysis

X-ray diffraction is a valuable tool in determining the mineralogy of sedimentary rocks. In case of cryptocrystalline and microcrystalline minerals, XRD is very useful for mineralogical determination. Most of the XRD peaks are common in the yellow, black, white and green porcellanites. Mineral quartz is identified by a peak at d value 3.35 Å and a peak at 4.26 Å in all the samples of porcellanite. Presence of albite is confirmed by the peaks at 4.03 Å and 3.19 Å. Sanidine shows its presence by a peak at 3.78 Å chiefly in yellow porcellanite. A peak at 2.57 Å shows the occurrence of muscovite. (Figure **5**)

4. DISCUSSION AND CONCLUSIONS

The porcellanite is a chemically precipitated sedimentary rock composed primarily of microcrystalline and/or chalcedonic quartz with subordinate megaquartz along with minor impurities. The major difference between the Precambrian and Phanerozoic chert / porcellanite lies in their mode of precipitation [12]. Also, it is now understood that most Phanerozoic chert and porcellanite are the diagenetic descendants of originally biogenous silica [2, 3]. In the Phanerozoic chert and porcellanite, silica-secreting organisms play a major role in their formation, but in the Precambrian, the absence of these organisms cannot be accounted for their role in silica cycle and the chert formation. Hence, the Precambrian porcellanite and chert precipiatation require another mechanism than the biochemical.

The petrographic study of the Mesoproterozoic bedded porcellanite suggests that the black and green porcellanites are typically chert and the yellow and white porcellanites may either be rhyolite itself or porcellanite. The main trigger mechanisms are firstly earthquakes, secondly overloading from volcanic rocks and thirdly, to a lesser extent, subaqueous currents [7, 13]. The small lateral extent for the development of SSD structures suggest that they either formed by overloading from volcanic rocks or by subaqueous currents. Their development along unstable continental slopes in oceanic basins is more likely in the present case [14, 15]. However, Roep and Everts [16] attributed the occurrence of pillow structures with seismicity. Furthermore, the occurrence of mud flasers within the bedded porcellanite is indicator of tidal influence during their sedimentation [17]. The occurrence of shale in between the chert and porcellanite shows that the siliciclastic supply was intermittent in the basin. The porcellanite and chert deposited when the siliciclastic supply was minimum and shale was deposited when it was supplied to the basin. Chert and porcellanite deposit in the deep marine conditions as well as in shallow marine conditions and alkaline lakes [18]. As the Vindhyan basin was an intracratonic basin, it can be visualized that it was a shallow basin rather than the deep basin. Furthermore, radiolarian chert deposits in a deep marine condition, which is a rare possibility in the present case. Horizontal fine lamination in the bedded chert suggests weak current activity that favours the preservation of laminae [19]. In the green porcellanite, the presence of fine-scale wavy laminae suggests weak current activity, but the occurrence of waves during its precipitation. Furthermore, the occurrence of

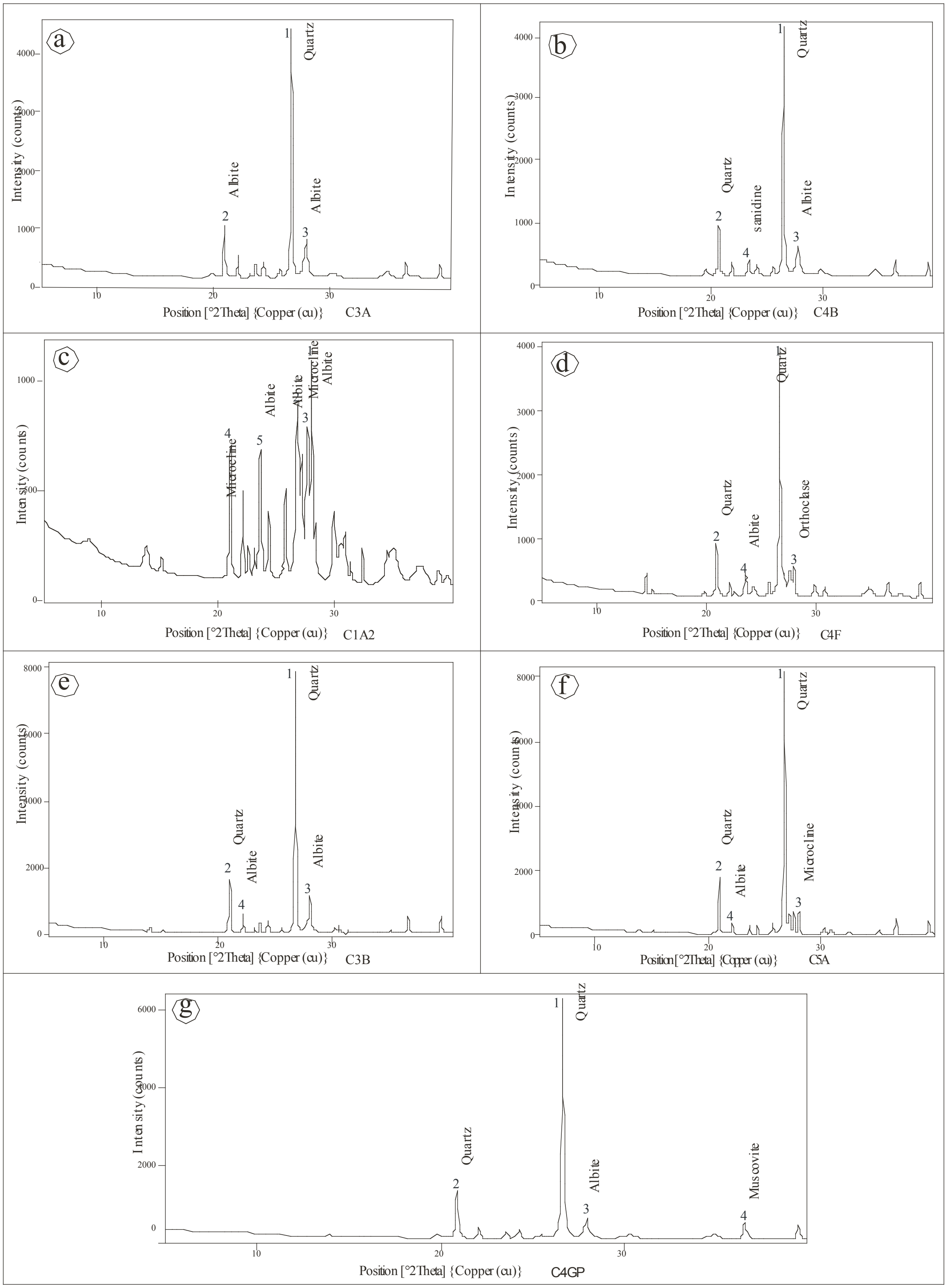

Figure 5: X-ray diffractograms of the porcellanite samples of the Chopan porcellanite Formation, Vindhyan Supergroup. Diffrctograms a & b from yellow porcellanite, c & d from black porcellanite, e & f from white porcellanite and g from green porcellanite.

wavy laminae suggests that the precipitation took place above the wave-base in a shallow marine condition.

The source of the silica and the mechanism of the porcellanite and chert formation are enigmatic. The possible source of silica may be a volcanic igneous rock that evolves on continents and ocean floors. The shallow marine origin of the chert and porcellanite suggests that the volcanic materials evolved chiefly within the oceans. The occurrence of both K-feldspar and plagioclases and muscovite as the xenocryst suggests that the composition of the volcanic rock that acted as the source of silica was rhyolitic [20]. The occurrence of sanidine as a xenocryst in some samples suggests that it was supplied from a high temperature volcanic igneous rock such as rhyolite. Most likely, the composition of the source was rhyolitic for the studied porcellanite. The rhyolitic material was fully or partly dissolved in the sea water which was later precipitated as chert and porcellanite. A few crystals of feldspar and mica remained undissolved those found as xenocryst in the studied porcellanites. Radiolarian and diatom oozes are accumulating on the ocean floors at the present times and they precipitate chert and porcellanite [21]. Notably, the radiolarians arrived not earlier than Cambrian and similarly diatoms originated during early Jurassic [18]. Based on the present work, it is envisaged that the Vindhyan porcellanite of Mesoproterozoic age was originated through the chemical precipitation rather than the biochemical precipitation of Mesoproterozoic seawater. Inorganic precipitation of silica can take place where there is large variation in pH [18]. The occurrence of chert and porcellanite in the present case suggests fluctuations in pH of the seawater from which they precipitated. Porcellanite contains clay as impurities besides microcrystalline quartz {22]. The clay was supplied to the oceans from the continental part during the typical porcellanite formation. However, it may not be out of place to consider silicified volcaniclastic tuffaceous mudstone to these porcellanites [11, 22]. Further, the volcaniclastic tuffaceous mudstones should contain sedimentary rock fragments [23] that is absent in the studied porcellanites.

Earlier workers such as Mehrotra and Banerjee [8], Mehrotra *et al*. [9], Srivastava *et al*. [5] and Mishra and Sen [10] considered the Chopan Porcellanite Formation as representing volcaniclastic sediments where the material originated as a result of the subaerial or aqueous volcanic eruption was later transported to the depositional basin. We suggest that the Chopan Porcellanite is of sedimentary origin with its chemical precipitation in view of the fact that it occurs in bedded form, contains fine algal laminations and the chemically precipitated chalcedony. Furthermore, the dominance of microcrystalline and cryptocrystalline quartz (up to 99.0 percent) in many samples suggests that the formation of porcellanite took place by chemical precipitation from seawater that was rich in silica. The source of silica was a rhyolite that evolved on the ocean floor. The alkaline pH was responsible for dissolution of silica and the alkalinity was achieved due to the presence of phytoplanktons. The evaporation of seawater and lowering of pH facilitated the precipitation of chert and porcellanite. The crystals of feldspar and muscovite those were un-dissolved remained as xenocryst in the studied chert and porcellanite. The fluctuation in pH because of addition of volcanic materials at times and the clay supply from the continent were responsible for the occurrence of bedded chert and porcellanite here. However, we cannot rule out that the yellow and white porcellanite being the rhyolite with some alteration in the shallow marine environment. Thus, the Chopan Porcellanite Formation may not be a typical porcellanite, but it may be a combination of rhyolite and chert.

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