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Annals of Precambrian Lithospheric Evolution and Metallogeny in the Dharwar Craton, India: Recent Paradigms and Perspectives

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This article brings out a comprehensive overview of the scientific studies that have been executed in different parts of Dharwar Craton during last four years 2016-2020. Recent trends of research and scientific perspectives have emphasized on integrated approaches involving a wide spectrum of geochemical, isotopic and geochronological proxies to address fundamental questions in the Dharwar Craton on Precambrian evolution of the earth, episodes and mechanisms of crust generation and the mantle dynamics. The excellent preservation of Precambrian lithologies including basement gneisses, volcano-sedimentary sequences of greenstone belts, granitoid plutons, ultramafic–mafic complexes, ultrapotassic magmatism and dyke swarms in the Dharwar Craton have provided an opportunity for understanding the geodynamic transitions in the secular evolution of the Earth. A four year status report including the principal lithological associations of Dharwar Craton have been described in this communication detailing the scientific investigations and their implications are brought out under various sections. The salient aspects of the scientific contributions on granite-greenstone terranes of Dharwar Craton emphasising on geochronology, geochemistry, biogeochemical processes, geodynamics and mineralization.

Keywords: Dharwar Craton; Greenstone Belts; Mafic-Ultramafic Complexes; Geochronology; Geochemistry

Introduction

The Archean geological record spanning from 4.0 to 2.5 Ga corresponds to one third of our planetary history thereby preserving the signatures of crust building episodes and continental reconfigurations in the juvenile earth. The Archean cratons all over the world are endowed with a remarkable thickness, extraordinary longevity with petrological, mineralogical and geochemical peculiarities largely attributable to a cold, non-convective, highly depleted mantle root underneath formed as a residue of extensive melt extraction. This Archean cratonic mantle root (ACMR) remained physico-chemically distinct and isolated from the convective mantle asthenosphere accounting for the long-term stability of the Archean cratons since 2.5 Ga. The Archean crustal nuclei with the ACMR are natural archives of ancient lithospheric remnants that records early differentiation products of primitive mantle and serve as primary resource to identify the complex processes that sculpted the earth as we see today. The driving mechanism and pattern of aggregation of Archean protocontinental blocks into a unified super craton by 2.5 Ga invoke intraplate, convergent margin and plume tectonics in terms of rifting, back arc basin formation, parallel arc accretion, subduction of oceanic lithosphere, and arc-continent or continent-continent collision. The ancient continental nuclei nested in Archean cratons all over the world are predominantly composed of TTG basement gneisses, surrounded by older and younger supracrustals of volcano-sedimentary sequences and intrusive granitoid plutons marking final phase of cratonization events. These Precambrian crustal components representing vestiges of differentiated mantle of primordial earth provide substantial insights into the early evolution of the earth in terms of crustal accretion, continental growth and mantle heterogeneity. The Indian Shield has a complex framework with different tectonic provinces including cratons, orogens, volcanic provinces, mobile belts and

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shear/suture zones developed through a long history from Archean to Cenozoic. The Precambrian lithotectonic configuration of the Indian subcontinent has been primarily sculpted by the congregation of five oldest surviving cratonic blocks as Dharwar, Singhbhum, Bastar, Bundelkhand and Aravalli cratons, mutually separated by transcrustal shear/suture zones, which potentially preserve Paleoarchean to Neoproterozoic crustal record.

The Dharwar Craton is among the largest cratons of the world with crystalline basement rocks ranging in age from Mesoarchean to early Paleoproterozoic (Fig. 1). This craton exposes the Archean continental crust marked by a progressive transition from upper to lower crustal levels with granite-greenstone terranes grading southward into granulites. On the basis of the age of basement gneisses, degree of regional metamorphism and crustal thickness, the craton has been divided into the western Dharwar Craton (WDC) and the eastern Dharwar Craton (EDC). The Closepet granite was considered to mark the boundary between WDC and EDC. The contrasting features between the WDC and the EDC also support this subdivision, with restricted occurrence of stromatolites, Mn formations, predominance of conglomerates and banded iron formations in WDC in contrast to the gold-bearing greenstone sequences in the EDC. Subsequent studies have proposed a steep high strain mylonitic Gadag-Mandya shear zone present along the eastern margin of the Chitradurga greenstone belt representing the boundary between the two crustal blocks of the Dharwar Craton. The contact between WDC and EDC is not sharp and a transition zone extending from Closepet granite to Chitradurga shear zone corresponds to the boundary between these two sectors of Dharwar Craton which has been demarcated as the Central Dharwar Province (CDP) or Central Dharwar Craton (CDC) based on magmatic and metamorphic age data (Peaucat *et al*., 2013; Li *et al*., 2018). The WDC, CDC and EDC preserve signatures of independent magmatic, metamorphic and tectonic events. The greenstone belts of Dharwar Craton represent remnants of Precambrian crust that derived through variable mantle processes and accreted under diverse geodynamic conditions and potential sites to study distinct geological and geochemical imprints of mantle evolution, crustal growth and mineralization.

Petrological, geochemical, isotopic and geochronological studies of distinct Precambrian crustal segments from Dharwar Craton, including basement gneisses, volcano-sedimentary sequences of greenstone belts, Neoarchean-Paleoproterozoic granitoid plutons, metallogeny, magmatic and sedimentary assemblages of Proterozoic intracratonic basins, Proterozoic kimberlites, lamprophyres, lamproites and dyke swarms provide insights for a comprehensive understanding of the evolution of the dynamic earth, Archean geodynamics and mantle heterogeneity, magmatism, crust generation and terrane accretion processes in diverse tectonic regimes. For decades, the fields of geochemistry and geodynamics have been viewed as only being loosely connected. Based on the published data, Raju and Mazumder (2019) have evaluated the Archean sedimentological history from the older and younger greenstone successions of Dharwar Craton. Compiling the new U-Pb detrital zircon data with the existing dates, Krapez *et al.* (2020) have demonstrated the evidence of magmatic components of ~3600 Ma in the Dharwar Craton and elucidated three stage tectonostratigraphic history. Recent advances made on the basis of the concept of "Chemical Geodynamics" have bridged geochemistry and geodynamics. The geochemical proxies have provided a clear avenue to constrain the longstanding questions relating to the formation, evolution, reworking and recycling of the lithosphere. Integrated approaches involving a wide spectrum of geochemical, isotopic and geochronological proxies have addressed fundamental questions like nature and composition of primitive mantle and crust extracted from it; changes in mantle processes, magma genesis and tectonic environments through the Hadean-Archean boundary; crustal recycling, mantle re-fertilization and mantle heterogeneity; evolution of sub-continental lithospheric mantle (SCLM);crust generation, terrane accretion and continental growth during Precambrian timeframe; dichotomy of Plate Tectonics and Plume Tectonics towards crustal growth mechanisms on ancient and modern earth.

Archean Basement Gneisses

The origin and evolution of the basement lithologies of Archean cratons yield important constraints on ancient crust-building processes. Seventy five percent of Earth's continental crust was formed during the

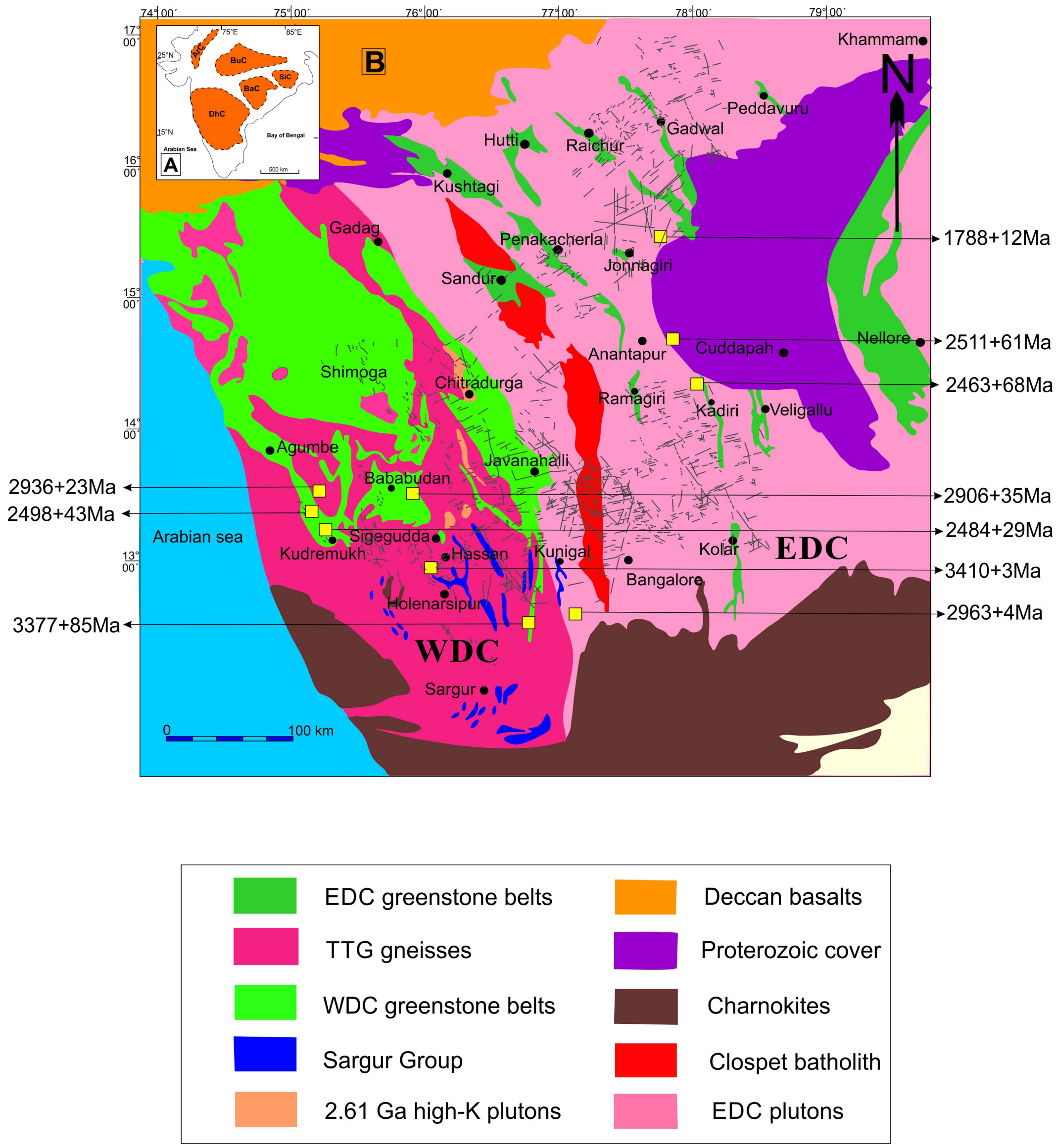

Fig. 1: A) Inset map showing different cratons in India, B) Simplified geological map of Dharwar Craton with various greenstone belts of western, and eastern sectors of Dharwar Craton with oldest and youngest ages of TTGs (Guitreau *et al.,* 2017; Friend and Nutmann, 1991); granites (Pahari *et al.,* 2019; Dey *et al.,* 2014), mafic volcanics (Kumar *et al.,* 1996; Pahari *et al.,* 2019); dykes (Pahari *et al.,* 2019; Demirer, 2012) and detrital zircons (Wang and Santosh, 2019; Lancaster *et al.,* 2015)

Archaean Eon (4.0-2.5 Ga) with a peak at 2.8-2.7 Ga marked by copious emplacements of tonalite-trondhjemite-granodiorite (TTG) and supracrustals. However, the growth of continental crust is seemingly periodic with most significant crust generation episodes at ~3.8, ~3.3, ~2.9, ~2.7 and 2.6-2.5 Ga. TTG gneisses making up more than 80% of the surviving Archean crust predominantly consist of high-Al TTGs with subordinate proportions of their low-Al counterparts. The oldest detrital zircons in sedimentary rocks were sourced from TTG protoliths thereby representing the oldest preserved component of felsic continental crust on the earth. The early Archean primordial ultramafic crust (>18 wt.% MgO) that differentiated from the Hadean magma ocean could not be a viable source for TTG rocks. The low-MgO (<18 wt.%), garnet-bearing hydrated basaltic crust metamorphosed to amphibolite or eclogite facies is the primary prerequisite to produce first-generation continental crust of TTG composition. Understanding the nature of Archaean felsic crust production, including the source, melting conditions, geodynamic setting, and geochemical evolution is the key to comprehend the inception and development of the crustal components.

To understand the crustal processes, Guitreau *et al*. (2017) studied the zircon U-Pb ages and Lu-Hf isotope systematics on the granitic and trondhjemitic gneiss and a biotite-rich enclave from the western Dharwar Craton. They reported the igneous record of 3410.8 ± 3.6 Ma granitic gneiss and inherited zircons, with ages up to 3607 ± 16 Ma from a trondhjemitic gneiss and a mica-rich enclave present within the trondhjemite (Fig. 1). These ages provide evidence for the presence of older crust than the Hassan Gorur gneiss (3342 Ma; Beckinsale *et al*., 1980; Jayananda *et al*., 2015). They suggested that the oldest zircons could have been sourced from Eoarchean-Hadean precursor(s). They have identified pre 3400 Ma, 3400-3200 Ma in which the latter timeframe corresponds to mildly depleted to near chondritic Hf isotopic signatures whereas the former age exhibit multiple zircon εHf signatures indicating the involvement of several distinct sources. According to the authors, a drift of zircon εHf signatures after 3200 Ma is due to crustal reworking and/or buffering of newly formed granitoids. They explained the evolution of WDC through mantle plume emplacement, oceanic plateau formation subduction initiation on the edges of the plateaus, short lived oceanic arcs which got accreted to the plateaus. Jayananda *et al*. (2018) reviewed the field, petrographic, geochronologic, elemental Nd-Hf-Pb isotope data for greenstones, TTG gneisses, sanukitoids and anatectic granites from the Dharwar Craton to evaluate the accretionary processes of juvenile crust, mechanisms of continental growth, and secular evolution of geodynamic processes through the 3600-2500 Ma window. The authors emphasized that the continental crust accreted in five major magmatic episodes during ca. 3450-3300 Ma, 3230-3150 Ma, 3000-2960 Ma, 2700-2600 Ma, 2560-2500 Ma. These felsic crust accretion events are spatially and temporally linked to greenstone volcanism and crustal reworking. The secular changes in the composition of TTGs through time has been attributed to the increase in the depth of melting of the arc crust and involvement of enriched mantle during 2700-2600 Ma. The magmatic protoliths of oldest gneisses (3450-3200 Ma) in the western block of Dharwar Craton (low-Al and high-Al gneisses) and the 3230-2960 Ma gneisses in the central block formed by melting of oceanic island arc crust at different depths (~40-60 km). Higher REE and Nd isotope signatures in 2700-2600 Ma transitional TTGs are attributed to composite sources involving melting of both oceanic arc crust and enriched mantle at about 45-60 km with minor influence of ancient crust. Melting of slabs at great depth during ca. 2700 Ma generated magmas and their upward passage enriched the arc mantle. Breakoff of the downgoing slab into asthenosphere initiated mantle upwelling that caused melting of already enriched mantle during 2560-2520 Ma which generated sanukitoid magmas. The heat and fluid flux associated with sanukitoid magmas caused lower to mid crustal melting resulting in anatectic granites (Jayananda *et al*., 2018). Further, the U-Pb zircon geochronology of the TTG from the Kudremukh greenstone belt indicate their age 3068+34 Ma and the whole rock geochemical signatures reflect that they were generated through high pressure melting of mafic crust in a garnet spinel peridotite mantle regime with the assimilation of upper crustal material in a subduction zone environment (Pahari *et al*., 2019).

Greenstone Belts: Volcano-Sedimentary Sequences

Archean ultramafic-mafic complexes, as attributed either to extrusive magmatism of mantle origin or to layered intrusions of subvolcanic magma chamber crystallization, are associated with a wide variety of tectonic settings ranging from intraoceanic (oceanic crust or oceanic plateau) to oceanic ridge, forearc basin, marginal back arc basin and active continental rift environments and provide significant clues for understanding dynamic mantle processes during early stages of the earth. These magmatic bodies are important source for several types of ores like chromite (Cr), magnetite (Fe, V, Ti), gold (Au), Ni-Cu and base metal sulphides (Cu-Pb-Zn) and platinum group of elements (PGE). Petrological, geochemical and geochronological studies over the last three decades from all major cratons of the world have documented diverse magmatic suites which are juxtaposed in most of the greenstone terranes through plume-arc interaction and subduction-accretion processes.

Recently, a comprehensive geochemical, zircon

U-Pb isotopes and zircon geochemistry has been carried out on the Archean Konkanhundi gabbro-anorthosite complex from the Dharwar Craton to evaluate the timing, petrogenesis and tectonic implications (Santosh and Li, 2018). The Konkanhundi complex is very significant as it is present within the southern domain of Chitradurga shear zone, welding the eastern and western blocks of the Dharwar Craton. The $^{207}Pb/^{206}Pb$ ages of magmatic zircons yielded ages of 2601 ± 12 Ma for pyroxenite, 2616 ± 12 Ma for gabbro, 2615 ± 13 Ma and 2627 ± 14 Ma for anorthositic gabbro, 2594 ± 16 Ma for anorthosite and 2605 ± 27 Ma for microgabbro. These consistent ages from the different lithologies mark the emplacement of the complex at 2.6 Ga into the surrounding older TTG gneisses which is dated as 3321 ± 11Ma. Zircon εHf(t) values of –4.9 to –0.7 suggesting heterogeneous components at the magma source. The geochemical and zircon U-Pb isotopic data suggest that the parent magma of this gabbro-anorthosite suite was derived from subduction-related depleted mantle source that was contaminated with continental crustal components. Based on the geochemical and isotopic data, Santosh and Li (2018) suggested that extensive arc magmatism of similar age evidenced from the adjacent greenstone belts which mark the trace of ocean closure and correspond to multiple converge of microblocks at the end of Archean which are responsible for building the cratonic mosaic of the Dharwar. Based on the mineral chemistry, zircon U-Pb geochronology, rare earth element (REE), Lu-Hf isotopes, and whole rock geochemistry, Han *et al.* (2019) investigated a suite of serpentinized dunite, dunite, pyroxenite, and clinopyroxenite from an ultramafic complex situated along the collisional suture between the western Dharwar Craton (WDC) and the Central Dharwar Craton (CDC). Zircon U–Pb age range from 2.9-2.6 Ga with an early Paleoproterozoic (ca. 2.4 Ga) metamorphic age which is considered to mark the timing of collision of WDC and CDC. Mineral chemistry data from a chromite show distinct characteristics of island arc setting and the zircon REE patterns suggested the involvement continental crust in the magma source. Based on zircon Lu–Hf data with positive and negative εHf(t) values from ~3.9 to 1.5 and Hf depleted model ages (T_{DM}) of 3041-3366 Ma for the serpentinised dunite and ~0.2 to 2.0 and 2833-2995 Ma for the pyroxenite, the authors suggest that the magma was sourced from a depleted mantle and was contaminated with the ancient continental crust which is supported by the whole rock geochemistry. Based on the petrographic and geochemical characteristics, mantle plume emplacement in a marine environment was been suggested as a possible source for the genesis of J.C. Pura and Banasandra komatiites (Jayananda *et al.*, 2016). To understand the evolution of Archean mantle, age and petrogenesis, Maya *et al.* (2017) studied the major, trace and Sm-Nd isotopic systematics of the spinifex-textured komatiites from Mesoarchean Banasandra greenstone belt of the Sargur Group in the Dharwar Craton. These komatiites are aluminium undepleted to enriched type and their trace-element modelling indicates that the mantle source has undergone multiple episodes of melting prior to the generation of magmas parental to these komatiites at a depth ranging from 120-240 km. Based on the Nd isotope ratios, they suggested that globally there are two events of mantle differentiation (4.53 and 4.3 Ga) with progressive decrease in the mantle depletion with time due to mixing of enriched reservoirs. Coupled chronometer of $^{146,147}Sm$, $^{142,143}Nd$ suggests that the Banasandra komatiites crystallized at 3.14 Ga from a source that was separated from the initial bulk silicate reservoir at or later than ca. 4.3 Ga as evidenced by the absence of radiogenic ^{142}Nd anomaly. Khanna *et al.* (2018b) reported high silica-high-Mg mafic volcanic rocks which are geochemically resembling with Phanerozoic boninites from the 3.3 Ga Holenarsipur greenstone belt of WDC and interpreted their genesis from a refractory peridotitic mantle in a subduction zone setting. These studies reflect on the role of plate tectonics during the Paleo-Mesoarchean time frame. Ganguly *et al.* (2019) evaluated the geochemical signatures of komatiites from Mesoarchean Sargur Group and Neoarchean Dharwar Supergroup greenstone belts of Dharwar Craton, corroborated possible proponents for Archean upper mantle hydration and suggested a gradual temporal transition of mantle characteristics during Meso-Neoarchean times. Recently, Pahari *et al.* (2019) have reported U-Pb zircon age and detailed geochemistry of the island arc basalts and Nb-enriched basalts from the Kudremukh greenstone belt of western Dharwar Craton which were erupted at 2498+43 Ma and these are geochemically similar with the Phanerozoic counterparts. The arc basalts were generated by the melting of subcontinental lithospheric mantle wedge with the influence of slab derived fluids and the Nb enriched basalt are formed due to melting of slab and subsequent fluid fluxed metasomatism and melt fluxed hybridization. Their studies have documented the development of granite-greenstone association in the westernmost part of WDC within a short span of time at different phases from 3.3-2.5 Ga through plume-arc accretion in the WDC. Further, Chandan Kumar and Ugarkar (2017) studied the geochemistry of mafic-ultramafic rocks of the Kudremukh belt, reported komatiites and boninites, identified the plume and subduction zone signatures and explained their genesis through plume-arc model. Ganguly *et al.* (2016) reported boninites for the first time from the Shimoga greenstone belt of WDC. Their geochemical signatures suggest their generation in an intraoceanic arc setting followed by accretion to an active continental margin. A Sm-Nd isochron age of 2638±66 Ma has been attributed to the metavolcanic rocks of Medur Formation, Shimoga greenstone belt, WDC (Giri *et al*., 2019). The 2638 and 2601Ma age for the mafic and felsic volcanism respectively represents the tectono-magmatic event that culminated in the cessation of greenstone magmatism in the western Dharwar Craton. According to the authors, the younger mafic lithologies of the Dharwar stratigraphy represent accretionary orogens and the obtained ages point towards the final stages for the assembly of the western Dharwar craton by subduction processes during the Neoarchean. Li *et al*. (2018b) conducted U-Pb zircon and Pb-Pb monazite geochronology on five samples of high-pressure, upper amphibolite and granulite-facies meta-igneous and metasedimentary rocks from the southern portion of the Chitradurga shear zone, which is at the border of WDC and CDC. They recorded metamorphic conditions of ~820-875 °C, at ~10 kbar, indicating equilibration at the base of thickened continental crust. The studies indicate parent mafic magma crystallisation at c. 2.61-2.51 Ga and subsequent metamorphism at c. 2.48-2.44 Ga, immediately post-dating terrane accretion and collisional orogeny between the Western and Central Dharwar Craton. Detrital zircon grains with ages of c. 3.10-3.03 Ga and c. 2.97-2.86 Ga imply contamination of these magmas with Mesoarchean material sourced from the Western Dharwar Craton continental nucleus. This data is in support of subsequent regional metamorphism at c. 2.48-2.44 Ga, bracketing the timing of micro-block accretion to the Archean-Proterozoic boundary. Comparison of these metamorphic and magmatic age data with the recorded dates of EDC, the authors inferred that WDC, CDC, and EDC have accreted synchronously, driven by two separate eastward-dipping ocean continent convergent plate margins (Li *et al*., 2018b). Adrija (2018) and Manikyamba *et al*. (2019) have conducted detailed petrological and geochemical studies on mafic, intermediate and felsic volcanic rocks of Kadiri greenstone belt of EDC and identified LREE enriched and depleted basalts, Nb-enriched basalts, high Mg-andesites, sodic and potassic adakites, andesite-dacite-rhyolite sequence. The authors suggested their genesis in an island arc environment. According to them, the island arc volcanism has been initiated in an intraoceanic setting, gradually approached towards the continental margin with the involvement of continental crust in the genesis of Andesite-Dacite-Rhyolite (ADR) sequence and K-adakites. The subduction initiation isevidenced by the island arc magmatism, the progressive stage can be visualized through the geochemical signatures of NEBA and Mg-andesites and the maturation stage of arc is evidenced through the presence of adakites and the role of slab melting. Both Na- and K-adakites were the products of slab melts erupted during the arc progression with the migration of the island arc towards the continental margin during the Neoarchean time frame. Khanna (2017a) evaluated the geochemical characteristics and initial $^{176}Hf/^{177}Hf$ isotopic composition of the basalts from the Gadwal and Veligallu greenstone belts which are the part of composite greenstone terrane from the EDC and proposed that they have a common Neoarchean mantle source which are obscured due to the sedimentary cover of the Proterozoic Cuddapah Basin. Further, Khanna *et al*. (2016a) reported the bulk-rock geochemistry and Lu-Hf isotope systematics of the ultramafic rocks from the Neoarchean Veligallu greenstone terrane, eastern Dharwar craton to infer the petrogenesis. The whole rock geochemistry of ultramafic, mafic and felsic rocks indicated the presence of boninitic rocks and adakites which were suggested to have been derived through Neoarchean intraoceanic subduction magmatism. The ultramafics along with the basalts and adakites yield a bulk-rock Lu-Hf isochron age of 2.696 ± 0.054 Ga, consistent with the available SIMS zircon U-Pb age of felsic volcanics (2.697+5 Ma). The rocks have positive initial εHf (2.696 Ga) = +3.0 to +6.5, consistent with an origin from a long term depleted mantle source relative to a chondritic reservoir at ~2.7 Ga (Khanna *et al*., 2016a). Wang and Santosh (2019) reported a bimodal Paleo-Mesoarchean (peak at 3227 Ma) and Neoarchean-Paleoproterozoic (2575 Ma) age distribution for the detrital zircon grains from metasediments including quartz mica schist, fuchsite quartzite, and metapelite from the southern domain of Chitradurga suture zone that demarcates western and central Dharwar Craton. U-Pb-Hf isotope systematics record a transitional and progressive maturation of the crust from purely juvenile to mixed juvenile-recycled compositions. Hf isotope studies bracket 3.67 to 2.75 Ga magmatic sources for the sediments that is correlatable with major crustal growth events at 3.2 and 2.6 Ga. The authors suggest micro-continent assembly and cratonization through subduction-accretion-collision processes in the Dharwar Craton.

Sindhuja *et al*. (2019) carried out geochemical studies on the Archean and Proterozoioc shales from the Chitradurga greenstone belt and Cuddapah basin to understand the weathering conditions, source rock composition, and depositional environment in order to decipher the evolution of crust during the Precambrian times. The authors suggest intense chemical weathering in the Archean shales compared to moderate weathering of Proterozoic counterparts. Tectonically, Archean shales akin to active continental margin and Continental Island Arc and the Proterozoic shales were deposited in a passive margin and Continental Island Arc. Ugarkar *et al*. (2017) studied the petrography and geochemistry of the greywackes from the Dharwar-Shimoga belts and inferred their genesis in a subduction related fore-arc basin. The clays present within the felsic volcanic rocks of Gadag greensone belt were are suggested to have formed through chemical weathering of felsic metavolcanic rocks present within the basin under tropical to sub-tropical humid and acidic conditions (Ugarkar *et al*., 2016). Khanna and Sesha Sai (2018a) studied the chromian muscovite bearing quartzites from Veligallu greenstone belt of eastern Dharwar Craton and explained that they are derived from a wide spectrum of ultramafic and felsic sources and their chrome content is from the leaching of hydrothermal fluids. Through field evidence, Sesha Sai *et al*. (2017) suggested the concealed high density igneous body possibly account the SW mafic-ultramafic sills presenting the Papaghni and Chitravati Groups whereas the arcuate western margin counterparts associated with the clastic and non-clastic sequences indicate a continental arc extensional setting in this Paleoproterozoic basin.

Manikyamba *et al*. (2017) evaluated the volcano-sedimentary sequences of the Dharwar Craton, in terms of mantle plume activity to subduction zone tectonics due to secular cooling of the mantle accompanied by a transition from stagnant lid tectonics to development of plate tectonics from 3.5-2.0 Ga. The Sargur Group to Dharwar Supergroup volcano-sedimentary greenstone sequences correspond to the continent generation, lithospheric evolution and crustal growth through early stage stagnant-lid convection tectonics to modern-style, episodic subduction-controlled plate tectonics. The lithological assemblages of Dharwar Supergroup greenstone belts from western Dharwar Craton show both plume and arc affinities collectively indicating plume-arc interaction associated with felsic magmatism at active continental margin setting. The geochemical signatures of greenstone belt volcanic lithologies from eastern Dharwar Craton reflect on subduction processes including slab dehydration, slab-melting, mantle wedge metasomatism and hybridization during juvenile to matured stages of subduction. The subduction signatures preserved in Dharwar greenstone belts are analogous to modern subduction processes operative at Phanerozoic arc of oceanic and continental regime. Therefore, the thermal and tectonic transition in our planet during Archean is preserved in the greenstone belt lithologies of WDC and EDC and provide clues for the continent generation, lithospheric evolution, crustal growth and gradual decrease of mantle temperature and thickening of lithosphere.

Precambrian Biogeochemical Processes

The Dharwar Craton has excellent preservation of life forming processes in the Neoarchean to Proterozoic sedimentary rocks such as stromatolitic carbonates, banded iron formations, manganese formations, cherts and carbonaceous shales that are present in various greenstone belts of WDC and Cuddapah basin. Some of these lithounits contain compelling geochemical evidence for episodic accumulation of dissolved oxygen in the oceans along continental margins before the Great Oxidation Event (GOE). Multiple lines of geochemical evidence provide strong support for shallow marine oxygenation and more oxygenated continental shelf margins on a regional scale thereby steering cyanobacterial activities and biosphere evolution in Archean oceans, much before GOE (Ostrander *et al*., 2019).

The stromatolitic cherty dolomites with varied morphological features preserved in the Vempalle and Tadpatri Formations of Proterozoic Cuddapah basin were studied for their geochemistry, carbon and oxygen isotopic characteristics. The Vempalle stromatolites recorded negative to positive excursion of $\delta^{13}C$ in which the positive excursion is very significant in contradicting the popular belief of negative $\delta^{13}C$ signatures during the boring billion (i.e. 1.9-0.9 Ga) whereas the Tadpatri stromatolites recorded the negative $\delta^{13}C$ following the global geochemical system (Khelen *et al*., 2017). The authors suggested that the magmatism in the Cuddapah basin has disrupted the biological activity in the Vempalle Formation. The depletion in $\delta^{13}C$ and $\delta^{18}O$ isotopic signatures in the stromatolites of Vempalle and Tadpatri Formations reflect on higher temperatures of Proterozoic sea water compared to modern sea water. Based on comprehensive morphological, petrological, whole rock geochemistry, carbon and oxygen isotopic signatures Khelen *et al.* (2017) explained the deposition of Proterozoic Cuddapah stromatolites in anoxic conditions at moderate water depth and shallow shelf environment covering subtidal-intertidal-supratidal zones with fluctuating fluvio-energy conditions. Similar studies on the Neoarchean stromatolitic carbonates of Sandur, Chitradura and Shimoga greenstone belts have provided insights on the Archean sea water conditions and depositional environment. Based on the variable La, Eu and Gd anomalies, $\delta^{13}C$ and $\delta^{18}O$ signatures (Khelen *et al.,* 2019) have suggested fluctuating oxic to anoxic; acidic to alkaline environment with locally varying Archean ocean water temperature from 25-75^oC. These conditions favored their deposition in a shallow marine environment ranging from supra to subtidal zones distal to mid oceanic ridge hydrothermal activity. Further, Khelen *et al.* (2020) estimated the U-Pb ages of the detrital zircons from the stromatolitic carbonates of the Dharwar Craton, which support the presence and involvement of 3.5 Ga crust in the deposition of Archean stromatolites. The Bhimasamudra and Marikanve stromatolites of the Chitradurga greenstone belt of Dharwar Craton display detrital zircon ages of 3426 ± 26 Ma to 2650 ± 38 Ma whereas the Sandur stromatolites gave an age of 3508 ± 29 Ma to 2926 ± 36 Ma suggesting Paleo to Neoarchean provenance. The detrital zircons of the Tadpatri stromatolites gave an age of 2761 ± 31 Ma to 1672 ± 38 Ma suggesting Neoarchean to Mesoproterozoic provenance. The zircon geochemistry, combined with bulk rock chemistry and the U-Pb ages of both Archean (3.5 to 2.7 Ga) and Proterozoic (2.7 -1.6 Ga) stromatolites collectively indicate a mixed granitoid and mafic source for both the Neoarchean and Proterozoic stromatolites displaying ~800-900 Ma duration for the deposition of Precambrian stromatolites in the Dharwar Craton (Khelen *et al.,* 2020). Basu *et al.* (2016) studied the black shales from the Mesoproterozoic Srisailam Formation of Cuddapah basin and inferred their deposition in the lacustrine environment. Based on the sedimentary facies analysis and the geochemical characteristics, the authors suggested a stable tectonic setting and semiarid climatic conditions, which favored steady-state weathering and erosion of highly differentiated upper crustal continental provenance and rule out its relationship with the Paleo-Mesoproterozoic supercontinent Columbia break-up. Recently, Dodd *et al.* (2019) reported evidence of early life from the Eoarchean to Paleoproterozoic Banded iron formations from different parts of the world in which consistent occurrence of apatite + graphite has been identified in the BIFs (>3800-1800 Ma) of ten different localities that are metamorphosed to various grades. Co-occurrence of poorly crystalline and crystalline varieties of graphitic carbon with apatite is identified in all these BIFs. Among which the Neoarchean Sandur BIFs have graphite and poorly crystalline graphite associated with apatite and pyrite. ^{13}C depleted graphitic carbon occurs as inclusions in apatite and carbonate suggested to represent the remineralization of syngenetic biomass whereas crystalline graphite represents the metamorphosed product of syngenetic organic carbon. It is suggested that poorly crystalline graphite was precipitated from C-O-H fluids partially sourced from syngenetic carbon. Consistent $\delta^{13}C_{gra}$ of ~25.2 (Brockman),

~27.8 (Temagami), –28.5 (Sandur), and –22.5 (Watai); –19.6 (Pääkkö), ~28.1 to ~26.4 (Nuvvuagittuq), and ~26.7 to ~22.0 (Anshan); ~28.1 (Biwabik) and ~17.5 (Akilia) are within the average composition of sedimentary organic matter over the last 3500 Ma. These observations of isotopically light organic carbon and graphite in association with apatite has been used to argue for a biological origin of graphite in the Eoarchean to Paleoproterozoic BIFs. Based on the results the authors suggested that fluid deposited graphite is commonly associated with apatite in Earth's oldest sedimentary rocks and an evidence for life's emergence on Earth. Absar *et al.* (2019) conducted geochemical and carbon and oxygen isotopic studies on the carbonate rocks of Bhima Group, EDC and provided constraints on the source of dissolved components, redox conditions and biogeochemical cycling of Mesoproterozoic ocean. Geochemical modelling suggests preservation of original seawater-like REY patterns and little influence (<1%) of clastic material on REY systematics in Bhima carbonates. The REE data indicate significant contribution (>10%) from continental run-off and minor input from oceanic hydrothermal sources to the sea water. The wide variability of $\delta^{13}C$ (5.15‰) indicate greater sensitivity of C-isotope system as a result of low level buffering capacity and shrinking of global dissolved inorganic carbon (DIC) reservoir, which increased the surface oxidation and release of oxygen into the atmosphere. The presence of original microbial texture and Proterozoic marine $\delta^{18}O$ values (~6.38 to ~7.17‰) indicate minimum diagenetic alteration. The variation in Th/U ratios from Archean to Phanerozoic boninites of greenstone belts to ophiolitic sequences reflection genesis of boninitic lavas at different tectono-thermal regimes. The U enrichment in Archean and Phanerozoic boninites has been attributed that U was soluble in oxygenated Archean marine water up to 600 Ma before the proposed great oxygenation event (GOE) at ~2.4 Ga which is consistent with large Ce anomalies in hydrothermally altered Archean volcanic sequences of 3.0-2.7 Ga (Manikyamba *et al.,* 2017b).

Proterozoic and Phanerozoic Magmatism

Proterozoic magmatism represents a transition from the juvenile stage of the early Earth's evolution to the Phanerozoic style of magmatism that continues till date. The Mesozoic and Cenozoic eras were marked by Large igneous provinces (LIPs) including continental and ocean basin flood basalts (CFBs and OFBs), giant radiating dyke swarms, volcanic rifted margins, oceanic plateaus, submarine ridges and seamount chains. These anorogenic magmatic events are often characterized by extensional tectonics and rifts developed in response to the melting of mantle plume head beneath sub-continental lithosphere and the magmatic pulsations are spatially and temporally linked with crustal extension and intracontinental rifting. Thus, these magmatic events are envisaged as principal proponents for continental fragmentation and opening of new ocean basins through space and time. Magmatic episodes in large intracratonic sedimentary basins in the form of CFBs and dyke swarms are often interlinked with plume activities leading to subsidence and crustal sagging followed by the deposition of extensive sedimentary units that are commonly overlain by them. The Meso-Neoproterozoic sedimentary basins of India, comprising ~ 4.5 to ~6.5 km thick sedimentary pile, consists of limited magmatism such as the lowermost sequences of Semri Group in the Vindhyan basin and the Vempalle and Tadpatri Formations of the Cuddapah basin. The occurrence of diamondiferous kimberlites extending from the west of Cuddapah basin to the fringes of Vindhyan basin supports a deep seated magma plumbing system in this region. The evolutionary history of the Cuddapah basin is characterized by sediment deposition, with minor eruptive pulses of magmas manifested as lava flows, sills and dykes at lower stratigraphic horizons and restricted to west and south-western part of the Cuddapah basin in Vempalle and Tadpatri Formations of the Papaghni and Chitravati Groups respectively. They preserve distinct records of multiple events of extrusive and intrusive igneous activities in the Cuddapah basin for which various tectono-magmatic and petrogenetic models are proposed ranging from a mantle plume to lithospheric extension.

Singh *et al.* (2018) identified Vempalle lava flows on the basis of three-tier arrangement of vesicular-entablature-colonnade zones and studied their geochemistry and platinum group element (PGE) systematics. Their HFSE characteristics indicate plume related intraplate magmatism with contributions from subcontinental lithospheric mantle (SCLM), crustal assimilation and fractional crystallization for the genesis of these flows. Their PGE chemistry attest to sulphur-saturated nature of magmas with pronounced sulphide fractionation. Rift-controlled intraplate setting associated with an ocean-continent transition zone (OCTZ) mark the tectonic environment for the emplacement of Vempalle lava flows (Singh *et al.,* 2018). Based on the field characteristics Goswami *et al.* (2018) have conducted volcanic facies analysis on the felsic volcanic rocks and associated tuffs from the Tadpatri-Tonduru transect of SW Proterozoic Cuddapah basin, identified surge, flow, fall and resedimented volcaniclastic facies and interpreted that these are associated with rifting and shallow marine environmental conditions. Further, Goswamy and Dey (2018) prepared a facies model suggesting that these lithounits erupted through the ~N-S trending rift-associated fissures due to lithospheric stretching during late Palaeoproterozoic in which the volcaniclastics were deposited in the deeper part of the basin in the east. The rifting and associated pressure release have provided suitable conditions of decompression melting at shallow depth with high geothermal gradient. Partial melting of mantle derived material at lower crust have produced mafic magmas, upwelled through the cold crust which melted and gave rise to felsic magmas. U-Pb dating of metamorphic monazite within a low-grade metasedimentary rock in the Nallamalai Fold Belt at the Mangampeta barite mine gave an age of 531 ± 7 Ma which is an evidence of Pan-African tectonism in the Cuddapah basin (Sheppard *et al.,* 2017a). SHRIMP U-Pb zircon dating on the felsic tuffs of Tadpatri Formation gave an age of 1860 Ma which is younger than the sills (1885 Ma) that are stratigraphically below them. Two samples of a felsic tuff from the upper part of the Tadpatri Formation gave the ages of 1864 ± 13 Ma and 1858 ± 16 Ma; and the weighted mean date of 1862 ± 9 Ma indicating that mafic magmatism continued until after c. 1860 Ma. The authors suggest that there may be upto five episodes of magmatism in the Papaghni and Chitravati groups of the Cuddapah Basin spanning more than 30 Ma. It is inferred that the prolonged interval of magmatism in the Cuddapah Basin implies that magma emplacement/ eruption rates in the basin were likely to be much lower than previously considered. Magmatic pulses in intraplate sedimentary basins are windows to understand the tectonomagmatic evolution and palaeoposition of the basin. Based on the zircon U-Pb systematics of the Vempalle flows of Proterozoic Cuddapah basin, Singh *et al.* (2019) recognised late Carboniferous-Triassic/Phanerozoic magmatism. Two distinct Phanerozoic magmatic events coinciding with the amalgamation and dispersal stages of Pangea at 300 Ma (late Carboniferous) and 227 Ma (Triassic) are identified from Cuddapah basin. Further, the authors evaluated geochemical and geochronological resemblances with Phanerozoic counterparts from Siberian, Panjal Traps, Emeishan and Tarim LIPs, inferred their possible coeval and cogenetic nature. Based on the palaeoposition of Indian subcontinent along with the Cuddapah basin during late Carboniferous-Triassic timeframe, the authors conform its juxtaposition to the Pangean LIPs and associated magmatic events. Banerjee *et al.* (2019) reported Phanerozoic type dolomitization signatures from Palaeoproterozoic dolomites of Vempalle Formation, Cuddapah Basin. The granitoid provenance for the deposition of Pulivendla and Gandikota quartizites from the Chitravathi Group is reconfirmed by Somasekhar *et al.* (2018) through their petrological and geochemical systematics. Purimetla, Kanigiri and P. C. Palle gabbro plutons of the Prakasam Igneous Province situated within the Nellore Schist Belt (NSB) have been studied for their geochemistry and U-Pb zircon geochronology which gave prominent Mesoproterozoic ages of 1334 ± 15 Ma, 1338 ± 27 Ma and 1251.2 ± 9.4 Ma (Subramanyam *et al.,* 2016). The cumulative $^{207}Pb/^{206}Pb$ mean age of 1315 ± 11 Ma has been considered as the timing of mafic magmatism in the Prakasam Igneous Province. These mafic plutonic complexes are interpreted vestiges of intraoceanic island arcs that were accreted on to the eastern continental margin of India during the prolonged subduction processes prior to the final collision in Neoproterozoic (Subramanyam *et al.,* 2016).

Granitoid Plutons

Precambrian crustal components play a vital role in understanding Earth's crustal growth, as more than 75% of global continental crust was formed during the Archean period suggested to be recycled and mixed with the younger crust through various tectonic processes. Recent studies indicate a large geochemical diversity in Archean granites among which the K-rich granites are linked to late stages of tectonic stabilization. The Proterozoic era in the Earth's magmatic history marked by peak granitoid magmatism, crustal growth and continent generation. Globally, Precambrian granite magmatism has played a significant role in the growth and stabilization of continental crust.

Jayananda *et al.* (2019) reported zircon U-Pb ages, Nd isotopes, major and trace element data for the magmatic-epidote bearing granitic plutons in Bellur-Nagamangala-Pandavpura corridor of WDC, suggested three successive episodes of anataxis, crustal reworking and continent generation in the WDC at 3.2, 3.0 and 2.6 Ga. These stages of crust generation were concurrent with intrusions of granodiorite (3.2 Ga), monzogranite to quartz monzonite (3.0 Ga) and monzogranite (2.6 Ga) plutons. The 3.2 Ga granodiorites are interpreted to be derived by shallow-level melting of mafic protoliths without any significant residual garnet, and the $\varepsilon Nd_{(T)}$ = 3.0 Ga ranging from +0.5 to –1.7 reflect on major crustal source with minor mantle input. Geochemical attributes for the 2.6 Ga monzogranite plutons suggest residual plagioclase in the magma source. The presence of magmatic epidote in all the plutons attests to their rapid emplacement and crystallization at ~5 kbars. Dey *et al.* (2017) reported Secondary Ion Mass Spectrometer (SIMS) U-Pb zircon dates on the granitoids of the NW part of the EDC to understand their origin and sequence of emplacement in EDC. According to the authors, in the northwestern part of the eastern Dharwar craton (EDC), the granitoid magmatism started at 2.68 Ga with gneissic granodiorites of intermediate character between sanukitoid and tonalite-trondhjemite-granodiorite (TTG). This was followed by intrusion of transitional (large-ion lithophile element-enriched) TTGs at 2.58 Ga. Finally, 2.53-2.52 Ga sanukitoid and Closepet type magmatism and intrusion of K-rich leucogranites mark the cratonization. These granitoids mostly display initial negative epsilon Nd and Mesoarchean depleted mantle model ages, suggesting presence of older crust in the area. Existing data show that most of the Neoarchean sodic granitoids in the EDC are transitional TTGs demonstrating the importance of reworking of older crust. It is suggested that the various c. 2.7 Ga greenstone mafic–ultramafic volcanic rocks of EDC formed in oceanic arcs and plateaus which accreted to form continental margin environment. Later on, the 2.7-2.51 Ga granitoid magmatism involved juvenile addition of crust as well as reworking of felsic crust forming transitional TTGs, sanukitoids and K-rich leucogranites. Dey *et al.* (2017) suggested that Microcratons were the possible source of older crustal signatures and their accretion appears to be one of the important processes of Neoarchean crustal growth globally. Slaby *et al.* (2019) evaluated the Mineral fluid interactions in the late Archean Closepet granite batholith, Dharwar Craton, identified symptoms of fluid rock interactions in both volatile-free (feldspar) and volatile-bearing minerals (apatite). Polytopic vector analysis (PVA) on these minerals suggested that the processes occurred in a ternary system, with two magmatic end-members and one end-member enriched in fluids. A dynamic tectonic setting promoting heat influx and its redistribution suggested a hotspot like environment for the emplacement of Closepet batholith (Slaby *et al.,* 2019). Li *et al.* (2018) documented multiple subduction and amalgamation of several microblocks in the Dharwar Craton and its southern domains during the Archean – Paleoproterozoic transition. They have studied the geochemical and zircon U-Pb geochronology on the igneous and sedimentary units from the Nallamalai suture zone (NLSZ). Zircon grains from the monzogranite, hornblende-biotite gneiss, amphibolite, granodiorite, diorite, charnockite, BIF (banded iron formation) and BMQ display the magmatic emplacement ages clustering around 2.50 to 2.56 Ga, except for the meta-monzogranite which reached upto 3.2 Ga, correlating with long-lived convergent margin magmatism through multiple slab melting episodes. All the rocks show tightly constrained early Paleoproterozoic (ca.2.46-2.48 Ga) metamorphic ages, including the metamorphic zircon in the BIFs, marking the timing of collision of the two continental blocks with consumption of the intervening oceanic lithosphere. The $\varepsilon Hf(t)$ of magmatic zircons from these rocks range from ~4.1 to +5.7, and with T^{C}_{DM} Hf model ages of 2672-3247 Ma, indicated the initiation of crustal growth ~3.3 Ga and continued to 2.7 Ga, followed by crustal reworking in a continental arc towards the end of Neoarchean. The geochemical data suggested low degree partial melting of a metasomatized peridotitic mantle wedge with reworking of older continental crust. Their studies suggest eastward oceanic subduction and ocean closure along the NLSZ which welded the Shevaroy and Madras Blocks. Nandy *et al.* (2019) studied the banded gneisses, TTG (tonalite-trondhjemite-granodiorite), biotite granites, alkali feldspar granite and gabbro associated with the metabasalts of Neoarchean Tsundupalle greenstone belt situated in the eastern fringe of the EDC to understand their emplacement history and crustal growth processes. Whole-rock major and trace element geochemical data are consistent with diverse sources, including both crust and enriched mantle in an evolving subduction zone. A convergent orogenic setting is proposed for interpreting the association of various granitoids in the Tsundupalle area. Finally, intrusion of crustally derived highly silicic, alkali-rich granite and mantle derived gabbro emplaced in a post-subduction regime is proposed for the genesis of these felsic plutonic rocks. The authors envisage lithospheric delamination and mantle melting as a possible mechanism for the generation of these rocks. The porphyritic granitoids of Adoni area, situated west of Cuddapah basin, are intrusive into the Peninsular Gneissic Complex (PGC) of Dharwar Craton have been studied to understand the geochemical signatures and tectonic affinity (Singh *et al.,* 2017). These are alkaline to peralkaline, A-type granitoids suggesting low pressure-high temperature partial melting of a tonalitic-granodioritic crust at mid to shallow crustal levels followed by fractional crystallization. The crustal melting has been induced by asthenospheric upwelling and minor basaltic underplating (Singh *et al.,* 2017). Shukla and Mohan (2018) carried out the geochemical studies on the Neoarchean granites and associated microgranular enclaves (MEs) from the Nalgonda region, EDC, and demonstrated the end-member magma mixing processes in the petrogenesis of the host granite. The geochemical heterogeneity in these granites are attributed to difference in the degree of mechanical dilution of mafic magma, fractional crystallization and diffusive fractionation in a subduction zone environment. Raju and Arif (2019) reported allanite from the syenites of Dancherla and adjoining areas and studied their geochemistry and REE potential. Narasimha *et al.* (2018) studied the whole rock geochemical characteristics of the Punugodu granites of Nellore schist belt, eastern Dharwar Craton and interpreted them as within plate anorogenic type granites.

Dyke Swarms

The assembly, evolution and dispersal of supercontinents in Earth history are significant not only to reconstruct the paleogeography of continental fragments, but also in understanding of the history of evolution of life, surface environment and mineral resources. Geochemical and paleomagnetic data integrated with precise geochronology for mafic dyke swarms provide pivotal evidence for identification of large igneous provinces, paleo-reconstruction of ancient crustal blocks and deconvolution of the history of supercontinent assembly and dispersal.

The dykes intruding into the volcano-sedimentary sequences of the Kudremukh belt of the western Dharwar Craton have been studied for their geochemical and zircon U-Pb geochronology which gave the emplacement age of 2484+29 Ma. The geochemical characteristics of amphibolitic and doloritic dykes reflect on post subduction collisional event in this part of WDC (Pahari *et al.,* 2019). Soderlund *et al.* (2018) reported eighteen new U-Pb baddeleyite ages of mafic dykes with varying trends, comprising the most prominent and extensive swarms from the eastern Dharwar Craton (EDC). These results enhance the identification and characterization of individual dyke swarms with respect to their extent, dominant trend and pattern. The majority of these emplacement U-Pb ages are within the 2.37-1.79 Ga interval. Along with their data, they compiled the currently available emplacement ages of dykes in Dharwar, suggested new names for some of the dyke swarms, and present a refined “magmatic barcode” record of short-lived pulses of Paleoproterozoic mafic magmatism. They have identified an apparent relative rotation of dykes and basement features of ~30^{o} between northern and southern Dharwar Craton and speculate whether rotation originated through orthogonal extension of its eastern convex side or pervasive dextral shearing within its southern portion. Khanna *et al.* (2016) reported the mafic dykes from Gadwal greenstone belt, which are alkaline in composition with OIB affinity and provided implications on the heterogeneous nature of the subcontinental lithospheric mantle beneath the Dharwar Craton. Ramesh Babu *et al.* (2018) reported new paleomagnetic results and precise paleopole position of the extensional study on < “2367 Ma mafic giant radiating dyke swarms from NE–SW Karimnagar-Hyderabad dykes and Dhone-Gooty sector dykes, in the Dharwar Craton and confirmed the presence of single magmatic event at ~2367 Ma.

Nagaraju *et al.* (2018 a) conducted paleomagnetic and geochronological studies on a ~450 km long (from 17 sites) N-S striking Paleoproterozoic dyke swarm exposed along a natural crustal cross section of about 10 km in the Dharwar Craton. Anisotropy of magnetic susceptibility (AMS) studies from all 13 sites along the 450 km length of this 2216 Ma dyke indicate a low degree of anisotropy and sub-horizontal flow even at deep mid crustal levels (Nagaraju and Parashuramulu, 2019). U-Pb/Pb-Pb dating on baddeleyite gives a crystallisation age of 2216 ± 0.9 Ma, while magnetogranulometry and SEM studies show that remnant magnetization in this dyke was carried by single domain magnetite residing within silicate minerals (Nagaraju *et al.,* 2018a). A Pb-Pb baddeleyite age of 2207 Ma has been documented for two Paleoproterozoic mafic dyke swarms, intruding Archean basement rocks in the northern and southern region of Cuddapah basin, Eastern Dharwar Craton (Nagaraju *et al.,* 2018b).

Petrogenetic and geodynamic aspects of NE-SW to ENE-WSW trending Paleoproterozoic mafic dyke swarms from southern part of WDC have been evaluated by Rai *et al.* (2019). Their petrological and geochemical characteristics suggest a basaltic to basaltic-andesitic composition and a sub-alkaline, tholeiitic nature of precursor melts. REE chemistry classified these dykes into three groups in which the parent magmas for Group 1 dykes were derived by ~20% melting of a primitive mantle source, while that for the remaining two groups originated from batch melting of metasomatized lithospheric mantle in an intracratonic setting. The third one due to lack of correlation with the EDC dykes suggest distinct mafic magmatic events in WDC and EDC. Singh and Manikyamba (2019) studied the geochemistry and PGE systematics of the Vempalle sills interlayered with the dolomites and mafic flows from the Vempalle Formation of the Proterozoic Cuddapah Basin. Their whole rock geochemistry suggests plume related intraplate magmatism with contributions from subcontinental lithospheric mantle (SCLM), lithosphere-asthenosphere interaction, crustal contamination, and fractional crystallization with moderate degrees of polybaric partial melting of the parent magma within spinel + garnet lherzolite domain where spinel > garnet. PGE systematics of these sills suggest sulphur undersaturated, enriched characteristics with prominent sulphide fractionation attesting to moderate degrees of partial melting and crustal contamination. Tectonically, the Vempalle sills suggested to have an affinity towards oceanic subduction unrelated setting and rifted margin corresponding to an ocean–continent transition zone (OCTZ) and P MORB to highly enriched type asthenospheric mantle. These dolerite sills are generated at a rift controlled intraplate tectonic regime in an ocean–continent transition zone (OCTZ).

Lamprophyres, Lamproites, Kimberlites

The spatial and temporal association of potassic–ultrapotassic, volatile-rich, ultramafic magmas, such as lamprophyres, lampriotes and kimberlites, with mantle plume activities and LIP formation posit significant insights into plume-lithosphere interaction, mantle metasomatism, sub-continental lithospheric mantle (SCLM) evolution and diamond genesis. Potassium-rich lavas characterized by K/Na>2 are common in orogenic and anorogenic magmatic provinces and in both cases, metasomatism of lithospheric mantle by sediments and hydrous melts is an essential pre-requisite for genesis of these rocks. The first report of a Late Cretaceous (~90 Ma) kimberlite activity in southern India was advocated by Chalapathi Rao *et al.* (2016). U-Pb SIMS dating for groundmass perovskite from Timmasamudram diamondiferous kimberlite of the Wajrakarur kimberlite field, in the Eastern Dharwar Craton of southern India yields a bimodal age distribution clustering at Meosoproterozoic (1086 ± 19 Ma and 1119 ± 12 Ma) and late Cretaceous (~90 Ma). Nd isotopic compositions of perovoskite suggest depleted and enriched mantle signatures for the Mesoproterozoic and late Cretaceous kimberlites respectively. The enriched mantle signatures in late Cretaceous kimberlite invoke plume activity and pronounced contributions from sub-continental lithospheric mantle (Chalapathi Rao *et al.,* 2016). Dongre *et al.* (2016 a, b) carried out systematic mineral chemical and whole rock geochemical studies of kimberlites from Wajrakarur field in EDC and provided valuable insights on kimberlite genesis and the geodynamic implications. Metasomatic enrichment of lithospheric mantle, plume- lithosphere interaction, erosion and destruction of Indian lithospheric roots by Marion (~90Ma) and Reunion (~65 Ma) plumes have been invoked as principal processes involved in the genesis of Wajrakarur kimberlites. Nd model ages (Dongre *et* *al.,* 2016b) have correlated the source enrichment and metasomatism for Wajrakarur kimberlites with assembly of Rodinia Supercontinent. Pandey *et al.* (2017 a) reported calc-alkaline lamprophyres from Mudigubba area near the western margin of Cuddapah Basin, EDC and suggested a subduction-controlled post-collisional emplacement. Geochemical and Sr-Nd isotopic studies of Mesoproterozoic shoshonitic lamprophyre dyke from the Wajrakarur kimberlite field, EDC place important constrains on their petrogenesis (Pandey *et al.,* 2017b). The geochemical and isotopic evidence collectively propound modification and enrichment of lithospheric mantle by paleo-subduction events and asthenospheric upwelling. Mineral chemical studies on clinopyroxene megacrysts of Udiripikonda lamprophyre from EDC reflect crystallization under high- to medium-pressure conditions during the evolution of lamprophyre magma (Pandey *et al.,* 2017c). Udiripikonda lamprophyre and Wajrakarur kimberlite magmatism have been genetically correlated with Mesoproterozoic lithospheric extension, mantle-heterogeneity owing to plume-lithosphere interaction and subduction-processed metasomatic enrichment of mantle (Pandey *et al.,* 2017 a, b, c). Neoarchean subduction-accretion processes for the evolution of Kadiri greenstone belt, EDC have been substantiated by the post-collisional calc-alkaline lamprophyres (Pandey *et al*., 2018). The mantle enrichment processes for the genesis of the lamprophyres have been attributed to convergent margin processes. Talukdar *et al.* (2018) studied petrological and geochemical aspects of the Mesoproterozoic Vattikod lamproites, EDC and suggested multi-stage metasomatism and enrichment of sub-continental lithospheric mantle ascribed to paleo-subduction events concurrent with Paleoproterozoic amalgamation of the Columbia supercontinent and carbonate metasomatism from Mesoproterozoic rift-related asthenospheric upwelling associated with the Columbia breakup. This study links lamproite emplacement with amalgamation and disintegration of supercontinents. Sharma *et al.* (2018) documented mineralogical, geochemical and Sr-Nd isotopic data for the recently discovered Ahobil kimberlite from Wajarakarur field of EDC. These kimberlites share similar characteristics with Mesoproterozoic lamproites of EDC and their Nd model ages suggest an older age as compared to that reported for Wajrakarur and Narayanpet kimberlites of EDC. The genesis and emplacement of Ahobil kimberlite have been inferred to be concomitant to the amalgamation of the Columbia supercontinent (Sharma *et al.,* 2018).

Metallogeny

The Neoarchean period (2.7Ga) was marked by large scale deposition of banded iron formations (BIFs), cratonization, regional deformation and metamorphism, development of shear zone systems, generation of deep-seated hydrothermal fluids, remobilization and mineralization of precious metals. The Archean cratons and late Neoproterozoic-Phanerozoic fold belts around the world are characterized by a variety of mafic and felsic igneous rocks and sediments including BIFs that host mesothermal orogenic gold deposits. The concentration of orogenic gold deposits at 2.8-2.55 Ga, 2.1-1.75 Ga and 750-735 Ma corresponds to well defined periods of lithospheric growth at continental margins. This contention is consistent with the fact that gold mineralization is associated with addition of new oceanic lithosphere onto older cratonic margins through mantle plume activity and subduction accretion events. The genesis of orogenic gold mineralization associated with Archean granite–greenstone terranes is primarily controlled by shear zone activity, structural style, tectonic setting, metamorphism and hydrothermal alteration. The Kudrekonda boninites of Shimoga greenstone belt contain native gold in the associated quartz veins (Ganguly *et al.,* 2016). The authors have also investigated the gold mineralization hosted in the banded iron formations (BIFs) of Ganajur, Karajgi and Palavanahalli areas of the Shimoga greenstone belt of western Dharwar Craton. EPMA data record 88.5-90.3 wt.% Au content with 7.7–8.4 wt.% Fe, 0.05-2.1 wt.% S and negligible Ag. Gold is hosted in Fe-oxides and the bulk chemical analyses show 4.1-684 ppb Au and 139-2186 ppb Ag in these rocks. The authors suggested that the gold mineralization of Kudrekonda boninites is syngenetic, mesothermal and convergent margin orogenic type. Decarbonation, desulphidization and metamorphism of subducted oceanic lithosphere and devolatilization of metasomatized enriched mantle wedge in intraoceanic arc setting are the viable processes that contributed to gold genesis in the Kudrekonda boninites. Devolatilization during prograde metamorphism, hydrothermal fluid generation, syntectonic gold remobilization and migration of gold enriched fluids through shear zones account for Au transportation and precipitation in quartz veins emplaced within the boninites. The BIFs from Ganajur, Karajgi and Palavanahalli areas of Shimoga greenstone belt are silicified, carbonatized, sulfidized and their immobile trace element abundances and ratios indicate hydrothermal origin and their deposition in a marine off-shelf environment proximal to a mid-oceanic ridge-rift system. These BIFs are characterized by pronounced enrichment in Au (706-15,831 ppb) and Ag (630-2435 ppb). Gold mineralization in Shimoga BIFs is epigenetic, epithermal type, vein and disseminated lode gold deposit and its genesis is attributed to migration of reducing, sulphidic–auriferous fluids of hydrothermal origin to the site of BIF deposition that served as chemical traps. Occurrence of gold in the quartz veins of Kudrekonda boninites and Karajgi BIF is interpreted as late-stage process involving syntectonic remobilization of gold, its transportation and precipitation through shear zone-controlled faults and fractures during collision-accretion at ocean-continent convergence (Ganguly *et al.,* 2016). Manikyamba *et al.* (2017) evaluated the iron and manganese mineralization in Dharwar Craton that has been attributed to hydrothermal processes associated with mid-oceanic ridge-rift system; while gold, Cu porphyry and volcanogenic massive sulphide (VMS) Cu-Zn deposits show prominent affinity towards metallogenic processes operative in Archean subduction environments. The authors proposed the diverse geodynamic conditions including mantle plume activity, divergent and convergent margin processes attribute to the mineral endowment of Dharwar Craton (Manikyamba *et al.,* 2017a). Muller *et al.,* (2017) reported bulk S-isotopes of the 3.2 Ga old barite deposit of the Sargur Group, Dharwar Craton and compared them with the coeval counterparts from Western Australia and South Africa. The authors observed that despite the pervasive ductile deformation and regional amphibolite facies metamorphism, high spatial heterogeneities in the Sargur Group of rocks, the $\delta^{34}S$, $\delta^{33}S$ and $\delta^{36}S$ measured by both in situ and bulk techniques are well preserved in these Paleoarchean barites and associated pyrites. These results overlap with other Archean barite deposits in Australia and South Africa, indicating that similar processes and sulfur sources were involved in the formation/preservation of Archean barite deposits on three continents. The authors confirm that Archean barites, even if they experienced high-grade metamorphism, can be considered as a powerful target of S primary isotopic signatures to evaluate the life processes and atmospheric evolution. Detailed evaluation of petrographic and textural features by Ghosh and Manikyamba (2019) identified gold, uranium, thorium and rare-earths minerals from the volcanic rocks of Kadiri greenstone belt and substantiated magma genesis and associated mineralization in intraoceanic arc-back regime during Neoarchean times.

Highlights: 2016-2020

- Recent work on the zircon U-Pb ages of the trondhjemitic gneiss provided much older ages (3607+16 Ma) than the existing ages of Gorur gneiss from the WDC opening the window for the presence of Eoarchean to Hadean crust in the Dharwar Craton.
- The oldest detrital zircons of metasediments from the western and central Dharwar Craton represent U-Pb ages of 3227 Ma and 2575 Ma respectively and their Hf isotopes indicate 3.67 to 2.75 Ga magmatic sources.
- The detrital zircons from the stromatolitic carbonates from Chitradurga, Shimoga and Sandur greenstone belts displaying various ages ranging from 3.5-2.6 Ga, further supporting the presence of oldest crust and ~800-900 Ma duration for the deposition of Precambrian stromatolites in the Dharwar Craton.
- The identification boninites of Shimoga belt and its gold mineralization throw light on the intraoceanic subduction zone processes in the WDC, which is supported by the boninitic rocks from the Holenarsipur belt reflecting on operation of plate tectonics in the Palaeo to Mesoarchean times in the Dharwar Craton.
- The zircon U-Pb ages obtained on the mafic volcanic rocks of the Kudremukh belt pushing the record of greenstone volcanism in the Dharwar Craton upto 2.5 Ga.
- The Phanerozoic magmatism in the Proterozoic Cuddapah basin throw light to revisit the

Proterozoic sedimentary basins for younger magmatic pulses.

- Presence of gold, uranium, thorium and rare-earth minerals in the volcanic rocks of Kadiri belt, EDC and higher concentrations of Au and Ag in the quartz veins associated with boninites, banded iron formations of Shimoga belt, WDC require detailed studies to explore their occurrences in other parts of Dharwar Craton.
- Microblock accretion during Archean-Proterozoic boundary, the synchronous accretion of WDC, CDC and EDC are suggested to be driven by two separate eastward dipping ocean continent convergent plate margins in the Dharwar Craton. It is also suggested that the lithospheric evolution and crustal growth in the Sargur Group to Dharwar Supergroup took place through early stage stagnant-lid tectonics to modern style, episodic subduction-controlled plate tectonic processes. The plume-arc affinities of the greenstone belts of Dharwar Supergroup and the predominant island arc processes of greenstone belts of EDC reflecting on the thermal and tectonic transition of our planet during the Archean and gradual decrease of mantle temperatures and thickening of lithosphere through time and space.
- With the identification of five magmatic episodes of crustal growth from 3.45-2.50 Ga, microcratons suggested to provide oldest crustal signatures and their accretion appears to be significant to evaluate the crustal growth process in the Dharwar Craton.

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