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Bundelkhand Craton

JAYANTA KUMAR PATI[1,2*] and ANUJ KUMAR SINGH[1]

[1]*Department of Earth and Planetary Sciences, Nehru Science Centre, University of Allahabad, Allahabad 211 002, India*

[2]*National Centre of Experimental Mineralogy and Petrology, 14 Chatham Lines, University of Allahabad, Allahabad 211 002, India*

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The Bundelkhand Craton (BuC), one of the five Archean age cratons of the peninsular India, is exposed over an area of ~29000 sq km in the north central India. The major rock types are granitoids of ~2.5 Ga age along with limited exposures of tonalite-trondhjemite-granodiorite (TTG) gneisses (~3.6 Ga) and metasupracrustal rocks. Two pervasive and prominent litho-tectonic elements (giant quartz veins with NNE-SSW trend dissected by NW-SE oriented mafic dykes of tholeiitic affinity) of possible Paleo-Mesoproterozoic age occur within the BuC as nearly linear bodies. In recent years, studies have shown the presence of three ~E-W-trending crustal-scale tectonic zones from north to south of the BuC associated with or without Archean Greenstone Belts and Paleoarchean TTG gneisses negating the earlier concept of the BuC occurring as a monotonous "batholith". This is also supported by the available geophysical data. New data pertaining to multiple phases of intrusive activity, deformation and imprints of high-grade metamorphism have contributed significantly to a better understanding of the evolution of BuC in space and time. Petrological, geochemical, structural and geochronological data provide evidences of Archean age plate tectonics in the BuC. Mineralization remains limited to sizable pyrophyllite-diaspore and iron deposits, and incidences of gold, PGEs (platinum group elements) and molybdenite associated with or without silico-thermal fluid activity. A confirmed meteoritic impact structure at Dhala, Shivpuri district, north central India, is known to contain substantial reserve of uranium ore within impact melt breccias.

Keywords: Archean Greenstone Belts; Tonalite-Trondhjemite-Granodiorite Gneisses; Dhala Impact Structure

Introduction

The evidences pertaining to the formation and geodynamics of the Archean crust, both continental and oceanic, and their subsequent reworking and preservation, are best enshrined in the exhumed cratonic nuclei with spectacular details (van Hunen and Moyen, 2012). At present, less than 10% of Archean continental crust is preserved in nature (Hawkesworth *et al.*, 2019). Hence, a detailed knowledge about the formation, evolution and reworking of the primordial crust by endo- and exogenetic (Johnson *et al.*, 2018) processes observed in different parts of the world is of great importance to better understand the early Earth evolution in space and time.

In this context, the peninsular India comprises relatively well studied cratons of Archean age, which include: i) Aravalli Craton (AC), ii) Bastar Craton (BC), iii) Bundelkhand Craton (BuC), iv) Eastern and Western Dharwar Cratons (DC), and v) Singhbhum Craton (SC), provides telltale signatures of the early Earth (Fig. 1A). Each one of these cratons preserves some unique and common signatures of the juvenile Earth, and subsequent episodic magmatic and tectono-metamorphic imprints. The BuC is one of the prominent Archean cratonic nucleus in north central India occupying nearly 29000 sq km area and bounded by the Paleoproterozoic Vindhyan sedimentary basin from all sides except northern and south-southwestern parts where it is overlain by Indo-Gangetic alluvium and in parts by basaltic lava (Deccan Traps), respectively (Basu, 1986; Naqvi and Rogers, 1987; Goodwin, 1991; Meert *et al.*, 2010; Ray *et al.*, 2015;

**Author for Correspondence: E-mail: jkpati@gmail.com*

Manglik *et al.*, 2015; Meert and Pandit, 2015) (Fig. 1B). The early workers (Medlicott, 1859; Mallet, 1869) reported mainly petrological findings while Pascoe (1950) provided a litho-stratigraphic status to the rocks of the BuC. The upsurge in interest in the geology of BuC was observed consequent to the publication of the seminal review by Basu (1986). Mondal *et al.* (2002) made an excellent contribution by upgrading the geochronological database of the felsic rocks from the BuC using $^{207}Pb/^{206}Pb$ zircon ages with a sizable and representative number of samples. Three most significant contributions appeared in 2006, 2008 and 2010 with respect to the discovery of an Archean age ophiolite sequence (Malviya *et al.*, 2006), world's seventh oldest meteoritic impact structure at Dhala, Shivpuri district, M.P. (Pati *et al.*, 2008a, 2010) and a high pressure (up to 20 kbar) metamorphic assemblage of Neoarchean age similar to white schist (Saha *et al.*, 2011) giving further credence to the Archean plate tectonics, respectively. These findings made profound impacts on the understanding of the geology of the BuC and its geodynamic evolution in space and time.

In recent years (2016-2019), several important contributions have appeared pertaining to geochronological, petrological, structural, metamorphic, geochemical and geophysical studies of the BuC (Kaur *et al.,* 2016; Saha *et al.*, 2016; Verma *et al.*, 2016; Ramiz and Mondal *et al.*, 2017; Joshi *et al.,* 2017; Chauhan *et al.*, 2018; Alfimova *et al.*, 2019; Nasipuri *et al.*, 2019; Singh *et al.*, 2019 and many more). The impact cratering research has added a new dimension in terms of extraterrestrial effects on cratonic crusts due to bolide impact (Pati *et al.*, 2017; Li *et al.*, 2018; Pati *et al.*, 2018; Pati *et al.*, 2019). In addition, studies on morphotectonics of cratonic rivers (Prakash *et al.*, 2016a, b), fluid inclusion study (Rout *et al.*, 2017) of giant quartz veins (GQVs), submagmatic fabric in granitoids (Sarkar *et al.*, 2017), magma hybridization (Ramiz and Mondal, 2017; Deb and Bhattacharyya, 2018) and possible causes of colour variation in granitoids (Sensarma *et al.*, 2018) have also helped in plugging important gaps in our understanding of the cratonic evolution.

Petrochemical and Geochronological Studies

The BuC consists predominantly of granitoids, TTG gneisses, metasupracrustals (amphibolites, banded iron formation, komatiitic basalts, metaperidotite, calc-silicate rocks, corundum-bearing phengite schist, quartz-sericite schists, fuchsite quartzite and quartzite), GQVs and mafic dykes (Fig. 1B).

The metasupracrustals are mainly confined to Bundelkhand Greenstone Belt (Malviya *et al.*, 2006) between West of Dhala and East of Kabrai associated with an Archean age suture zone, Bundelkhand Tectonic Zone (BTZ; Pati, 1999, Malviya *et al.*, 2006, Chauhan *et al.*, 2018, Nasipuri *et al.*, 2019). The lithology of this greenstone belt includes mafic-ultramafics, BIFs and metasedimentary rocks. The geochemical and Sm-Nd isotopic data of iron-rich layers and silica bands from BIFs of the BuC are analyzed along with those from Fennoscandian shield (FS) and East-European Platform (EEP; Alfimova *et al.*, 2019). The Algoma type BIFs of BuC and FS are compared with EEP and it is observed that $\varepsilon Nd_{[t]}$ for silica-rich layers is elevated compared to iron-rich layers for all the samples and the higher $\varepsilon Nd_{[t]}$ values (~+5.0) in silica-rich layers and lower $\varepsilon Nd_{[t]}$ values (–5 to +2) for iron-rich layers infer juvenile and continental sources, respectively despite their diverse spatial disposition worldwide. Linear slivers of metasupracrustals are also observed along Madaura-Rajaula-Girar-Baraitha belt (Malviya *et al.*, 2006; Singh and Slabunov, 2016; Slabunov *et al.*, 2017a; Mohanty *et al.*, 2018; Ramiz *et al.*, 2018) comprising quartzites, BIFs and mafic-ultramafic rocks (Singh and Slabunov, 2016; Slabunov *et al.*, 2017a and references therein). Based on geochronological data of zircons separated from quartzites, Slabunov *et al.* (2017a) established the existence of an Archean crustal block as their possible provenance. In Madawara-Ikauna and Lalitpur areas of the BuC, several scattered outcrops of mafic and ultramafic rocks (gabbro and peridotite) are exposed which are older than the anatectic granites (Slabunov and Singh, 2018). Ramiz *et al.* (2018) suggested that the formation of Madawara Ultramafic Complex (MUC) took place in a subduction zone setting refuting earlier proposed models of layered igneous complex (Slabunov and Singh, 2018) and Alaskan type intrusion.

Predominantly the TTG gneisses are exposed along ~E-W-trending BTZ (Pati 1999; Mondal *et al.*, 2002; Kaur *et al.*, 2014; Saha *et al.*, 2016; Nasipuri *et al.*, 2019). They are mostly associated with the metasupracrustals, and their geochemical characteristics are similar to the other worldwide

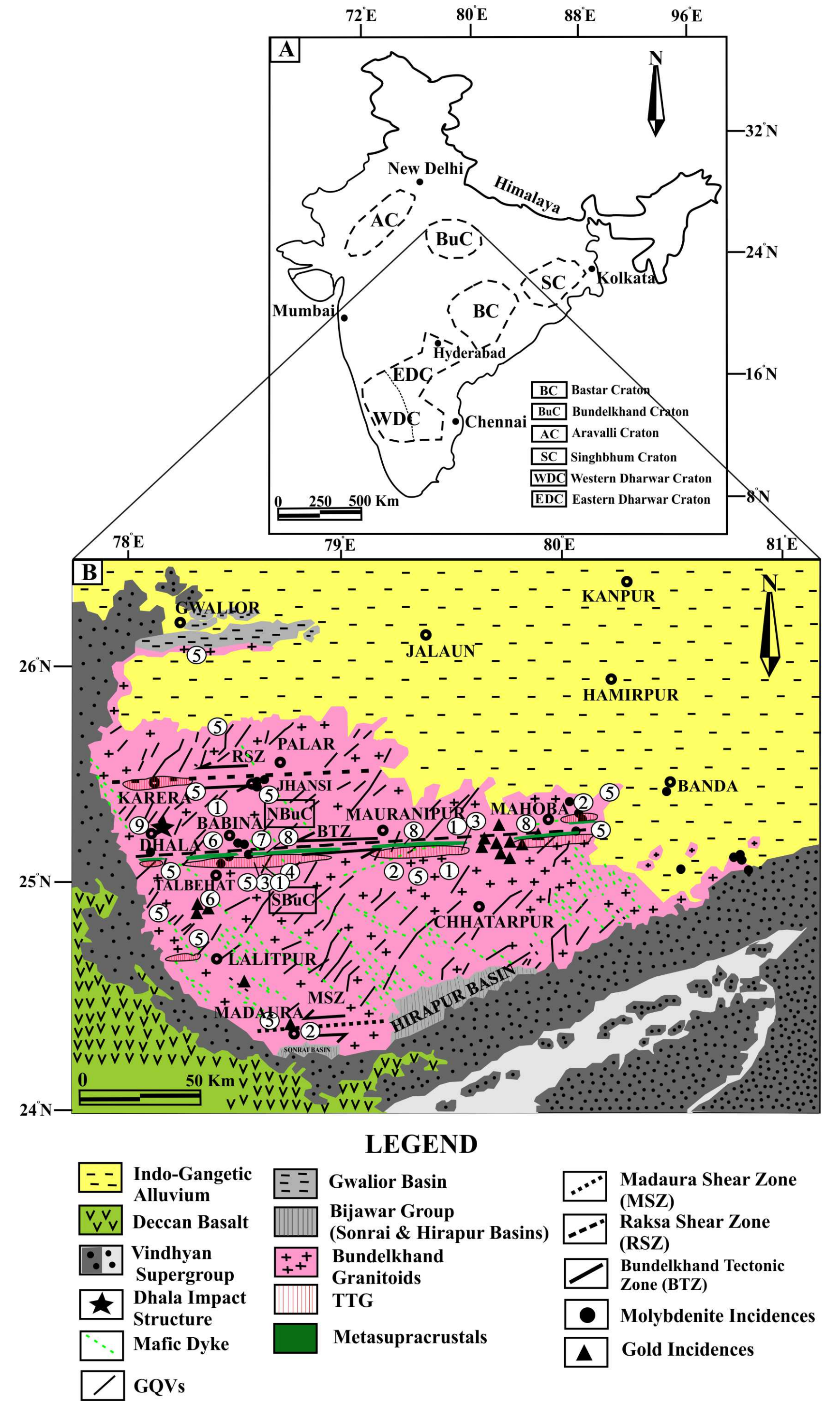

Fig. 1: A) Archean cratonic nuclei of the peninsular Indian Shield (AC: Aravalli Craton, BC: Bastar Craton, BuC: Bundelkhand Craton, EDC: Eastern Dharwar Craton, WDC: Western Dharwar Craton, SC: Singhbhum Craton). B) Geological map of Bundelkhand Craton (BuC) showing different lithological units and their ages (displayed with natural numbers in the circle) as reported earlier by several scientists/researchers based on their study. Ages are shown in white circles using natural numbers. U-Pb zircon age of TTGs: 1. (3.0-2.8 Ga), 2. (3.2 Ga), 3. (3.39 Ga) and 4. (3.55-3.56 Ga), U-Pb zircon age of granitoids and related rocks: 5. (2.55-2.58 Ga) and 6. (2.5 Ga), 7. U-Pb zircon and monazite apparent ages of metamorphism of corundum- bearing white schist: 2.6-2.8 Ga, 8. Nd model ages from mafic supracrustals: 3.3-3.4 Ga, and 9 SHRIMP U-Pb age of granitoid: 2.5 Ga represents the age of target rock of the Dhala impact structure. Bundelkhand Tectonic Zone (BTZ) divides the BuC into two parts: Northern Bundelkhand Craton (NBuC) and Southern Bundelkhand Craton (SBuC) based on available geological and geophysical data

occurrences of TTGs in Archean cratons. The geochemical analyses of these TTGs suggest their formation by partial melting of the mafic oceanic crust under physico-chemical conditions where garnet and amphibole are stable phases (Chauhan *et al.*, 2018). Joshi *et al.* (2017) classified TTGs into two categories (Low-HREE TTG and Enriched TTG) based on REE patterns. These TTG gneisses vary in age between 3.59 to 2.66 Ga (Mondal *et al.*, 2002; Kaur *et al.* 2016; Joshi *et al.* 2017; Saha *et al.*, 2016; Verma *et al.* 2016) and Kaur *et al.* (2016) reported four distinct episodes of TTG emplacement between 3.55 and 3.20 Ga. The isotopic data and bulk rock geochemistry of TTG gneisses suggest reworking of older mafic and felsic sources (Kaur *et al.* 2014, 2016; Saha *et al.*, 2016). Based on U-Pb zircon geochronological data, Verma *et al.* (2016) and Nasipuri *et al.* (2019) have demonstrated relatively younger ages of the TTGs. At most places, outcrops of garnet-chlorite schists, amphibolites, chlorite-actinolite-talc-bearing ultramafic schists etc. are exposed as enclaves within TTG gneisses (Nasipuri *et al.*, 2019). Limited geochronological studies (Sm-Nd isochron age) have inferred their age of emplacement to be ~3.4-3.3 Ga, significantly younger than the host rock (Mondal *et al.*, 2002; Malviya *et al.*, 2005; Singh *et al.*, 2019). Ramiz and Mondal (2017) described the texture and geochemical data of these enclaves and compared them with their host granitoids. They proposed that the rapid crystallization of mafic magma within a relatively cooler felsic granitoid is responsible for their generation. However, they did not agree with the concept of magma mixing of mafic magmatic enclaves with their host granitoids because of the depleted concentration of K, Ba, Rb and Sr. The mafic rocks of Mauranipur area are significantly enriched in REE compared to those exposed in Babina with similar negative Nb anomalies suggesting the effects of crustal contamination in the area (Singh *et al.*, 2019). Based on whole rock geochemical data, Singh *et al.* (2019) concluded that the mafic-ultramafic rock suites of the BuC originated in a subduction-related tectonic setting from a depleted mantle source.

Greenstone Belts

In the BuC, both metasedimentary and metavolcanic rocks are exposed along the BTZ comprising greenstone components (amphibolites, banded iron formation, pillow basalts, komatiitic basalts, calc-silicate rocks, white schists, quartzites, and metapelites) alongwith TTG gneisses and anatectic granites (Basu, 1986; Mondal *et al.*, 2002; Malviya *et al.*, 2006; Mohan *et al.*, 2012; Kaur *et al.*, 2014, 2016; Singh and Slabunov, 2016; Saha *et al.*, 2016; Verma *et al.*, 2016; Joshi *et al.*, 2017; Singh *et al.*, 2019). Babina-Mauranipur (central Bundelkhand) and Rungaon-Girar (south Bundelkhand) are two major greenstone belts exposed in the BuC which differ from other lithounits of BuC in terms of their grade of metamorphism, textures, structures etc. (Singh and Slabunov, 2015). The lithology of Babina-Mauranipur greenstone belt comprises mafic-ultramafic rock suites, felsic volcanics and at some places, BIF and metasedimentary rock units as well. This belt displays an angular relationship with the TTG gneisses (Singh *et al.*, 2018). They have divided the central Bundelkhand greenstone belt into two parts (Mauranipur greenstone belt and Babina greenstone belt). The lithology of Mauranipur belt is best exposed in Baragaon area (Malviya *et al.*, 2006), which includes metamorphosed pillow lava, basaltic komatiites, BIFs, metapelites and felsic volcanics (Singh and Slabunov, 2015; Slabunov and Singh, 2018; Singh *et al.*, 2019). Singh *et al.* (2018) divided basalts of Mauranipur greenstone belt into three major categories: type I, type II and type III basalts based on geochemical data. Type I and II basalts show negative anomalies of Nb, Zr, Hf and Ti, and are enriched in LREEs. Type III basalts have high Zr/Nb ratios (9.8-10.4), TiO_2 (1.97-2.04 wt. %) with relatively flat Zr, Hf, Y and Yb. In some places, metavolcanics and gneisses of this belt are intruded by pink granites (Singh *et al.*, 2018). The Babina greenstone belt comprises BIFs, mafic-ultramafic rocks and felsic volcanics (Singh and Slabunov, 2015). In the southern part of BuC, Rungaon-Girar greenstone belt is composed of quartzites, BIFs and mafic-ultramafic rock units (Slabunov, 2016; Slabunov *et al.*, 2017a; Singh et al, 2018). Recent studies have suggested that the emplacement of medium- to coarse-grained granites mark the culmination of greenstone belt evolution in central part of the BuC (Singh *et al.* 2018 and references therein).

Granites/Granitoids

Granitoids in the BuC mainly comprise syeno- and monzogranites, diorites, granodiorites and syenogranites (Mondal *et al.,* 2002; Pati *et al.*, 2007;

Kaur *et al.*, 2016; Joshi *et al.*, 2017; Nasipuri *et al.*, 2019). These granitoids show intrusive relationship with intensely deformed TTG gneisses and supracrustal units (Nasipuri *et al.*, 2019). Chauhan *et al.* (2018) have suggested the generation of Bundelkhand granitoids (mostly K-rich) by anhydrous partial melting of TTGs or mafic crustal components in a subduction-related tectonic setting similar to the study of Verma *et al.* (2016). Age of K-rich granitoids in Bundelkhand is restricted between 1.9 and 2.58 Ga (Kaur *et al.*, 2016; Joshi *et al.*, 2017). Several workers have presented major and trace element data of these granitoids in order to establish its petrogenetic correlation and geochemical significance (Kaur *et al.,* 2016; Joshi *et al.,* 2017). Based on their geochemistry, Joshi *et al.* (2017) divided high-K calc-alkaline granitoids into two major groups (Low-SiO_2 high-MgO; LSHM and High-SiO_2 low-MgO; HSLM) and explained their genesis by partial melting of crust and mantle at the same time in a narrow time interval of 30 my (Halla *et al.*, 2017). Further, these granitoids are classified into several categories based on their characteristic composition and REE concentrations (e.g., sanukitoids, closepet-type granitoids, low-HREE monzogranites, low-Eu monzogranites and monzogranites) while having their age (U–Pb zircon) of emplacement ca. 2.5 Ga (Verma *et al.*, 2016; Joshi *et al.*, 2017). Singh *et al.* (2019) reported whole-rock geochemistry and Nd isotope data for some specific granitoids (sanukitoids and anatectic granites) to explain their temporal evolution and genetic relationship.

Sanukitoids are a sequence of low silica, high-K and high-Mg dioritic to granodioritic rocks which are exposed as small plutons in Bundelkhand granite-greenstone belts (mostly in the northern and central part with few exposures in southern part), emplaced at around 2.95-2.55 Ga and often intruded by pink granites, pegmatites and quartz veins (Heilimo *et al.*, 2011; Joshi *et al.*, 2017; Singh *et al.*, 2019). These sanukitoids are relatively, more enriched in light rare earth elements (LREEs) and large-ion lithophile elements (LILEs) compared to heavy rare earth elements (HREEs) and are also depleted in high-field strength elements (HFSEs). Based on bulk-rock geochemistry, Sm-Nd isotopic data and U–Pb zircon ages, Singh *et al.* (2019) concluded that these sanukitoids are originated in a subduction-related tectonic setting and emplaced between 2.58 and 2.50 Ga which is contemporaneous with high-K anatectic granite magmatism (partial melting of pre-existing TTGs). Isotopic study of sanukitoids reveals that whole-rock εN_{dt} values are mostly negative (–3.6 to –1.6) suggesting a significant role of the crustal component in the generation of these granitoids. Possibly the mixing of metasomatized melts from the mantle with anatectic granitic melts, followed by homogenization at shallow crustal level, resulted in the formation of sanukitoids (Singh *et al.*, 2019). Joshi and Slabunov (2019) carried out a comparative study between Neoarchean sanukitoids from Karelian (2.68-2.74 Ga; Fennoscandian Shield) and Bundelkhand (2.53-2.56 Ga; Indian Shield) Cratons closely associated with respective greenstone belts having similar geochemistry and formed in a subduction-related tectonic setting.

Recent geochronological studies by Singh and Slabunov (2015) suggested the Neoarchean age and a subduction-related environment for the felsic volcanic rocks exposed in Babina, Baragaon, Karakhera, Umri, Maheshpura, Nayakhera and Mahoba area (Joshi *et al.*, 2017). Sensitive High Resolution Ion Micro Probe (SHRIMP) age data of zircons infer that these volcanics (dacites and rhyolites) range in age between 2.54 Ga and 2.81 Ga (Singh and Slabunov, 2015; Slabunov and Singh, 2018). The presence of arc-related felsic volcanism at 2.54 Ga also suggested the beginning of K-rich magmatism in the BuC (Singh and Slabunov, 2015; Verma *et al.*, 2016).

Fluid Inclusion Study of GQVs

In BuC, GQVs occur with predominantly NNE-SSW to NE-SW trend along tectonically (fault) controlled hydrothermal activity (Pati *et al.*, 2007). Rout *et al.* (2017) observed four different types of fluid inclusions within these quartz veins. They include aqueous biphase (type-I), pure carbonic (type-II), aqueous carbonic (type-III), and polyphase (type-IV) inclusions. The calculated salinity from temperature of melting of last ice (Tm) values are low to moderate (0.18 to 18.19 wt. % NaCl equivalents) and the liquid-vapor homogenization temperatures (Th) show a wide variation (101 to 386ºC). In addition, the data on pure CO_2 inclusions reveal a near constant value of T_{mCO2} at –56.6ºC suggesting the absence of CH_4. Bivariate plot between Th and salinity suggest three possible water types which control the overall fluid activity in GQVs of the BuC. A low saline and CO_2-bearing fluid phase registering higher temperature characteristic resembles a metamorphic fluid that could be the source for these GQVs. Also, the fluid characteristics of GQVs compare well with mineralized reefs of the Dharwar and Bastar Cratons (Rout *et al.*, 2017).

Structural and Metamorphism Evolution

First comprehensive report on high to ultrahigh pressure estimation of corundum-bearing white mica schist (12-20 kbar) in the Babina region, U.P., India established an Archean age metamorphic event (~2.78 Ga) followed by exhumation (~2.47 Ga) suggesting a Neoarchean subduction event in the north central India, later intruded by granitoid magma (Saha *et al.*, 2011). Recently, the data on structural mapping from BuC are summarized by Nasipuri *et al.* (2019). They show three sets of folds in TTG gneisses, of which first two generations of folds developed contemporaneous with crystallization of magma at ~3.39 Ga and third stage of folding triggered the development of E-W-trending sub-vertical axial planar foliation. A penetrative and pervasive ~E-W sinistral shear fabric in the form of mylonitized granitoids and related rocks accompanied by possible potash metasomatism, similar to earlier reports, is also observed. Verma *et al.* (2016) reported that TTGs associated with grey granitoids are sheared. Also, the presence of both dextral and sinistral shear movements may cause the overprinting of structural features in the BuC (Singh and Slabunov, 2016). Nasipuri *et al.* (2019) have suggested that the development of this shear fabric is contemporaneous to a Pan-African (~600-640 Ma) event which is unacceptable as the km-thick granite mylonites associated with the BTZ are dissected by Palaeoproterozoic GQVs (Pati *et al.*, 2007; Saha *et al.*, 2011). Singh and Bhattacharya (2017) have isolated some of the N-S-trending quartz veins (Basu, 1986; Pati *et al.*, 2007) from the pervasive NNE-SSW-trending voluminous GQVs (Basu, 1986; Pati *et al.*, 2007) observed in BuC and consider them as “a new shear system….in the form of N-S-trending quartz veins that are sometimes quartzo-feldspathic and rarely granitic in composition”.

The Neoarchean high-pressure tectono-metamorphic event (~2.8 Ga white schist; Saha *et al.*, 2011) and partial melting of TTG gneisses have also been recorded (Joshi *et al.*, 2017) along the BTZ, an Archean subduction zone. Mineralogical assemblage as well as petrographic studies of mafic and ultramafic rocks exposed in parts of Bundelkhand Greenstone Belt revealed greenschist to amphibolite facies metamorphism (Nasipuri *et al.*, 2019). Also, the amphibole-plagioclase-quartz assemblage in Babina area suggest P-T estimates in the range of ~6.5-8.5 kbar and 630-720°C (Nasipuri *et al.*, 2019). However, biotite registers relatively lower temperature (~500°C) of stability in the pressure range of 3.5-8.5 kbar possibly suggesting their formation during retrogression (Nasipuri *et al.*, 2019). Saha *et al.* (2016) have shown that at 3.6 Ga, the crust-forming process initiated in BuC, similar to BC, SC and other worldwide occurrences as a part of Ur Supercontinent.

Impact Cratering Research

The Dhala impact structure, Shivpuri district, M.P., India since its confirmation as a bona fide terrestrial meteoritic impact structure based on the observation of diagnostic evidences of shock metamorphism (Pati, 2005; Pati *et al.*, 2008; Pati *et al.*, 2019) continues to attract the attention of geoscientific community. Gaur *et al.* (2016) considered the impact melt breccia as “felsic volcanics” and further suggested that this “acid volcanic activity” is correlated to a global event at 1 Ga. Roy *et al.* (2017) reported subsurface data from 14 boreholes out of 70 locations drilled (up to a depth of 476.55 m) in different parts of Dhala structure in search of uranium and the laudable extensive drilling activity by the Atomic Minerals Directorate for Exploration and Research, Govt. of India immensely helped in the better understanding of the impact cratering process at Dhala. The maximum and minimum thicknesses of impact melt breccia observed are 261.15 and 8.75 m, respectively. Initially, they reported that the Dhala structure is a simple impact structure without a central uplift with a diameter of 7.5 km based on their subsurface data and witnessed a maximum shock pressure of 12 GPa. However, Pati *et al.* (2019) have reported shock pressures in the range between <2 and >60 GPa based on their detailed study of nearly all shock metamorphic features including shatter cones. Pati *et al.* (2017) have also shown the presence of 0.3 wt.% of extraterrestrial component in the Dhala impact melt breccia based on Cr and Ir data. They further reported the first Re and Os abundances in the impact melt breccias, and $^{187}Os/^{188}Os$ ratio of 0.133 confirming the presence of the impactor component (chondrite or iron meteorite). Li *et al.* (2018) studied the impact melt breccia and reported the presence of reidite, a high pressure polymorph of zircon and further constrained the age of Dhala impact between 2.44 and 2.24 Ga, although both findings have been questioned (Pati *et al.*, 2018).

Geophysical Studies

Podugu *et al.* (2017) reported heat flow, heat production and crustal temperatures of BuC based on data collected from 10 borehole cores in five locations (one to the north of BTZ and four to the southern part). They observe a low heat flow (32-41 mWm^{-2}) unlike AC but similar to Dharwar and other Archean Cratons worldwide. Radioelemental measurements comprising 243 surface and subsurface samples show significant variation in terms of average heat production between granitoids (4.0 ± 2.1 (SD) μWm^{-3}) and TTG gneisses (2.0 ± 2.1 (SD) μWm^{-3}). Their estimate suggests that the mantle heat flow values of BuC (12-22 mWm^{-2}) and Moho temperatures (290-420°C) are similar to DC despite observed variation in surface heat flow data indicating the disparity in upper crustal heat production. Ray *et al.* (2015) carried out radioelemental measurements on 27 samples comprising three granitoid types, gneisses and metavolcanics from the BuC and demonstrate three distinct domains of varying radioelemental concentrations: 1. the radioelemental abundances are the least along the BTZ, 2. maximum abundance is observed in the area south of BTZ, and 3. intermediate abundance is noted in the granitoids and gneisses occurring to the north of BTZ. The Bouguer gravity anaomaly map of BuC (Nabakumar and Kumar, 2018) shows a zone of gravity high to the south and the zone of low gravity is observed to the north separated by the trend of the BTZ (Pati, 1999). Chopra *et al.* (2018) measured thermal conductivity (TC), density (D) and porosity (P) of granitoids (potassic-, biotite- and sodic granitoids) and TTG gneisses comprising 21 samples and they report the range and average values. The average TC values (in $Wm^{-1}K^{-1}$) show significant variation: 2.95 ± 0.09 (Potassic granitoid: PG), 2.81 ± 0.04 (Biotite granitoid: BG), 2.95 ± 0.04 (Sodic granitoid: GG) and 3.08 ± 0.13 (TTG). Their corresponding density (g cm^{-3}) values (PG: 2.64 ± 0.02; BG: 2.67 ± 0.02; GG: 2.67 ± 0.002; TTG: 2.65 ± 0.02) and porosity (in %) data (PG: 0.21 ± 0.05; BG: 0.18 ± 0.04; GG: 0.18 ± 0.01; TTG: 0.08 ± 0.02) exhibit density similar to the upper crust average and low porosity.

Morphotectonic Studies

Limited data on morphotectonic investigation of cratonic rivers from the BuC suggest that the tributaries of Yamuna River draining the BuC exhibit a strong structural anisotropy in the basement of BuC which controls various tectonic and geomorphic landforms on the surface (Prakash *et al*., 2016 a, b). Broadly, the area exhibits dendritic drainage pattern, with some areas showing trellis and centripetal patterns. The elongated nature of the watersheds reflects a dominant control of regional linear tectonic elements pervasively present in the entire BuC (Prakash *et al*., 2016 a, b). A large number of first and second order streams in the BuC are characterized by the structural deformation, mainly as fractures, lineaments, and deformed lithounits. The trends of lineaments and faults have good correlation with orientations of streams. Nearly E-W oriented tectonic zones are likely to have controlled the drainage patterns in an early phase, followed by NW-SE and NE-SW trends. Recent studies advocate the probability that the NW-SE-trending tectonic lines (mafic dykes) have been reactivated in recent times (Late Pleistocene). The presence of E-W, NE-SW and NW-SE-trending streams indicate that these pervasive regional tectonic fabrics facilitated morphological advancement and hydrographic development of the drainage basins in the BuC.

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