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REVIEWS

Crustal Evolution of Kolli-Massif, Southern India

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Abstract | Southern India is a collage of numerous crustal fragments formed since the Archean (2500 Ma ago) and reworked several times during the geological history. A close look at these terrains provides a window to understand the crustal evolutionary processes experienced by the continental crust in the past, such as crustal growth (formation of crust through addition of new magma) and crustal reworking (modification of an already existing crust). Here we discuss the evolutionary history of such a crustal fragment from the Southern Granulite Terrain (SGT) in peninsular India, namely Kolli-massif. Geology, structural deformation through time, and the implications in crustal assembly of southern India are exponded.

Keywords: *Crustal evolution, Southern India, Kolli-massif*

1 Introduction

Our Earth has been evolving ever since it formed 4.56 Ga ago. The continental crust of the Earth was affected by several processes (internal and external agencies) with time. Understanding these processes and its timing will pave way to the crustal evolutionary history of the Earth. This study brings out geological evolution of southern India, where the Earth's crust experienced some of the extreme physico-chemical conditions ever reported on the planet.

Southern India is a collage of several crustal blocks which were amalgamated through numerous tectonic processes during various periods of geologic time-scale. As by definition, all these crustal blocks are demarcated by shear-zones or shear systems between them.[1,2] The northern part of the peninsular India is geologically known as the Dharwar Craton, dominant in granites and greenstone belts (see description), where the continental crustal growth and evolution happened around 2500 Ma ago (Archean time). Crust in the Dharwar Craton has been metamorphosed to greenschist to amphibolite facies (*P-T* conditions ranging from 2–10 Kbar, 400–800°C).[3,4] The region below Dharwar Craton is present with highly deformed region, traversed by various shear zones, metamorphosed to granulite facies (*P-T* conditions ranging from 8–20 Kbar, 800–1000°C,[5–15] designated as Southern Granulite Terrain (SGT),[16] comprising Coorg Block, Biligiri Rangan Hills (BR Hills), Shevroy Hills, Madras Block, Nilgiri Block, Palghat-Cauvery Shear Zone (PCSZ), Madurai Block, Trivandrum Block and the Nagerkovil Block (Ref. 3 and see Fig. 1), where the continental crust underwent high grade metamorphism since Archean.[15,17] This contribution, however, focuses on the region within the PCSZ between the Cauvery Shear Zone (CSZ) and Salem Attur Shear Zone (SASZ, see Fig. 1 and Fig. 2). The region was also addressed as Salem Block.[18] Another study[2] had demarcated the terrain boundaries from the lineaments using the Landsat satellite Imagery. However, there is no literature available so far that discusses, the evolution of the terrain detailed geology, age of formation' as well as the metamorphism. Here we discuss the afore said aspects, its relation with other crustal fragments of the SGT.

2 Evolution of PCSZ- Previous Studies

Palghat-Cauvery Shear Zone (PCSZ) had been in the limelight since early 80s, ever since the evolution of southern India was investigated in a regional scale. Drury and Holt[20] and Drury et al.[21] presented one of the first detailed accounts on this shear system, based on lineament mapping from satellite images. These authors are of the opinion that the PCSZ is a dextrally moved post Archean shear zone. During the early 90s, Ramakrishnan[22] suggested the region to be a

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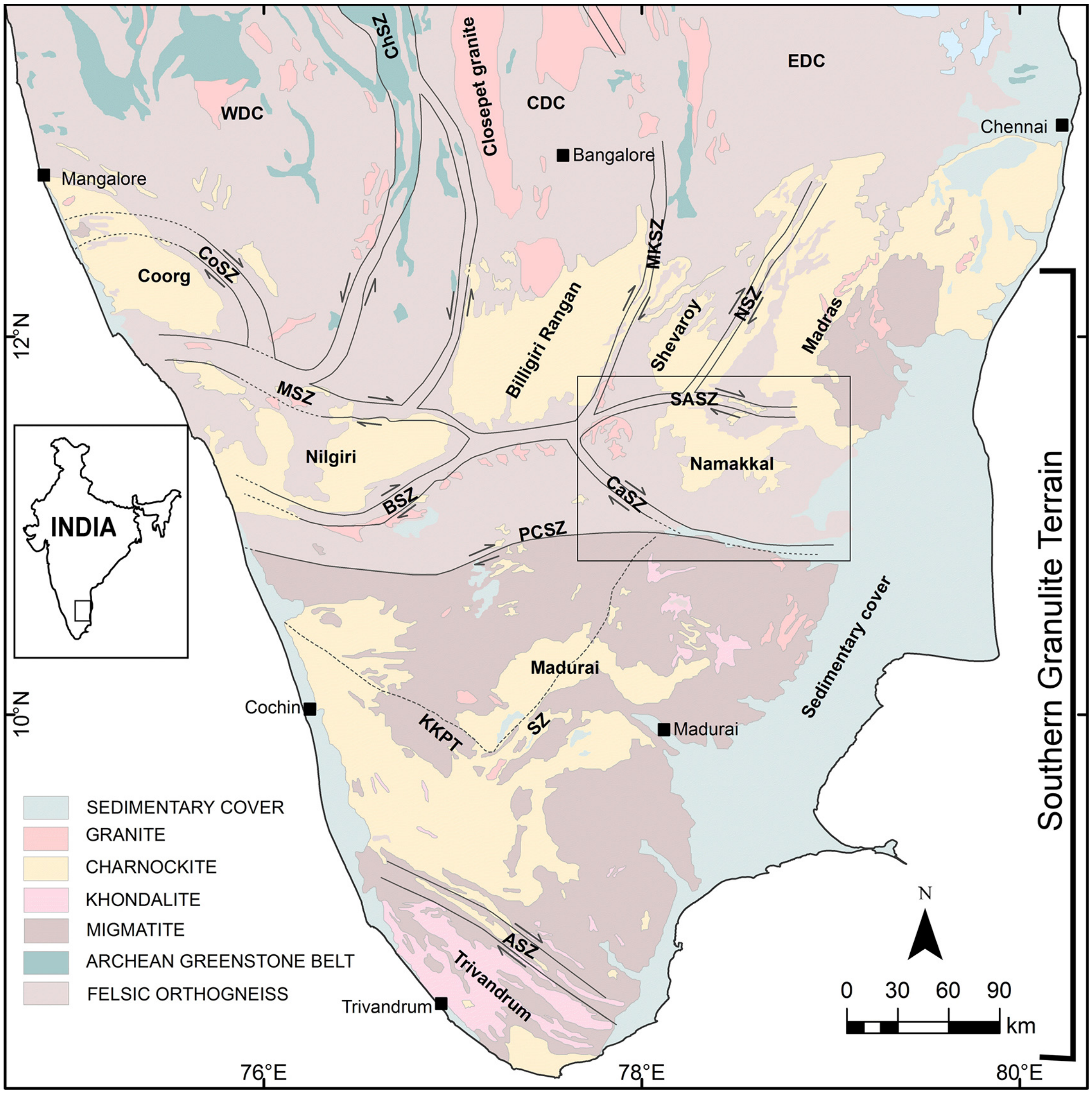

Figure 1: The geotectonic map of southern India (after Ishwar-Kumar et al.[3]). Location of the study area is shown in the map of India (inset). The grey box represents the study area. Acronyms: ChSZ—Chitradurga Shear Zone, MKSZ—Mettur-Kolar Shear Zone, NSZ—Nallamalai Shear Zone, MSZ—Moyar Shear Zone, BSZ—Bhavani Shear Zone, SASZ—Salem-Attur Shear Zone, CaSZ—Cauvery Shear Zone, PCSZ—Palghat-Cauvery Shear Zone, KKPT—Karur-Kambum-Painavu-Trichur shear zone; ASZ—Achankovil Shear Zone, WDC—Western Dharwar Craton, CDC—Central Dharwar Craton, EDC—Eastern Dharwar Craton.

central part of a mobile belt, namely The Pandyan Mobile Belt, similar to The Limpopo Mobile Melt in South Africa. However, later geochronological studies carried out to the north and south of the PCSZ[6,9] lead to the coinage of the name the Southern Granulite Terrain (SGT).[16] Harris et al.[23] considered PCSZ as the terrain boundary between Archean and Proterozoic terrains, based on isotopic data (Sm-Nd). One of the first publications on the ages (Sm-Nd whole rock and mineral model ages) of rocks of the PCSZ was presented by Bhaskar Rao et al.[6] through Sm-Nd whole ages from Sittampundi layered complex as ca. 2900 Ma and younger 800 Ma. According to these authors, the PCSZ represents a reworked Archean crust in the Neoproterozoic time. Later, Chetty and Bhaskar Rao[2] termed the PCSZ as a dextral-ductile shear transpressive zone exhibiting 'flower structure'. A later study[24] considered the Palghat-Cauvery Shear Zone as a Cambrian suture formed during Gondwanan amalgamation. This proposal was later elaborated as of 'Pacific type orogeny model' for the formation of PCSZ by Santosh et al.[25] According to this model a two sided subduction—beneath the southern margin of Dharwar Craton and the Madurai Block—during

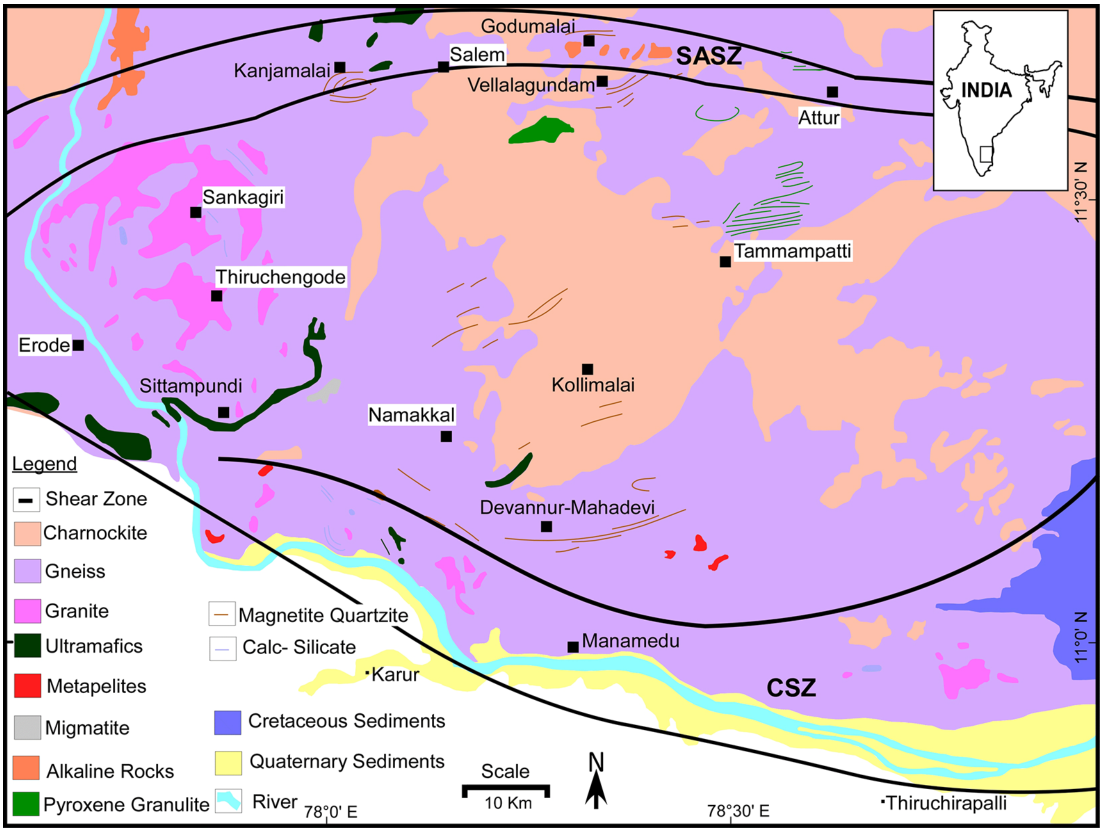

Figure 2: Detailed geological map of the study area (redrawn from Geological Map of Tamil Nadu and Pondicherry, Geological Survey of India[19]). Acronyms: CSZ – Cauvery Shear Zone, (SASZ is same as in Fig. 1). Major towns and the locations discussed in the text are marked with black filled squares. Inset: The study area is demarcated in map of India.

Gondwana amalgamation resulted in the formation of PCSZ. This view was also supported by Clarke et al.,[18] who reported the magmatism and metamorphism of charnockite from Salem Block as 2520 Ma and 2480 Ma respectively, which apparently indicates a subduction related magmatism and metamorphism in the Archean-Proterozoic boundary. Sajeev et al.[7] reported eclogite within the layered anorthosite complex from Sittampundi and interpreted it as an evidence for the presence of suture (*P-T* condition 20 Kbar and 1020 °C) during Gondwana amalgamation during the Cambrian period. Geochronological studies[26,27] on granulites from Kanjamalai region near Salem, within the Salem Attur Shear Zone (see Fig. 2) further confirms magmatism and metamorphism during late Archean. Yellappa et al.[28] and Chetty et al.[29] reported ultramafic-mafic sequence from the Manamedu located within the Cauvery Shear Zone (CSZ), which was designated as an Ophiolite Complex. Santosh et al.[30] determined the U-Pb age of the plagiogranite as 790 Ma and interpreted it as the remnants of the Mozambique Ocean, existed before the amalgamation of Gondwana supercontinent around 550 Ma. At the same time, Yellappa et al.[31] reported an Archean dismembered ophiolite (see description), namely the Devannur ophiolite, from the southern margin of the CSZ, which was dated (U-Pb zircon) as ca. 2520 Ma from Trondhjemite sample. These authors inferred it as the ophiolite complex, to have formed in an accretionary prism setting during collision when these continents were growing. The absolute age of the layered complex in Sittampundi was determined for the first time using U-Pb zircon geochronology.[32] Anorthosites of Sittampundi yielded magmatic age of 2530 Ma, and was metamorphosed around 2450 Ma. Geochronological studies from Kanjamalai on high-pressure granulites[8,33] also underscored Archean crustal formation and the metamorphism in the Paleoproterozoic. Anderson et al.[33] dated kyanite-garnet bearing granulite and inferred that the high pressure texture grew ca. 2490 Ma with *P-T* conditions 14–16 Kbar and 820–860°C. Similar *P-T* conditions were proposed earlier from the region.[5] Noack et al.[8] however, dated the garnetiferous mafic granulite from the region using Lu-Hf systematic from garnet and found that the peak metamorphism happened in the Paleoproterozoic around 2480 Ma.

The southern part of the PCSZ is also reported with the presence of Mg-Al rich granites which are younger in age. Massive plutons of granite have intruded into the hornblende gneiss of Sankagiri-Tiruchengode region, which occurs to the west of Cauvery Shear Zone. The age of this granite is determined to be ca. 550 Ma.[34] However, granites to the south have been dated as ca. 800Ma.[35] This shear zone is reported with Ultra-High-Temperature (UHT) assemblage such as sappherine-quartz in a rock with garnet-gedrite-kyanite-biotite-sapphrine-corundum granulite.[36–40] The presence of UHT metamorphism was, however, questioned by Raith et al.[10] These authors believe that the presence of corundum is by the dehydration of muscovite happening at around 800°C, and hence cannot be regarded to have undergone UHT metamorphism. From the above descriptions it is very evident that the PCSZ is a zone that has been affected by crustal evolutionary processes at least two times – by the end of Archean and during Neoproterozoic.

However, the extent of this shear zone and the Archean crust is debated.[17] Some of the previous studies (e.g. Bhaskar Rao et al.,[6] Ghosh et al.,[42] Tomson et al.[43]) are of the view that the Archean crust extends till northern part of Madurai block till the KKPT shear zone (see Fig. 1). This is based on the results from the geochronological studies from northern part of Madurai block, which yielded Archean ages.[34,44,45] However, the report of Cryogenian age (ca. 800 Ma) from layered complex in Madurai Block[34,46] are cited as evidence for Gondwana amalgamation in the Cryogenian.[25,30,47,48] Geophysical evidence also proves that the PCSZ is the terrain boundary.[49,50] These authors demonstrated that the PCSZ is a deep crustal feature and there are Moho-offset making the PCSZ an independent evolved crustal block from the adjacent crustal blocks.

3 The Kolli- Massif

We consider the region between Salem-Attur Shear Zone and the Cauvery Shear Zone as a separate crustal fragment namely Kolli-massif, having separate evolutionary history because of the following two reasons.

3.1 *Structural aspects*

The shear zones mentioned above are found to have converged near Bhavani. (see Fig. 1 and 2), As reported in the previous studies,[2,20,51] it is now evident (from Fig. 3) that the terrain had experienced multiple episodes of crustal deformation during and after its formation. In the shear zones, the rocks are highly deformed and are represented by mylonites or phyllonites (see Fig. 4) of granulite or gneisses with 'steep strain' zones (see Fig. 4). Apart from the shear zones SASZ and CSZ, there are also several structural lineaments in the region. A prominent feature known as the Gangavalli Shear Zone (GSZ) considered to be the continuation of Madras block and the Eastern Dharwar Craton (EDC), continues to the north of Madurai block till Karur- Kambam- Painav-Trichur (KKPT).[2,42,51,52] However, Chetty and Bhaskar Rao[2] consider folded structures in the region to be due to regional deformation – due to dextral transpression. These authors consider the lineament feature as structures as 'low strain zones' formed during the deformation, forming antiforms or synforms trending NE- SW, especially in the central and eastern part, and join major shear zones, and therefore, consider it as a part of positive 'flower structure'. Although we accept the structural deformation pattern proposed by these authors, the proposal of 'flower structure' is not wholly accepted as the lineament pattern that was disturbed by the intrusion of major granite pluton in the region, namely *Sankagiri Granite*, (discussed below). We however consider, the structural features as the ones formed during the regional metamorphism by the end of Archean. Notably there are no younger ages (than Paleoproterozoic) reported sofar from the region and also in our unpublished data.

3.2 *Crustal reworking*

Although the age of PCSZ remains equivocal – Archean or Neoproterozoic, it is now widely agreed and accepted that the PCSZ is an Archean crust that underwent several episodes of reworking till the Neoproterozoic[6,41] (see Fig. 5), as is also evident in the structural data observations (discussed in the latter part of this contribution). The reworking is widely reported in the southern margin of the CSZ.[10,30] Recently, studies were carried out on the derformed alkaline complexes from the northern margin of PCSZ along SASZ and MSZ.[47] According to these authors, the alkaline magmatism that happened in Cryogenian (ca. 800 Ma) is due to crustal recycling, as indicated by negative εHf values obtained from the zircons. Extensive crustal reworking is also evident from the occurrence of massive granite Neoproterzoic 34 pluton in the Sankari-Tiruchengode area, which is to the west of the Kolli-massif. Therefore, we consider the region having a Archean continental core and Neoproterozoic periphery.

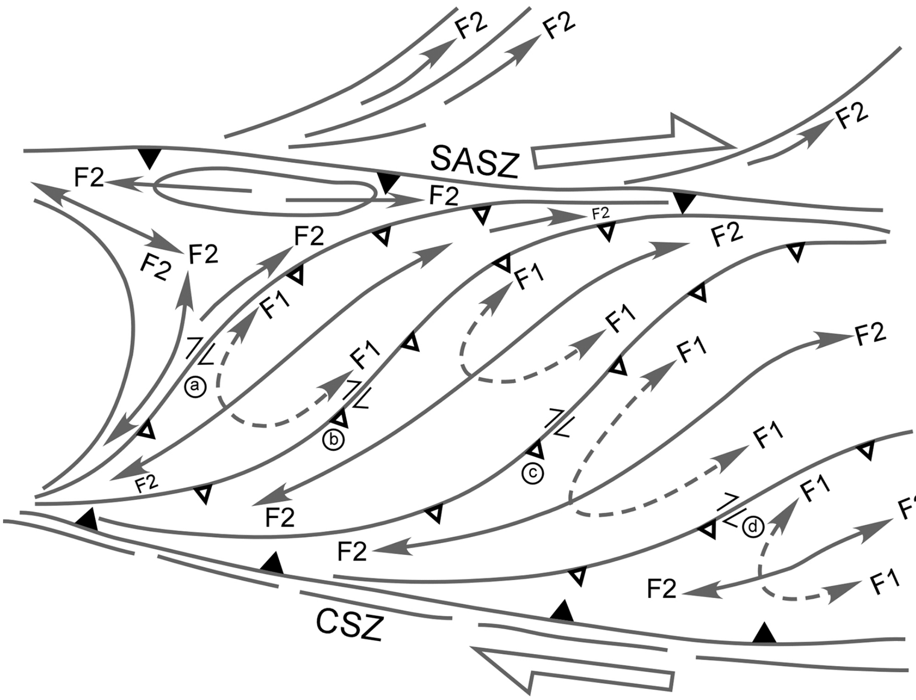

Figure 3: Structural deformation of the study area shown through lineaments and the boundaries of shear zones (redrawn from Chetty and Bhaskar Rao[2]). The folded lineaments (F1 and F2) show that the region has been deformed at least two times.

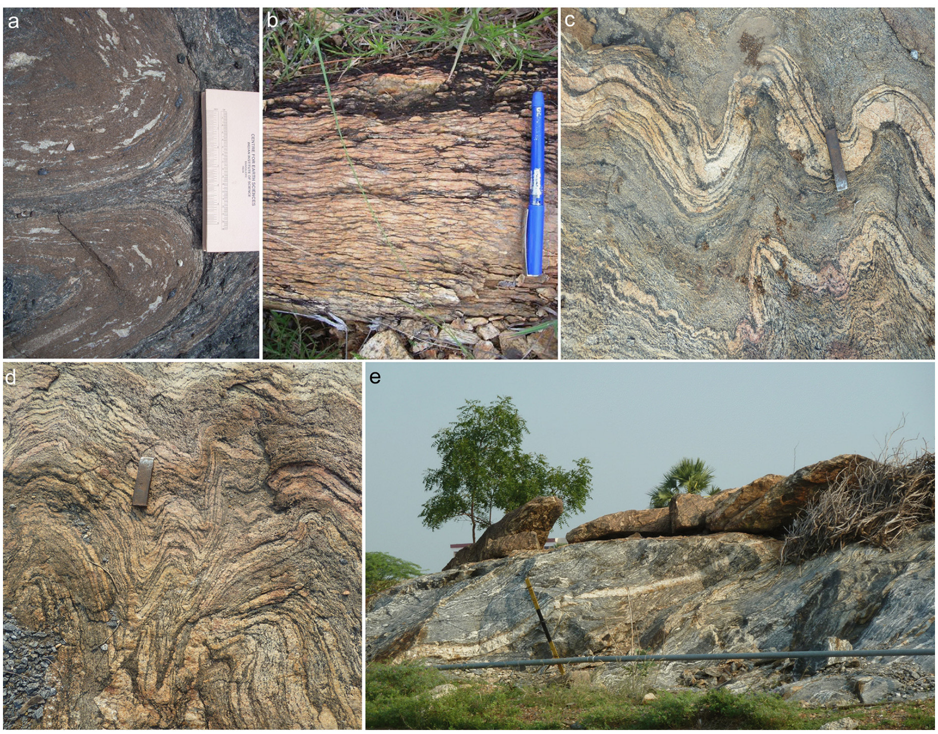

Figure 4: Exposures from the shear zone: a) folded quartzo-feldspathic rock near Salem in the SASZ, b) highly deformed rock near Godumalai, also in SASZ, c) exposure showing folded fabric in CSZ, d) highly folded and sheared fabric, also in CSZ, near Sankagiri, same location as in 1c, e) a view from the road at the same location. Note the multiple stages of deformation experienced by the rocks, represented by several folded structures.

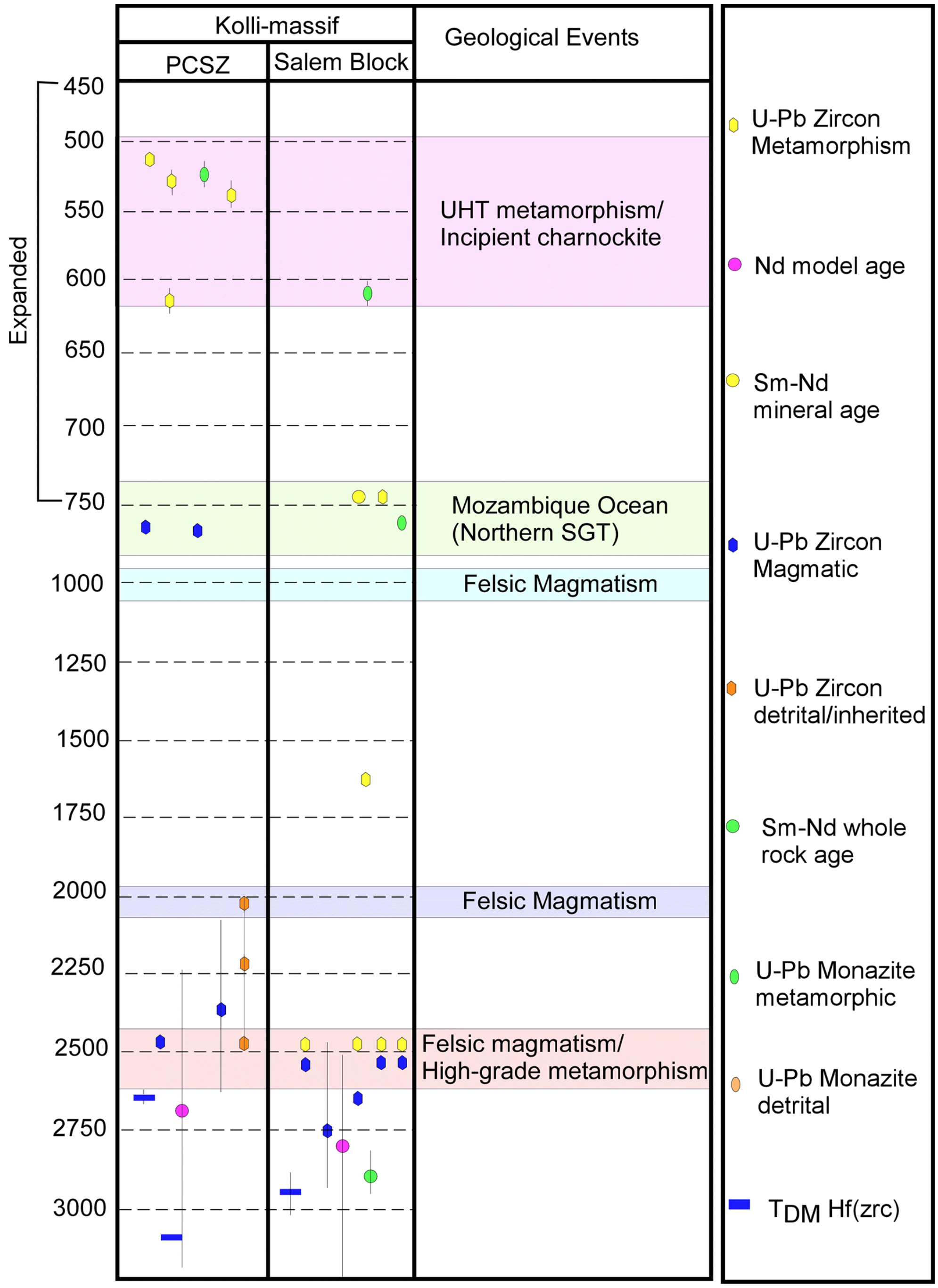

Figure 5: Compilation of the published ages of the study area along with major geological events (modified from Collins et al.,[17] details on references are same as discussed in the paper). The study region is discussed in the literature as PCSZ and Salem block, hence both the region are shown. Spread of ages shows that the region had experienced metamorphism (reworking) in Paleoproterozoic and the Neoproterozoic.

4 Structural Deformation and lithology of Kolli-Massif

Major structural component of Kolli-massif includes the shear zones and deformations during granulite metamorphism, which are discussed below. A detailed description on the lithology, including the age of formation and metamorphism (geochronology) of each rock type is followed.

4.1 *Salem Attur Shear Zone*

The Salem-Attur-Shear-Zone (SASZ) marks the northern entity of the Kolli-massif and extends between the towns of Salem and Attur over

100 kilometers long and 2–5 kilometers wide, with a general E-W trend. The shear zone is the reflection of two fault zones, i.e., Vellar fault in the north and Sweta-Nandi fault in the south,([53] and references there in) and stands as a divide between the charnockite hill ranges in Sheveroy, Madras, to the north and that Kolli-massif in the south. The major rock types of the region are quartzo-feldspathic gneiss (Fig. 4a), charnockite, pyroxene granulite and banded magnetite quartzite. All rock types are highly sheared, especially the quartzo-feldspathic gneiss that dominate the region. The rocks are crushed into mylonites (<10 μm) being subjected to high grade metamorphism and shows plumose structure under microscope. Phyllonites reported from the region[54] consist of crushed quartz, feldspar, sericite, muscovite and chlorite, and also display ductile shearing. The Salem Attur Shear zone is thought to have moved dextrally with respect to its surrounding blocks.[54,55] The age of this shear zone is considered to be late Archean with reports of ages from rocks found at Kanjamalai region that lie in the shear zone.[26,27]

4.2 *Cauvery shear zone*

The Kolli-massif is bounded by Cauvery Shear Zone to its south. It is considered to be the eastern flank of the Palghat Cauvery Shear System, which is 400 Km long and 70 Km wide. The general trend is E-W. This structural lineament is considered to be remnants of a suture formed by the disappearance of Mozambique Ocean during the final assembly of Gondwana during the Neoproterozoic.[25,30] Major rock types of this shear zone are hornblende gneiss (Fig. 4c-e) and granites. Parts of the CSZ are also reported with high Mg-Al granulites.[38,24,40,10] The evolution of CSZ is widely discussed in the literature, with respect to 1) dextral shear zone,[21] 2) suture zone[56,25,30] 3) Neoproterozoic terrain boundary,[23] 4) reworked Archean crust.[6,42] It is now widely agreed that the Cauvery Shear Zone (CSZ) represents an Archean reworked crust, as discussed before. There are evidences for multiple reworking in the shear zone from Paleoproterozoic (ca. 2480), Cryogenian (ca. 800 Ma) and Cambrian (ca. 500 Ma).

4.3 *Mafic- ultramafic suite*

The mafic- ultramafic bodies are found mostly along the Salem Attur Shear Zone and the Cauvery Shear Zone. However, three major occurrences can be found in the Kolli-massif, one in the north- at Kanjamalai, to the south at Devannur- Mahadevi region and to the south-west generally known as the Sittampundi Layered Complex (see Fig. 2).

Kanjamalai hills lie 12 kms south-west of Salem Town, having an isoclinally folded structure and is considered to be a part of Salem Attur Shear Zone. The major rock types of this region are websterite (±olivine), meta-gabbro, quartzo-feldspathic gneisses, banded magnetite quartzite and granite and little occurrences of amphibolites and leuco-granites.[8,5,26,57] The age of this complex is determined to be late Archean, with magmatic zircon U-Pb age of ca. 2500 Ma,[8,26,27,33] and thought to be metamorphosed ca. 2490 Ma.[32] Mukhopadhay and Bose[5] reported the region to have experienced *P-T* conditions close to eclogite-granulite facies (c. 15 Kbar and 850°C). Websterites have mineral assemblage as orthopyroxene + clinopyroxene + magnetite, while meta-gabbros have garnet + clinopyroxene + hornblende + quartz + plagioclase ± orthopyroxene. This sequence is interpreted as ocean floor stratigraphy;[30] a recent study,[8] however, presented evidences for the gabbros being produced at MORB like setting.

The region around Kanjamalai is also reported with isolated ultra-mafic bodies such as dunite, talc-schists, magnesite bodies, which are altered to form crysotile asbestos.[57] Deposits are well exposed in the quarries to the south of Salem. However, petrology and the tectonic significance of these formations are yet to be investigated.

Sittampundi layered Complex is situated near Namakkal town. A comprehensive study in the region, including detailed mapping was made by Subramaniam.[59] The major rock types here are peridotite (dunite), websterite, meta-gabbro, chromitite, amphibolite, anorthosite, and banded magnetite quartzite. The eclogites blocks within anorthosite are reported[7] with omphacite (Na_2O Wt. % > 4) formed under 1020°C temperature and 20 Kbar pressure. The age of the layered complex was first determined as ca. 2900 Ma through Sm- Nd whole rock isochron age[6] from mafic granulite (gabbro). Neoproterozoic ages was also reported from the complex ca. 730 Ma, based on garnet-plagioclase-hornblende Sm- Nd Isochron[6] from a garnet bearing granulite. Later zircon U-Pb age ca. 2541 Ma was reported from the anorthosite from the region.[32] Hf isotopes of these zircons yielded εHf positive values stating the source of magma as juvenile.[32] Another study by Dharma Rao et al.[60] on the chromite-silicate chemistry observed that the tectonic setting of the Sittampundi Layered Complex was subduction related arc magmatism.

The Devannur- Mahadevi region (see Fig. 2) marks the southern margin of the Kolli-massif in the margin of Cauvery Shear Zone. This region is also reported[30] with sequences of rocks ranging from pyroxenite-gabbro-amphibolites-pyroxene

Figure 6: Meta-gabbro exposure near Namakkal: a) Highly foliated gabbro, b) a garnet (brownish red) rich domain.

granulites and banded magnetite quartzite. Meta-gabbro present here (see Fig. 6) are more rich in garnet and amphiboles than in Kanjamalai and Sittampundi. The garnets are 3–5 mm in dimension in the microscopic view. The U-Pb zircon ages from the trondhjemite sample here yielded an age ca. 2520 Ma, and hence, designated as Archean in origin. Santosh et al.[30] regard this complex as Archean dismembered ophiolite sequence, formed in a supra-subduction zone setting, during accretion of continents.

Another sequence of ultramafic -mafic sequence was also found in Manamedu region in the margin of Cauvery Shear Zone with age Cryogenian (ca. 800 Ma) from the zircons recovered from a plagiogranite.[30] This is interpreted as remnants of closure of Mozambique Ocean prior to the amalgamation of Gondawana supercontinent around ca. 550 Ma, as discussed before.[25]

4.4 *Central charnockite massif*

Charnockites make the most dominant rocks of the Kolli-massif covering almost central to Eastern part. These rocks are found in contact with granite gneiss in the west and pyroxene granulite in the east, while few charnockite bodies are found in contact with the ultramafic - mafic occurrences at the shear zones. Our field studies show that the charnockites are massive without much intrusions (see Fig. 7). Petrographic observations revealed that the charnockites have mineral assemblages such as orthopyroxene + quartz + K-feldspars + biotite ± garnet. A major occurrence of charnockite are found in Kollimalai, which is also regarded as *Kollimalai massif*,[21] where the above charnockite are also found, i.e., garnet bearing and garnet absent. The garnets seem to have come/grown/appreared/produced out of the restite (pertitectic growth).

Ghosh et al.[42] found the age of these charnockites to be 2500 Ma (U-Pb single zircon, using TIMS). Tomson et al.,[43] however, determined the model age of the charnockite from Kollimalai as ca. 2800 Ma using Sm-Nd isotope systematic. Tomson et al.[61] characterized geochemically the charnockites of this region as tonalite, with high Na_2O and Al_2O_3, because of high plagioclase content. The negative εNd isotopic signature also proved that the charnockite magma originated from a middle crustal region due to crustal recycling. The magma composition of the charnockites from the region found that charnockites are high in magnesium as well as they are calc-alkaline in nature. The charnockites are also found to be formed due to subduction.[62]

4.5 *Gneiss*

The gnessic rocks of Kolli-massif can be classified as 1) quartzo- feldspathic gneiss gneiss, 2) hornblende biotite gneiss and 3) biotite gneiss.

Quartzo- feldspathic gneiss are mostly found in the north and north western part of the terrain, where it is found mingled/mixed with the mafic-suites, prominently in Kanjamalai, within the shear zones and the with the charnockites in the central portion. The mineral assemblage for this rock type includes quartz + Kfeldspar + plagioclase ± garnet. The gneissosity is rarely seen. The age of granitic gneiss was determined by Ghosh et al.[42] to be 2500 ± 17 Ma.

The hornblende-biotite gneiss is mostly seen in the south-eastern part of the massif. These rocks occur in contact with charnockite (down hills of Kollimalai, see Fig. 8) and the mafic-ultra mafic suites in the proximity of Cauvery Shear Zone in the south. As designated, these rocks have quartz-hornblende-biotite-Kfeldspar-plagioclase

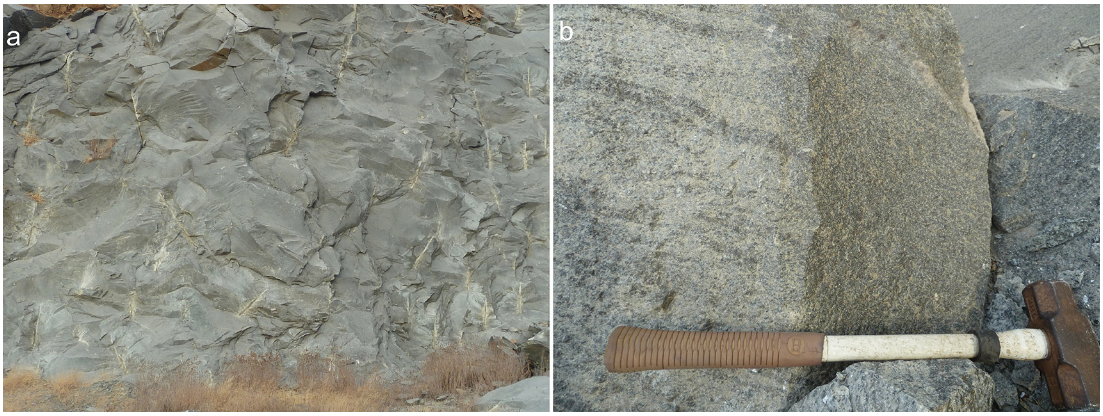

Figure 7: Exposure of charnockite in a quarry near Namakkal: a) Massive appearance on long view, b) closer view at the same location. Charnockite at this location shows garnet along the foliation plane.

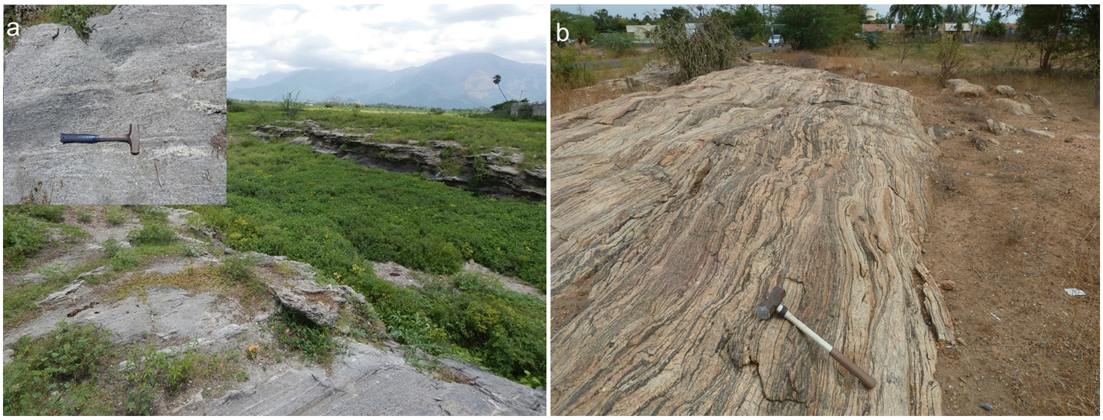

Figure 8: Exposure of hornblende gneiss at the southern flanks of Kollimalai (in the back ground): a) close-up view in inset, b) highly foliated quartzo-feldspathic gneiss near Sittampundi.

as mineral assemblage and have an E-W trending foliation. The U-Pb zircon age of this these rock is determined to be ca. 2500 Ma.[42]

Biotite gneiss is mostly found intercalated with the granites, and are seen as enclaves within granites. These are rich in biotite and have quartz along with k-feldspar and plagioclase in them. They have feeble foliation with east-west trending.

4.6 *Pyroxene granulite*

The pyroxene granulite are found in association with mafic-ultramafic in the block and suites as well as the charnockites in the east. At Kanjamalai, the pyroxene granulite is found to be in contact with meta-gabbro and the quartzo- feldspathic gneiss. At Tammampatti, pyroxene granulites are found as enclaves in charnockites or as isolated bodies within charnockites (see Fig. 9). The mineral assemblage of this rock includes quartz + clinopyroxene + orthopyroxene and k-feldspar. Ghosh et al.[42] reported the age of such rocks from an outcrop near Namakkal, having core age ca. 3000 ± 170 Ma and rim age around 720 ± 16 Ma.

4.7 *Younger granites*

The western part of Kolli-massif is found/ present with huge granite pluton, especially in and around Tiruchengode- Sankagiri area, which are considered to have formed by ca. 550 Ma.[34] Granites in Kolli-massif, not only in Sankagiri, are seen with biotite gneiss (see Fig. 10) as enclaves, and have been cut by several pegmatite veins, or some times by leuco-cratic granites. Granite bodies are also found in the south in the margin of Kolli-massif within CSZ, as isolated bodies with age 800 Ma.[32,35] The petrology of Sankagiri granites and its relationship with the granites in the south are yet to be constrained. Corundum bearing granites are reported with the Cauvery Shear Zone. The age of these rocks also are constrained to be Neoproterozoic 530 Ma.[10]

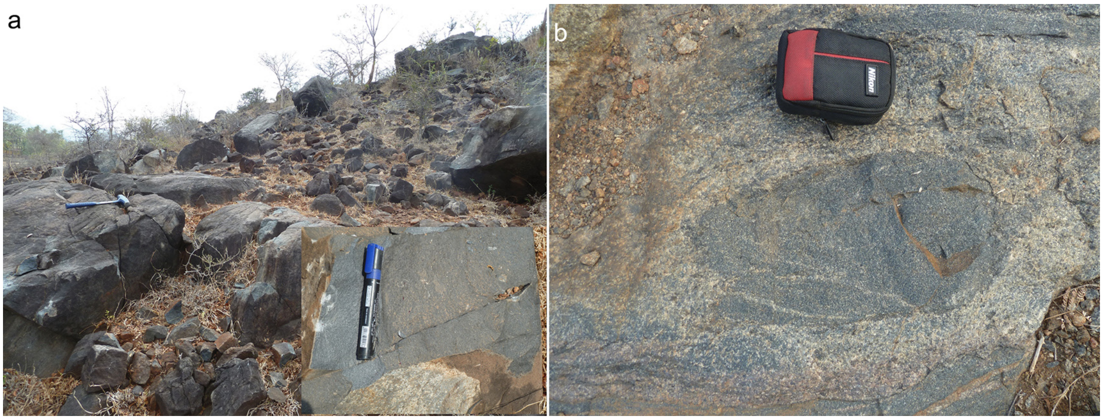

Figure 9: Exposure of pyroxene granulite, near Attur: a) Massive appearance of pyroxene granulite (close-up view in set), b) enclaves of pyroxene granulite in charnockite near Tammampatti.

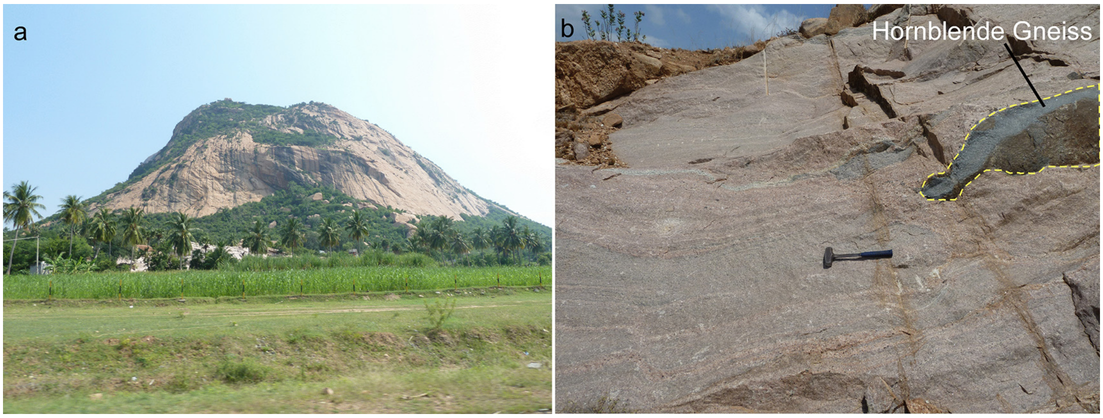

Figure 10: Granite exposure at various locations in the study area: a) granite bodies appears as massive plutons, a view from Sankagiri-Thiruchengode road, b) granite exposure enroute Manamedu from Namakkal, with enclaves of hornblende gneiss (demarcated in yellow dotted lines).

4.8 *Meta-sedimentary rocks*

4.8.1 Magnetite quartzite: The iron formations are found intermingled with the other rock types; however, the association varies from place to place. Over the years, there were only limited studies reported from the region, on the origin and evolution of iron formations.[57,63,64] In the field, they generally strike east-west direction and are found as long bands ranging from meters to kilometers with a width of ~1 meter. From the general field appearances iron formations can be well foliated or banded, feebly foliated or massive (see Fig. 11).

The iron formations are found in direct contact with high-pressure granulites or the pyroxene granulites in and around Salem, i.e., to the northern part of the block in several hills, which are reserved forests such as Kanjamalai, Godumalai and Vellalagundam.[64] Towards the centre of the Kolli-massif, iron formations are found mostly with charnockites. Long bands of E-W trending iron formations are seen as enclaves in charnockites (± garnet), especially around Kollimalai hills. A 19-km long band trending E-W is found across the Kolli-massif (see Fig. 2). Iron formations in the south Near Namakkal town are mostly associated with gabbros. However, the ones in the Sittampundi ultramafic complex are found in the proximity of mafic bodies. Iron formations are also found in the eastern side of the Kolli-massif near Tammampatti, where their associations are with garnetiferous charnockite and pyroxene granulite. Mineral assemblages also vary with locations as magnetite+quartz+orthopyroxene ± amphibole. A detailed study on the origin and deposition of these iron formation with its tectonic implications is yet to be carried out.

4.8.2 Calc-silicates: Several bands of calc granulites are found in the block associated with granites in the Sankagiri area. They are

Figure 11: Views of magnetite quartzite bands in the study area: a) at Godumalai, within SASZ, b) a band near Sittampundi.

also reported as a part of Sittampundi layered complex area.[59] Pristine calcite grains are also found in this rock. Not much is known about their significance or relationship with other rocks when the evolution of the block is considered. Sengupta et al.[65] reported formation of skarns and calc-silicates syngenetic with tectono-thermal events that formed the massive granite pluton in the region. These authors report that the skarn deposits are found at the intrusive contact of the granite and the marble, which were later folded several times during metamorphism. The mineral assemblages in the skarn deposits include wollastonite, clinopyroxene, scapolite and grandite, which might have formed due to the infiltration fluids rich in silica.

4.9 *Alkaline rocks*

Rocks with syenite composition are found to the northern part of Kolli-massif (See Fig.2). Alkaline rocks here are represented by syenites and shonkinite. Not much is known about the tectonic settings that gave rise to these rocks. However, recent studies on the alkaline complexes of southern India[47] report that these alkaline complexes represent rift setting happened between the continental blocks of the SGT. Considering the studies reported from the nearby alkaline complexes[66,46] within the Moyar Shear Zone, the age of these rocks should be around ca. 800 Ma.

5 Discussion and Implications

From the above descriptions of geology, structural aspects and geochronology, it is obvious that the Kolli-massif is an isolated continental fragment. This continental fragment was further subjected to various geological processes such as magmatism and metamorphism.[17] All these processes left imprints on the terrain, making the understanding of the geological evolutionary history very complex. Previous studies found that the structural aspects of the region are very different from the adjacent crustal blocks,[2] but never discussed alone on this the region having a separate geological history. A major reason is that PCSZ was considered to be formed during a major geological event such accretion of the crustal blocks[7,30,56] during Archean as well as the Proterozoic, and as a lower crustal manifestation of the Archean Dharwar Craton.[52] The possibility of PCSZ as an amalgam of reworked continental crustal fragments, including the Nilgiri block to the west, has never been discussed. Consequences or the impacts of such possibility has to be thought of, but is not the theme of this study.

Ingeology,massifisunderstoodas*topographically high part of the Earth's crust that is bounded by faults and may be shifted by tectonic movements*.[67] In case of the newly proposed Kolli-massif it is true that it is separated by rest of the SGT by SASZ and CSZ as discussed above. Along with the structural studies, the geochronological studies also support the above proposal. Together, structural and geochronological studies suggest the Kolli-massif has an Archean 'nucleus' which was reworked in Neoproterozoic from 800–500 Ma. Hence, Kolli-massif can be considered as a zone of crustal reworking as described by some previous studies.[6,42] All of the above discussions have been summarized in Figure 12.

The formation and evolution of Kolli-massif has major implications to the crustal evolution of southern India. Orogenisis are the key processes in the growth and evolution of continental crust all through the Earth history, and can be divided into a) collisional orogens, b) accretionary orogens, and c) inter-cratonic orogens.[68] Among the three, accretionary orogenesis has been responsible for the

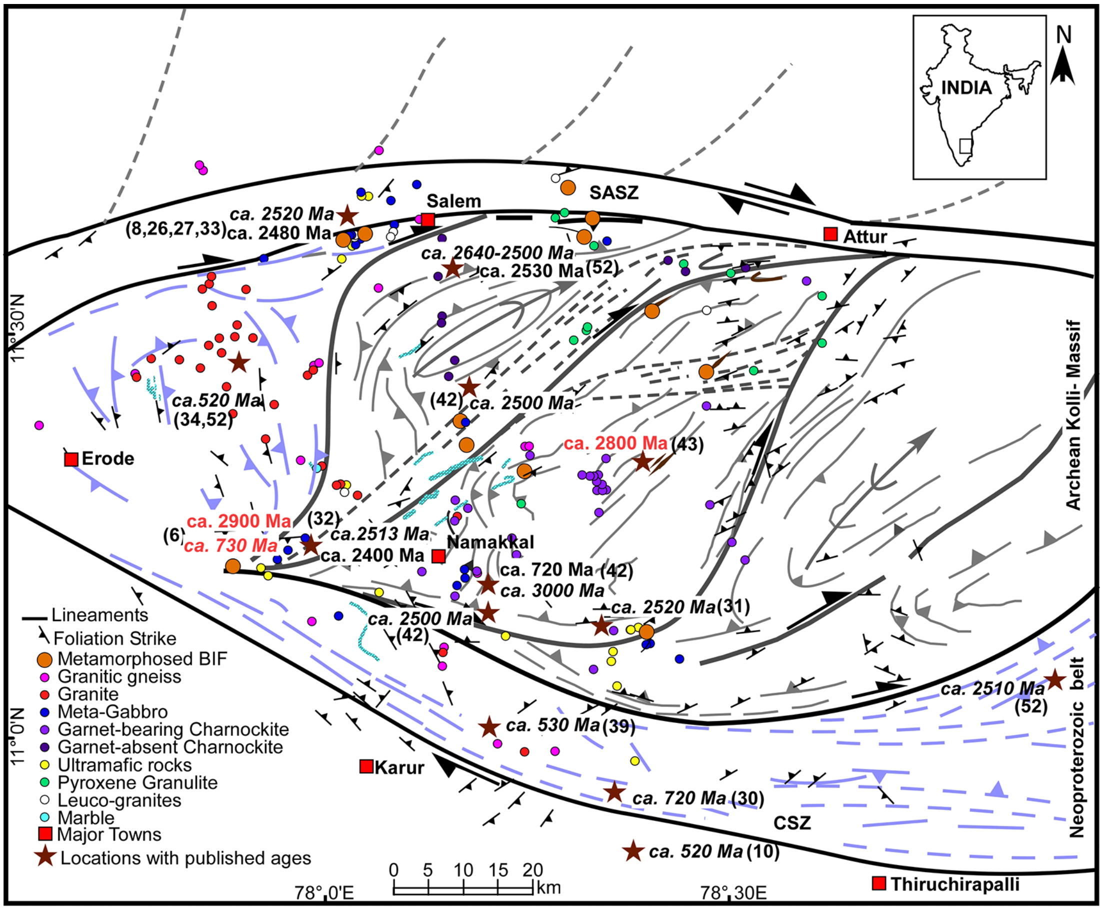

Figure 12: Map showing structural lineaments and shear zone boundaries of the newly proposed Kolli-massif. Shear zone boundaries are redrawn from Chetty and Bhaskar Rao[2]. Foliation strike and dip data collected from map from Geological Survey of India[19] and the data collected by the authors. Locations of sample collected by the authors are shown with respective colours in legend. Compilation of ages published in the Kolli-massif also shown (locations marked in filled star) with corresponding references in brackets. Ages in italics (black) are core ages, while other ages in black colour are rim ages. Red colored are whole rock Sm-Nd ages. Mineral ages are given in italics.

growth of continental crust ever since the Archean. For accretionary orognesis to happen, it requires horizontal interactions of the plate and the major crustal growth, and reworking happens at the plate margin through subduction. Arc magmatism resulting due to subduction is the major input material for the growth of crust apart from the plume. The geochemical and isotopic studies available from the Kolli-massif[30,32,43] suggest that the arc magmatism (modified magma) has been instrumental in the evolution of the terrain since the Archean. A recent study from the adjacent Nilgiri block[69] also suggests arc magmatism due to supra-subduction of the continent. Further studies on the neighbouring crustal sections would bring more insights in to the crustal assembly of southern India.

The reports of Neoproterozoic (ca. 550 Ma) reworking from the Kolli-massif suggest that it is a major site of the final assembly of the supercontinent Gondwana. Palghat-Cauvery Shear Zone is already proposed as a linkage between India and Madagascar.[3] The Betsimisaraka Shear Zone in Madagascar is proposed as the continuation of PCSZ, because of the similar geologic regimes. More investigations on Kolli-massif will bring more understanding on the continental correlations, especially during Gondwana amalgamation.

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