Chapter 2

GEOLOGY
2.1 Introduction:

The Indian Peninsular Shield is a stable continental mass among several others on the Earth. Peninsular India consists of the following shields and they are 1) Southern Indian Shield 2) Northwest Indian Shield, 3) Central Indian Shield and 4) Eastern Indian Shield. Each of the above shields is characterized by one or more Cratons and mobile belts usually with tectonized boundaries (Radhakrishna, 1990). The Southern Indian Shield consists of 1) Dharwar Craton, 2) Eastern Ghat Mobile Belt, 3) Southern Granulite Terrane and 4) Proterozoic Sedimentary Basins. During the early Cretaceous, the Southern Indian shield was part of the Gondawana super continent and was extending to the present day Africa to the west and Australia to the east (Naqvi and Rogers, 1987).

2.2 Dharwar Craton:

The Dharwar Craton covers an area of 238,000Km$^2$ lying between the latitudes N 12º 0' to N 18º 0' and longitudes E 74º 0' to E 80º 0' (Fig.2.2). The Dharwar Craton occupies the northern part of the Southern Indian Peninsular Shield and is bound by the Deccan Traps towards north and the high grade granulite terrains to the south and east. The Dharwar Craton is divided into an eastern and a western domain with reference to N-S trending granitoid called “Closepet Granites” (Viswanatha and Ramakrishnan, 1981; Allen et al., 1986). Subsequently, Chadwick et al., (1992) suggested that N-S sinistral shear zone that forms the eastern boundary of the Chitradurga Schist Belt marks the boundary between eastern and western parts of the Dharwar Craton.

The late Archaean Dharwar Craton is a model of Archaean and Proterozoic terrains in Peninsular India (Ramakrishnan, 1993). Areas east and south of the Craton are characterized by structures; metamorphism and igneous bodies related to the Pan-African assembly of Gondawana, but the interior of the Craton largely escaped significant Pan-African overprinting. The northern margin of the Craton is concealed by Proterozoic sedimentary rocks and Deccan traps, whereas the east is overlain by the Meso-Neoproterozoic Cuddapah basin. Late Archaean metamorphism in western part of the Craton varies from Low Temperature green schist to amphibolites facies in contrast with High Temperature green schist to amphibolites facies in the eastern part which related to the emplacement of voluminous granite.
2.3 Classification of Dharwar Craton:

Dharwar Craton is divided into Eastern, Kolar-type and Western Dharwar-type blocks distinguished by differences in the volcano-sedimentary supracrustals, magmatism, grades of metamorphism and temporal evolution. Isotopic age studies using K–Ar, Rb–Sr and Pb–Pb methods placed the Western Dharwar Craton (3000 Ma) to be older than the Eastern block (2500–2600 Ma). Some workers believe that the Closepet granite massif marks the boundary between Eastern and Western Dharwar (Fig.2.1), while others are of the opinion that the eastern boundary fault of the Chitradurga basin demarcates the two. Various views are put forth regarding the evolution of Dharwar Craton. The most characteristic structural feature of the Archaean cover sequence of the Dharwar Craton is the arcuate NNW–SSE trend with convexity towards the east. The major geological features in the Dharwar Craton include the Archaean–Early Proterozoic green schist belts set in a matrix of Peninsular Gneiss–Migmatitic complex and the intrusive, younger potash-rich granites.

The Western Dharwar Craton, a typical Archaean low-grade terrain, is characterized by the mature sediment dominated greenstone belt of the Dharwar type. Two main divisions, viz. the older igneous Bababudan group and the Chitradurga group composed of conglomerates, quartzites, limestones, greywacke and associated manganiferous and ferruginous cherts, are identified. These groups of sediments are deposited in three basins: the Shimoga, the Chitradurga and the Sandur basins. Banded iron-ore formations are exposed in the southern part of Shimoga basin in the Bababudan and Kudremukh belt in addition to Sandur and Goa basins. Magnetite, quartz and clay are the main mineral components of the iron-ore formations. The development of iron-formation points to stable conditions.

The western Dharwar Craton is characterized by the presence of bimodal volcanic, volcano-clastic and chemical sediments with the sedimentary component dominating over the volcanic. Chitradurga Schist Belt, Bababudan group and Shimoga Schist Belt, to a few, form part of the western Dharwar Craton. The eastern Craton is interspersed with several schist belts such as the Kolar, Ramagiri and Hutti Schist belts, which are surrounded by late Archaean granitoid rocks. The schist belts of the eastern Dharwar Craton are made up of basaltic rocks subordinated with chemical
sediments. Unlike their western counterparts, clastic sediments such as argillite and greywacke are found only in negligible quantity.

Fig.2.1: Geology of Dharwar Craton (adapted from project VASUNDARA, GSI, 1994).

Area west of the Closepet Granite (represented by deep red) is the Western Dharwar Craton while to its east is the Eastern Dharwar Craton. Inset: Generalized geological map of India showing several of the Cratons and regional structures (after Rogers, 1990) a-Delhi Supergroup; b-Singhbhum orogenic belt; and c-Granulite terrain.

CH-Chotanagpur; EG-Eastern Ghats; and SO-Southern granulite terrains, separated from the Dharwar Cratons (ED and WD) by a non-tectonic zone. Archaean gneissic terrains with infolded supracrustal rocks: AR-Aravali; BU-Bundelkhand; SI-Singhbhum; BH-Bhandara; ED-Eastern Dharwar; WD-Western Dharwar. Rift valleys: N-Narmada; S-Son; M-Mahanadi; and G-Godavari. Major thrusts: 1-unnamed thrust in WDC, 2-Eastern Ghats front; 3-Sukinda; 4-Singhbhum (copper belt); 5-thrust south of Son valley; and 6-Great Boundary Fault.

East of the steep belt of mylonites of the Dharwar Craton is contrastingly different. It is dominated by voluminous granites, granodiorites and their high strain gneissic equivalents, c2750-2550 Ma (Balakrishnan et al., 1990; Friend and Nutman, 1991; Krogstad et al., 1991, 1995; Peucat et al., 1989, 1993; Subba Rao et al., 1992; Zacharaiah et al., 1995; Nutman et al., 1996). EDC has a series of linear and irregular schist belts with sedimentary and volcanic rocks that have many lithological aspects in common with the Dharwar Supergroup in the west. Limited isotopic age data
indicates that volcanism took place during c2750-2650 Ma (Balakrishnan et al., 1990; Zacharaiah et al., 1995; Nutman et al., 1996). Pb/Pb data indicate that metamorphic recrystallization of the limestone in the Sandur schist belt took place 2475±65 ago. The difference in the timing of metamorphic crystallization in western and eastern Karnataka suggests that regional heating related to granite emplacement in the east of the Craton outlasted metamorphic effects in the west.

The Eastern Dharwar block, comprising the Kolar-type schist belts, is typified by volcanic dominated greenstone belt (Keewatin type) characterized by low-pressure metamorphism. The prominent schist belts trending NNW–SSE are volcanogenic with thick pile of basalts and subordinate clastic and chemical sediment. These are known for their gold mineralization. They are mainly igneous in character with very subordinate sedimentary intercalations. The major belts in the Kolar type include Kolar, Veligullu–Ramagiri, Huttī–Muski, Hungund– Kushtagi and Raichur–Deodurg.

Table 2.1: Greenstone belts of Dharwar Craton

<table>
<thead>
<tr>
<th>Western Greenstone Belts-Western block (Sargur)</th>
<th>Low grade green schist facies belt-Western block(Dharwar)</th>
<th>Eastern greenstone belts-Eastern block (Dharwar)</th>
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<tr>
<td>i. Sargur</td>
<td>i. Western Ghat</td>
<td>i. Kolar</td>
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<td>ii. Holenarsipur</td>
<td>ii. Kudremukh</td>
<td>ii. Huttii</td>
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<td>v. Ghattihosahalli</td>
<td>v. Chitradurga–Gadag including Javanahalli</td>
<td>v. Mangalur</td>
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<td>vii. Jayacharmarajapura (J.C.Pura)</td>
<td>vii. Sigegudda</td>
<td><strong>Transitional belts in Eastern block</strong></td>
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<td></td>
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<td>i. Sandur belt</td>
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<td>ii. Javanahalli belt</td>
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<td></td>
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<td>iii. Huliyurdurga–Kunigal belt</td>
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<td>iv. Small belts of Ghataparhi, Parasurampur, Saggere, Bidalotti and Hesseraghatta enclaves at the margins of Closepet granite.</td>
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Ramakrishnan, et al., (1994) have proposed a four division classification of schist belts of Dharwar Craton namely;

1. Western block (Dharwar); 2. Western block (Sargur); 3. Eastern block (Dharwar), and 4. Transitional belts (Table 2.1)

### 2.3.1 Classification of Dharwar based on Aeromagnetic data:

The ‘Dharwar Craton’ named by Pichamuthu (1962), is one of the oldest Precambrian terrains of the world preserving within its limit the geological history of a very ancient (3400 to 2600 Ma) continental crust. The Dharwar Craton is well known for its granite–greenstone association, covering the states of Karnataka and part of Andhra Pradesh. It is delimited on the west by the present-day coastline and on the south and east by the dominantly Proterozoic high grade terranes (Anand and Mita Rajaram, 2002).

In the north it is bounded by the Bhima and Kaladgi basins and the Deccan volcanic province. Detailed geochemical and geophysical investigation of the granite–greenstone belts is important from the point of view of the reconstruction of the mineralization, tectonic history, grades of metamorphism, etc. of the Dharwar Craton. Towards this end, the analysis of magnetic data can give a new perspective to probe the Dharwar Craton. The source rock of magnetic anomalies is charnockites in the SGT, mainly intrusive and iron-ore bodies in the Dharwar Craton.

The aeromagnetic total field anomaly map (Fig.2.2) and its analytical signal map give a general idea about the distribution of magnetic sources in the Dharwar Craton consistent with the known tectonic trend. Based on the nature of the anomaly trend, the area under investigation can be divided into three major blocks: the NNW–SSE-trending Dharwar block, E–W-trending high-grade terrain of the Southern Granulite Terrain (SGT) block and the NE–SW-trending Eastern Ghats block. The Dharwar can be further divided into Eastern and Western blocks depending on the distribution of magnetic sources. The criterion adopted for this division is the presence of iron-ore. The magnetic anomaly sources in the Western block are mainly iron-ore, while in the Eastern block it reflects the gold-bearing schist belts. Keeping this in view, the magnetic data suggest that the Chitradurga schist belt, divides the Dharwar Craton into the Western and Eastern blocks. A surprising result of the study of aeromagnetic
data is that the schist belts in the Eastern block, not showing clear evidence in the published long wavelength maps are better defined in the present map, created using finer grid interval, implying their depth extent may be shallow.

![Fig. 2.2: Total field magnetic anomaly image map of Dharwar Craton (after Anand and Mita Rajaram, 2002)](image_url)

The magnetic signature associated with the Western Dharwar block comprising the Shimoga, Chitradurga and the Sandur basins comes from the associated iron-ore formations, either exposed or in the sub-surface. Removing the signatures associated with iron-ore belts from the Western Dharwar results in a magnetically flat region with low gradient and low amplitude, possibly reflecting the basement. Analyzing the nature of the anomalies suggests the basement to be composed of low-grade gneiss, consistent with several previous studies.

The magnetic response of the Eastern Dharwar block is surprisingly high, i.e. the density of high-amplitude anomalies is more. When compared with the Western block, the Eastern block has a paucity of ultramafic/anorthositic layered complexes and lesser incidence of Banded Iron Formation. The difference in magnetic signature of the Eastern and Western blocks can be explained either in terms of the difference in environment of deposition and/or the difference in grades of metamorphism. This difference can be due to either or a combination of the following: (a) The Western
Dharwar has a larger sedimentary component, while the Eastern is dominantly volcanic in origin. (b) Metamorphism affects the nature of iron compounds in rocks and thus affects susceptibility. The magnetic field of the Eastern Dharwar is consistent with a higher grade of metamorphism compared to the Western Dharwar. (c) The Eastern Dharwar Craton might have been uplifted with respect to the Western Dharwar Craton, with the characteristics of the deeper crustal layers now exposed by erosion. Any theory of the evolution of the Dharwar Craton should incorporate the difference between the Eastern and the Western Dharwar, as evidenced from different data sets: magnetic, geology, gravity, heat flow, radiometric dating, seismic, magneto-telluric, etc.

**2.3.2 Classification of Dharwar based on Mineral occurrences:**

Mafic magmatism of the supracrustal groups of Western Dharwar Craton (WDC) and greenstone belts of the Eastern Dharwar Craton (EDC) are the most important. V-Ti magnetite bands constitute the most common deposit type recorded in the mafic – ultramafic complexes of the Sargur Group with commercially exploitable chromite deposits occurring in a number of belts. PGE mineralization of possible commercial value has so far been recorded in a single mafic-ultramafic complex, while copper-nickel mineralization occurs at certain localities in the Sargur and Chitradurga Groups. Gold mineralization hosted by mafic rocks has been noted in many of the old workings located in supracrustal groups of rocks in the WDC and in the greenstone belts of EDC. Economically exploitable mineralization however occurs mainly in the greenstone belts of the Kolar, Ramagiri-Penakacherla and Hutti-Muski and along the eastern margin of the Chitradurga belt, where it is associated with a major N-S striking thrust zone separating WDC from the EDC.

**2.4 Dharwar Batholith:**

Eastern part of Dharwar Craton is surrounded by voluminous plutonic rocks like granites, granodiorites, monzonites and diorites of the calc-alkaline suite. Most were emplaced as steep wedges or elongate domes trending N-S or NW-SE. Similar orientations of tectonic fabrics in the schist belts and the magmatic and tectonic fabrics in the plutonic rocks indicate that many were emplaced syntectonically, but some granites are post-tectonic, e.g., the Joga granite in the north of Sandur schist belt (Chadwick et al., 1996).
Chadwick et al., (1996) proposed that the two fold division of the Dharwar Craton into the western part comprising the basins of the Dharwar Supergroup and their sialic basement and the eastern part comprising the Dharwar batholiths and its Late Archaean schist belts is consistent with a convergent plate setting. The western part represents a continental margin (fore land) with marginal or back arc basins represented by the Dharwar Supergroup, where as the eastern parts represents batholiths and intra arc basins (schist belts) which accreted against the continental margin. The subduction direction is not clear. The limited evidence of thrust thickening from NE to SW in the Sandur schist belt (Chadwick et al., 1996) and SW vergence of structures in the Dharwar supergroup north of Honnali (Chadwick et al., 1991) suggest that subduction was broadly from west to east. On the other hand the back arc or continental margin setting of the Dharwar Supergroup suggested by the geochemistry of its volcanic rocks (Bhaskar Rao and Naqvi 1978; Anantha Iyer and Vasudev 1979; Drury 1983), and the spatial setting of anatectic granites in the foreland Chitradurga granite (Taylor et al., 1988) and the western part of the Dharwar batholiths (Friend and Nutman, 1991) favor east to west subduction. The ambiguity in the subduction direction is complicated by transcurrent sinistral displacements in the foreland and the batholiths which indicate an oblique component to the convergent system. (Chadwick et al., 1997).

2.5 Sandur Schist Belt (SSB):

Newbold (1838) proposed that the Sandur Schist Belt was intruded by the adjoining granites, but Foote (1895) interpreted the structure of the belt in terms of two great synclines, he believed that the limbs of one of these synclines formed the hill ranges southwest and northeast of the Sandur valley, whereas he placed the other major syncline in the hill ranges (Copper Mountain belt) on the northeast of the schist belt. He remarked that the synclines were linked by the broad spread of volcanic rocks (trap) in the Joga-Lingadahalli- Sultanpura area. Most of the later workers agreed to the Foote’s concept of Sandur schist belt.

Foote’s interpretation of the structure was argued by Matin and Mukhopadhyay (1987) and Mukhopadhyay and Matin (1993), who showed that the sedimentary assemblages on the limbs of the regional syncline suggested Foote (1895) and Roy and Biswas (1983) in the southwest of the schist belt are different and not the same
stratigraphic level repeated by folding. Moreover, they show that these alleged fold limbs do not join at the northwestern or southeastern hinge areas of the supposed syncline. They also demonstrated that there is no systematic difference in the vergence of small folds on each limb as expected if there was a major syncline.

Banded Iron Formations of Sandur Schist Belt (Fig. 2.3) are remarkable from the point of view of the depositional process and environments. Naqvi et al., (1987) reported microscopic structures and interpreted them as silicified cyanobacterial remains. They also reported organic matter in stromatolitic limestones from Yeshwanthnagar (Murthy and Reddy, 1984). Manikyamba et al., (1993) based on geochemical data concluded that the iron formations were the result of submarine hydrothermal venting at mid oceanic ridge, terrigenous and volcanoclastic sediments and biogenic activity.

Krishna Rao and Hanuma Prasad (1995) proposed that the fine grained clastic rocks from eastern side of schist belt derived from intra basinal tholeiitic basalts and felsic material from an extra basinal granitoid source. Geochemical data of felsic and mafic rocks indicates an arc setting (Hanuma Prasad, 1994).

The Sandur Superterrane (SST) is unique amongst the composite greenstone-granite terranes of the Dharwar Craton, in that its geological and geographic position is within the belt of Closepet granite complex (Fig.2.3). There are lithotectonic differences between greenstone terranes of the EDC and WDC (Manikyamba and Khanna, 2007). However, the SST has excellent preservation of lithologies commonly present in both the EDC and WDC.

Iron formations of the Sandur belt consist of cherts (C), ferruginous cherts (FC), cherty BIF (CBIF), shaly BIF (SBIF), ferruginous shales (FSH) and shales/phyllites (SH). In fact there are two end members namely cherts (C), and shales/phyllites (SH), in which a variation in the proportion of SiO₂, Fe₂O₃ and Al₂O₃ bearing minerals has produced the observed compositional scatter, as has been earlier found by Beukes (1980) for the BIF of the Transvaal Basin.
The Donimalai BIF from the eastern part of the Sandur belt is made up of meso- and microbands of chert and iron minerals. Iron oxides (haematite/magnetite) dominate over carbonates (siderite/ankerite). Sulfide (pyrite) and silicate (cummingtonite/grunerite) bands are also found but they are not as abundant as the iron oxide bands. Two types of banding are noticed, one in which along with the chert a great concentration of iron minerals is found. In this type the Fe and SiO$_2$ rich layers are microlaminated. The other type is one in which laminated chert and carbonates with sporadic development of magnetite/haematite is found. In such cases a gradual change from an iron-rich layer to a chert rich layer is found. The individual thickness of the iron-rich laminae with abrupt change to chert varies from a few mm to 2-4 cm. The thickness of the laminae showing a gradual decrease of iron minerals into chert laminae are about 5-10 mm. Fine dust of iron oxide is seen gradually diminishing into pure chert (Manikyamba et al., 1993).

Sandur Schist Belt consists of different types of metavolcanics. The Metavolcanics exhibit well developed pillow structures, which are elongated and stretched due to deformation. A study on the stretching of pillow had indicated structural evolution of schist belt. The pillow structures of the Deogiri and Donimalai formations on the western margin are stretched, whereas pillows of both the formations from the eastern part of the belt have normal length and width. All along the western margin of the
belt, the pillows are compressed in NE-SW and stretched in N40-45° W direction. About 80% of the pillows have stretched to give the length/width ratio ranging between 3 and 30 and 81% of the pillows have length/width ratio between 3 and 12. Most of the pillows show convexity towards east and 90% of them have length/width ratio between 1 and 2. This shows that in the entire belt, the maximum deformation, elongation and compression have occurred along the western part of the belt. This suggests that in addition to confining pressure the lavas of the western margin were subjected to a directional stress, which continued to produce post consolidation brittle deformation. This indicates that lavas of the western margin were part of a subducting slab and compression continued till the closing of proto ocean. There it is argued that the western margin of the Sandur belt has been overridden by its eastern part. Furthermore, geometry and the wavelength (2-10m) of the D1 fold closures at the northern and southern termination of the belt substantiate the inference that horizontal compression and crustal shortening have been a very significant and frequent aspect of tectonic evolution of Sandur Schist Belt (Manikyamba and Naqvi, 1996).

The Sandur Superterrane has three phases of deformation (Mukhopadhyay and Matin, 1993), and the metamorphic grade varies from green schist to upper amphibolite facies depending on the terrane. U-Pb SHRIMP age of zircons from the Eastern Felsic Volcanic Terrane (EFVT) yielded an age of 2.7 Ga (Nutman et al., 1996), and the poorly defined Sm/Nd date for Sultanpura Volcanic Terrane (SVT) komatiites is 2.7 Ga (Naqvi et al., 2002). The composite supracrustal terranes have been intruded by a series of granitoids after their accretion, among which one granitoid from the EFVT has been dated at 2719±40Ma (Nutman et al., 1996).

2.6 Geodynamics of SSB

Geodynamics is a subfield of geophysics dealing with dynamics of the Earth. It applies physics, chemistry and mathematics to the understanding of how mantle convection leads to plate tectonics and geologic phenomena such as seafloor spreading, mountain building, volcanoes, earthquakes, faulting and so on. It also attempts to probe the internal activity by measuring magnetic fields, gravity, and seismic waves, as well as the mineralogy of rocks and their isotopic composition. Methods of geodynamics are also applied to exploration of other planets (Wikipedia).
Dharwar Craton comprises of a foreland with its volcano sedimentary basins classified under Dharwar Supergroup and their basement Peninsular Gneiss comprising older supracrustal rocks in the western half of the Craton and, an accretionary complex dominated by polyphase calc-alkaline plutonic rocks interspersed with relics of intra-arc basins (schist belts) in the eastern half (Chadwick et al., 1996, 2000). Kolar, Hutti, Ramagiri, Jonnagiri, Gadwal, Raichur, Kushtagi-Hungund and Sandur belts form part of the accretionary complex.

The Foreland basins are characterized by shallow marine or fluvial orthoquartzites, bimodal basaltic and rhyolitic suites, banded iron formation, polymict conglomerates, greywacke and limestone. They have unconformable or faulted contacts with basement ortho gneisses.

The eastern accretionary complex comprises multipulse anatectic and juvenile granites and granodiorites with subordinate diorites. The schist belts represent intra arc and marginal basins which are also of mixed mode type with dominant bimodal volcanic, subordinate sedimentary suites.

Gold mineralization in the accretionary complex as well as the Foreland took place during progressive development of ductile schistosity during the first major event of deformation (D1) that overlapped with retrogression to green schist facies associated with hydrothermal activity (solution transfer and volume reduction) along high strain zones disposed parallel or subparallel to the D1 regional schistosity. This event was an integral part of a continuum of NE-SW and E-W orogen-normal shortening and granite emplacement during Neoarchaean oblique convergence in the foreland and accretionary complex. Conjugate small scale shear zones at a high angle to the D1 schistosity also developed during this continuum indicating that deformation in the continuum became increasingly brittle and localized as a result of dehydration processes.

The geochemical characteristics of the metabasalts of the greenstone belts supports the Island arc tectonic setting of schist belts in the Foreland and intra arc basins were thickened by thrusting during NE-SW to E-W shortening.

Worldwide abundance of gold in Neoarchaean rocks is possibly direct consequence of the major period of growth and stabilization of continental crust via plate tectonic
processes and the distribution of metal deposits is related to progressive cooling of the earth and its geodynamic evolution from mantle plume to modern plate tectonics (Grove et al., 2005; Kerrich et al., 2005).

Almost all major Neoarchaean gold bearing greenstone belts from Dharwar Craton, hosted largely in Intra Arc Basalts, but in close association with rocks similar to adakites. Gold bearing greenstone belts of the Eastern Dharwar Craton are generally made up of mafic-felsic volcanic rocks including adakites, where as greenstone belts of western Dharwar Craton are predominantly made up of sedimentary, where gold mineralization is found in a sediments and island arc basalts. Kolar “champion gneiss” coined by Smeeth (1915) is also an adakite (felsic volcanic rock).

The Sr, Nd, and Pb isotopic data from pyrite and host rocks for several lode gold deposits of young subduction complexes indicate that the hydrothermal fluids responsible for the pyrite and gold mineralization were probably derived from a mixed source (i.e., degassing of mantle magmas and meteoritic water that had leached the country rocks (Yang and Zhou, 2001). Consistent association of adakites with gold mineralization in Dharwar greenstone belts strengthens the compressional geodynamic and subduction related processes.

Sengör and Natal'in (1996) compared accretionary and continent–continent type orogens. The former, also termed Turkic or Cordilleran orogens involve accretion of multiple allochthonous terranes of different lithotectonic associations, across multiple sutures, as a subduction–accretion complex migrate ocean ward. The latter, also termed Alpine–Himalayan type orogens result from collision of two continental lithosphere plates across a single suture. Sengör and Natal'in (1996) suggested that the Neoarchaean Yilgarn Craton was an Archaean counterpart to Proterozoic accretionary orogens such as the Altaids of central Asia, or the Mesozoic–Cenozoic Cordilleran orogen of North America. Accretionary orogens are characteristic of many Archaean composite greenstone terranes, including the Superior Province, Canada (Kerrich et al., 2005), and based on the results of this study the Sandur Superterrane also meets the criteria for an accretionary orogen.
2.7 Radiometric age data:

The available geochronological data suggests that 2.7-2.69 Ga corresponds to a major event of greenstone volcanism and surround TTG accretion. On the other hand 2.55-2.52 Ga event corresponds to a major episode of calc-alkaline magmatism and reworking followed by metamorphism. The 2.55 Ga magmatism in EDC could be related to arc accretion which can form adakites. This arc accretion followed by plume impact at 2.52 Ga (Jayananda et al., 2000) that caused reworking of 2.7-2.55 Ga crust, shear deformation, gold mineralization in greenstone-granites. Felsic volcanics from the greenstone belts of Dharwar Craton are dated between 2.6-2.7 Ga (Nutman et al., 1996; Balakrishnan et al., 1990, 1999) whereas some of the gneisses of the EDC, shear deformation and metamorphism away from the mineralized belts are dated around 2.55-2.51 Ga (Jayananda and Peucat, 1996). Some parts of the EDC appear to be affected by shear deformation and metamorphism during 2.55-2.50 Ga as revealed by regional distribution of shear zones, emplacement of granites are related to a sub crustal mantle plume (Jayananda et al., 2000). The relation between Juvenile magmatism, thermal events and shear zones with gold mineralization is not very clear. The heat needed to remobilize 2.7 Ga old slab – wedge complexes might be provided by juvenile magmatism.

U–Pb SHRIMP age of zircons from the eastern felsic volcanic terrane yielded an age of 2.7 Ga (Nutman et al., 1996), and Sm/Nd isotopic ratios for komatiites of the Sultanpura volcanic terrane define a poorly constrained eight point isochron of 2706±184 Ma (Naqvi et al., 2002a). The composite supracrustal terranes have been intruded by a series of granitoids after their accretion, among which one granitoid from the eastern felsic volcanic terrane has been dated at 2719±40 Ma (Nutman et al., 1996).

2.8 Classification of Sandur Schist Belt (SSB):

Chadwick et al., (1996) have proposed a new term ‘SANDUR GROUP’ with six formations. Way up criteria shows that the oldest formation occurs on the southwest of the schist belt; the rest of the group become progressively younger across strike to the northeast. They also reported that schist belt is surrounded by granites with discordant or concordant intrusive contacts variable depending on the nature of
deformation. Chadwick et al., (1996) proposed six new formations to replace the four in earlier classification (Table 2.2).

**Table 2.2: Classification of Sandur schist belt compared by different workers**

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2.9 Depositional Environment:

Deformed pillow structures of Sandur Schist Belt indicate the subaqueous eruption. The occurrence of banded iron ferruginous chert suggests shallow marine shelf setting agreed by many workers.

The combined thickness of the lavas and the stratiform intrusion in Taluru formations is approximately 8000m which may be an effect of volcanic and sub volcanic accumulation within a major submarine eruptive regime.

2.10 Granitic Intrusions adjacent to Sandur Schist Belt:

The Sandur Schist Belt is surrounded by granitic rocks which range from banded migmatitic gneisses to porphyritic granites. Many have intrusive contacts parallel to the schistosity in the belt. Gneisses and granites have been classified into six types, which are based partly on relative age and partly on deformation. They are dominated by microcline, plagioclase, quartz and biotite with common accessory titanite,
epidote, allanite, apatite and zircon, and trace amounts of fluorite. NE-SW compression led to large scale buckling and layer shortening. The c.35km thickness of the Sandur group and the consistent north-easterly younging direction are attributed to this thrust stacking. The absence of high P metamorphic mineral assemblages indicate that the thrust pile has not attained vertical thickness of 35km, but stacked in a series of steeply inclined thrust blocks.

Emplacement of granites adjoining to the schist belt have contributed in the development of regional sheath folds and steepening of bedding and schistosity, as justified by mylonitization and local folding.

The granites adjacent to Sandur schist belt are Late Archean polyphase granite terrain that underlies most of the eastern Karnataka and some parts of Andhra Pradesh and Tamilnadu. Chadwick et al., (1996) coined a term ‘Dharwar Batholith’ based on the scale, variations in composition and structure. Many workers have included the granites adjacent to Sandur schist belt within the classification of Closepet granite (Radhakrishna, 1983; Oak, 1990; Friend and Nutman, 1991), but this correlation is not clear based on the grounds of their multipulse and juvenile characteristics which are different from the anatectic granites in the south of Closepet granite belt.

The volcanic and sedimentary rocks of the Sandur schist belt over the western margin of Dharwar batholiths with its mixture of anatectic granites (c2500Ma) and Peninsular Gneiss (>2900Ma) and late Archaean juvenile granites occupies eastern part of the schist belt. The occurrence of abundant felsic and basic volcanic rocks in the Sandur group indicate that it might have developed as an intra arc basin; this is supported by composition of basaltic and rhyolitic rocks (Hanuma Prasad, 1994). The basin may be juxtaposed onto the older Archaean continent represented by Peninsular Gneiss in the west (Chadwick et al., 1996).

2.11 Geology of Joga area:

Joga is a part of Sandur Schist Belt located on the northern portion of schist belt. The region consists of Granites, Metabasalts, Gabbro dyke, dolerite dyke, BIF and Phyllite (Fig.2.4). Banded Iron Formations are minor and discontinuous bands occur on the central and south western regions, showing a trend of EW and dipping towards south predominantly. Metavolcanics are the predominant litho units exposed in the study
area, which is exhibiting pillow structure prominently, suggesting a depositional environment near to volcanic vent. Vesicles, Amygdales are common in the basalts. The basalts vary in composition from andesitic to basaltic. Quartz Carbonate (QC) veins are prominent near shear zones within Metabasics, these QC veins are complex in structure and exhibit brecciated nature near the sulphidic zone. The common sulphides observed are Pyrite, Pyrrhotite, and Chalcopyrite etc.

**General Stratigraphy of Joga area**

<table>
<thead>
<tr>
<th>Gabbroic dyke/Doleritic Dyke</th>
<th>Sultanpura volcanic block (SVB)/ Taluru Formations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juvenile Granites</td>
<td></td>
</tr>
<tr>
<td>BIF with intercalations of Dolomite Metavolcanics Conglomerates</td>
<td></td>
</tr>
</tbody>
</table>

Joga area evidenced the existence of dyke bodies with variable characteristics. The prominent one is coarse grained Gabbro dyke which runs through the research area along North West-South East direction with a considerable width varying from few meters to more than 100 metres. The coarse grained gabbro dyke shows branching into two parts on the north western side of study area. The gabbro dyke is regional one and has a strike length of approximately 10kms.

The other minor dyke bodies are represented by fine grained dolerite dyke, four such bodies have been identified in the study area. Dolerite dyke bodies have no specific trends, however three of the dyke bodies run sub parallel to the coarse grained gabbro dyke.

The dolomite bands are occurring with BIF bands discontinuously along the strike direction, preferably on the footwall side of the BIF. Ankerite is also found associated with Banded Iron Formations and occurs sporadically. The study area has witnessed prominent carbonatization process with all the litho units.
Fig. 2.4: Geology of Joga (inset red block showing mineralized zone) (after Suresh et al., 2014)