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An Overview of Structure, Deformation Style and Kinematic Analysis of Mylonites of Kanjamalai Region Salem District, Tamilnadu, India

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Abstract: various lithological structures have been studied with the help of previous surveys and many detailed explanation have utilized to get a clear representation. here the study demonstrates a methodology for identification of mylonites in Kanjamalai.
Keywords: Kanjamalai, mylonites, SGT,.

I. INTRODUCTION

The enigma of structure of Kanjamalai fascinates the geologists around the world, and also from the subcontinent. It possesses the records of geological events that have happened since 2.5 billion years before present. The tectonic setup of Kanjamalai puzzles the geoscientists, and hence an attempt is made to unravel the knot for reconstruction the stratigraphy of the region the structural study may supplement the available source of information about the natural resources of Kanjamalai and provide a better understanding on the evolution of Kanjamalai (Biswal et al. 2010).

Salem is a municipal corporation town in the Salem district in Tamil Nadu located in the southern most state of India. The study area lies between E780 to 7805' longitudes and N11035' to 11040' latitudes forms part of Toposheet 58 I/2 published by Government of India. The nearest Railway station is Salem Junction on Chennai-Erode Broad Gauge section of Southern Railway. Salem–Vridhachalam Metre Gauge passing through middle of the study area. The National highway namely NH-7, passing nearby the study area. The area is well served by motorable roads except some hilly terrains (Santosh et al.2009).

The maximum altitude of the area is 900m and the minimum altitude of the area is 200m.The area exhibits ridges, peaks, and valley and drainage patterns. The local geomorphology is controlled by the folding and faulting activities. High or steeply inclined slopes found in the area are profoundly affected by erosion and leaching. They resemble relict mountains. The drainage pattern is most probably radial and dendritic type, running along the fault planes (Biswal et al. 2007).

Erosion in stream valleys due to drainage takes the form of bank cutting, but bottom scour also occurs when the gradient is steep. Bank cutting is particularly noticeable on the outside bank at the beginning of the bends of the meandering streams. The visible mechanical load transported by a stream consists of material carried in suspension, saltation, and by rolling at the stream base, the invisible chemical load is the mineral matter carried in solution. Both sides of Kanjamalai displays detached hill ranges composed of high grade metamorphic rocks. The Salem district is situated in SE part of Tamil Nadu in India. The climate of Tamil Nadu is essentially tropical. The temperature in summer is normally 430 C and in winter below 180 C. Temperatures and humidity remains relatively high all year round. April and May are the hottest months of the year (Ramakrishnan, 2003).

In the present study, structure and deformation style of Kanjamalai which exhibits folding and faulting episodes. The area in Kanjamalai displays varieties of rocks like pyroxinite, HB- biotite gnessis, pyroxene granulite and eclogite. The Salem - Attur shear zone having different opinions because of lack of shearing evidences in hard rock terrain. The shearing evidences are not well developed around Salem area but some places shearing & mylonization are observed. The shear zone is very important for the understanding of the evolution history. The purpose is better understanding of shear zone through structural mapping, study of microstructures, stress analysis. These all help to make up whole story of Salem-Attur shear zone and disposition of Kanjamalai in relation to Moyar-Bhavani shear zone.

II. SOUTHERN GRANULITE TERRAIN (SGT)

The Southern India consists of the Archaean granite, greenstone rocks of Dharwar craton, Proterozoic rock of Cuddapah, and high grade Proterozoic rocks of Eastern Ghats high grade Archaean-Proterozoic rocks of Southern Granulite Terrain (SGT) also known as the Pandyan Mobile Belt (PMB) in the south and the cretaceous igneous rocks of Deccan Trap. The southern Granulite Terrain (SGT) Of India covering almost 2x100,000sq.km area, to formed major "Charnockite region" (Ramakrishnan, 1993) which are covering entirely Tamil Nadu, Kerela and some part of Karnataka. Fermor was the first to divide Indian Peninsular shield into "charnockite and Non charnockite" Regions, prior to that both were grouped together as the Archaean "Dharwar system". The charnockite were considered as early intrusive into the schist and gneisses while all granite were considered later intrusive, equivalent to the Closepet Granite and gneisses were regarded as basement of supracrustals correlatable with the "Peninsular Gneissic Complex" (PGC).

Fermor (1936) suggested that the Dharwars of this area form a part of the iron ore regions of charnockite division. The ferruginous quartzites are the oldest member in this region. They occur as distinct bands which were folded in the form of syncline. These were intruded by ultramafic magmas which have given rise to pyroxenite and amphiboles which now occur as detached patches in the younger eclogite gabbro complex. These Dharwars were again subjected to gabbroic intrusions which have subsequently been metamorphosed to eclogites. Later, the whole area was intruded by large masses of granites in which the earliest mentioned basic members of Dharwars occur as caught-up pockets and patches.

III. DHARWAR CRATON

The SGT is separated from the Dharwar Craton by the orthopyroxene isograd known as the Fermor line. However, there exists a narrow transition Zone along which the low-grade greenstone granite domain transforms to high-grade granulite facies rocks (Swaminath et.al., 1976). The SGT is composed of rocks of two different ages, the northern; part is of Archaean age and the southern part (PMB) is of neoproterozoic age. Charnockite, basalt, calc granulite, anorthosite, nepheline syenite and carbonatites are the typical rocks of the granulite terrain. The area is made up of high grade supracrustals of Archaean age comprising Khondalite Group, Charnockitte Group and Satyamangalam Group and younger intrusive alkaline syenite-carbonatite complexes, ultramafics, basic & acids rocks. The Khondalite group occurs as dismembered parallel lenses of varying width and length in Attur valley. It comprises garnetiferous Sillimanite gneiss and graphite bearing quartzofeldspathic gneiss as interbands within charnockites (Mohan and Jayananda, 1999). The Charnockite group occupying the eastern& central parts of the Salem district includes charnockite, pyroxene granulite and banded magnetite quartzite. The charnockite in the kolli hill and Shevaroy hill is altered to bauxite & laterite. A number of shear zones traverse E- W trending foothill of the kolli Malai. Pyroxene granulite bands associated with magnetite quartzites occurs as interbanded sequence with charnockite and form good marker in deciphering the structure of the area as seen around Attur. The Satyamangalam group of rocks comprising fuchsite quartzite and amphibolites occur in a linear zone surrounding the Sankari dome.

The lithounit occurs as dismembered lensoid in the fissile hornblende gneiss, known as Bhavani gneiss, and in the granite. The Meta pelite occurs as band rich in garnet, kyanite, and sillimanite, interlayered with limestone bands. These bands are fine to coarse grained, whitelight grey and yellow crystalline in nature occurs northeast of Pudupalayam & east of pallakayam. The limestone bands at pudupalayam are extensively quarried. Alkaline Carbonatites complex trending in NE-SW direction consists of Pegmatite syenite, Gneissic syenite leuco-syenite, porphyritic syenite, Pink coarsegrained syenite, corundum syenite & Carbonatites. In Sankari area, Upper Proterozoic to lower Proterozoic granite is emplaced into the Bhavani Gneissic complex and Satyamangalam group (Mukhopadhyay et al 2001). Pegmatite is most abundant in western part of Salem, especially around Idappadi and Jalakandapuram. The thin olivine dolerite dykes are reported around Kinattuppalayam and Reddipalayam. Dolerite dykes trending NE-SW, ENE-WSW and NW-SW direction are dominant in the Attur valley. Krishnan and Aiyengar (1944) studied the area between Talamalai on the south and Ponnaiyar River on the north, Pachamalai on the east to Kanjamalai on the west. In support of King and Foote view, additional bands were discovered samples were collected and analyzed in the Presidency College, Madras and Calcutta.

IV. LITHOLOGY

A wide variety of lithologies including pyroxenite, amphibolites, banded magnetite quartzite, garnetiferous metagabbro, ultramafic and vast areas of quartzofeldspathic gneiss hornblende-biotite gneiss, granite gneiss, quartzite, represent different stratigraphic units of diverse ages in various tectonic blocks surrounding the study area. Madic granulite, quartzofeldspathic gneiss and amphibolites constitute the major rock types. Presence of gneiss and supracrustal rocks within the highlands is rare. Moyar Bhavani shear zone is marked by intense development of mylonite, mylonitised and granitoids intrude the quartzofeldspathic gneiss, magnetite quartzite of Kanajamalai. Dark coloured mafic enclaves, now occurring as amphibolites, are either intensely folded or sheared along with the country rocks. Irregular infolded patchy outcrops of garnetiferous sillimanite-cordieritegneiss/schist, amphibolites, quartzite, marble and calc silicate (e.g., Madikkarai area) are seen within the gneiss and constitute supracrustals of diverse ages. Most of the sequences within the gneisses, trend regionally E-W in contrast to the N-S trending supracrustals belts within the Peninsular Gneiss.

V. PETROGRAPHY OF KANJAMALAI

A. Mylonite

Mylonite is a term coined by Charles Lap worth in 1885 (Barker 1990) to describe a fine grained, well-laminated rock he had found in the Moines Thrust Zone of the Scottish Highlands. (Tulles et al. 1982) The term has come into general usage to indicate any foliated (and usually lineated) fine grained metamorphic rock which shows evidence for strong ductile deformation. Mylonite zones can be found in rocks of all ages, from Archean to present. These zones can be of almost any scale. Some, like those which cut through the granite in the Sierra Nevada, are only a centimeter wide. Others can be much larger, such as the mylonite zone found in the Canadian Shield, which are many kilometer thick and hundreds of kilometer long. Mylonite zones can also be found in all tectonic settings. They are present on all three types of plate boundaries as well as in plate interiors (Tullis et al. 1982).

Many metamorphic rocks can be characterized by their texture. Some are classified as S-tectonites and others as L-tectonites. S-tectonites have pronounced foliation, a planar texture. L-tectonites have pronounced lineation, a linear texture. Mylonites are classified as L-S tectonites, because they display both types of texture (Barker 1990). As well as having two types of textures, mylonites have two types of constituents, matrix and porphyroclasts (Passchier and Trouw, 1996). The matrix is composed of the more ductile elements of the rock. This part of the rock appears almost fluid, flowing through the rock like molasses. The porphyroclasts are the more brittle elements of the rock, they do not appear to be a flowing stream of rock, but are rather like small lumps of crystallized sugar in the molasses. A true mylonite will be composed of 10-50% porphyroclasts (Spry 1696). Within the category of “mylonite,” there are many different forms a rock can take. Each of these forms receives its own name. Some of these types of mylonite are:

B. Primary mylonite

A mylonite which formed during only one metamorphic episode.

C. Secondary mylonite

A mylonite which shows evidence of multiple metamorphic episodes.

D. Protomylonite

A rock that began, but did not complete, the transition from micro-breccia to mylonite. These rocks have 10 - 50 % crushed matrix

E. Ultramylonite

A mylonite that contains over 90% matrix, or less than 10% porphyroclasts.

F. Blastomylonite

A mylonite in which late recrystalization is so pronounced that the original cataclasticnature may not be recognizable,

G. Layered mylonite

A mylonite with pronounced compositional layering that was developed by metamorphic differentiation during deformation.

H. Hyalomylonite

A mylonite which contains glassy materials produced by melting during the deformation of the rock. This type of mylonites is nearly synonymous with psuedotachylyte.

I. Phyllonite

A rock that is a combination of a phyllite and a mylonite. It is a phylitic rock that was formed from a coarser grained protolith by mylonitic metamorphism (Spry 1969). The mylonite of the study area is composed quartz and feldspar essentially, and sporadic occurrences of hornblende and biotite minerals help them to classify as hornblende biotite gneiss. This gneiss is the equivalent of Bhavani gneiss and show higher order of deformation or multi phased deformation.

VI. STRUCTURE OF KANJAMALAI:

An irregular depression is found on the east of siddhar koil, and this depression is backed by the main mass of Kanjamalai in the easterly direction. A low broken ridge forms the northern boundary of this depression while “Chinna Kanjamalai” (Small

Kanjamalai) is its Southern boundary rising to heights of 200 to 300m forming the continuation of the main ridge of the mountain. The slope on the northern side is somewhat gentle and has less vegetation. Contrary to the northern slope, the southern slope of the hill is clothed thickly with thorny bushes and shrubs. The slope is steeper and scarred by ridges and valleys, thus presenting a diversified morphological aspect. Kanjamalai, by virtue of its situation, stands out as a gigantic hill on the plains of Attur valley. The bold relief of the flanks of the hill exhibits dark bands which stands out as ribs.

The first detailed account on the structure and geology of Kanjamalai was given in by king and Foote (1864). They interpreted the structure of Kanjamalai as a basin and dunite pockets with veins of magnesite regarded as the later intrusive in the earlier gneisses. Some sort of dislocation is of noticed near Siddhar Koil adjacent to dunite.

The formation at the northern slope trends E-NE and W-NW till the bend of the mountain is reached where they trend almost in an E-W direction. The formation along eastern and western flanks trend generally in north- south direction. In all cases they dip towards the mountain, the amount of dip varies from 60^0 to 90^0. Rapid variation is noticed in the amount of dip of the iron ore bands along the northern portion of Kanjamalai. There is a small anticlincal Structure exposed on the north eastern foot hills of Kanjamalai.

The appearance of anticlinal structure at the border can be explained owing to the intrusion of dunite and later granites. The force of intrusion might have buckled the northern limb of the already folded syncline. The plunging nature of the syncline is further supported by the outcrop pattern on the eastern end of the foot hills. Here the outcrops on either side of the flanks are not connected up around the terminal slopes, but they are separated by the country rocks. This is an avidence for the easterly plunge of the fold axis. In some cases, great difficulty is experienced in ascertaining the dip from lineation direction on a more or less elliptical and rounded surface of the area. Siddhar Koil is situated on the north-Western foot hills. Here the hill shows clearly that the rocks around the place are eroded away to give a notch like look to the land. The tall cliffs, south of the hill shows scarps of the prominent rock bands. The iron ore bands of these western peaks suddenly end in this cliff. Above all, east of this area is depression, there is a dunite intrusion.

This dunite instrusion is in line with the chalk Hills (North-East of Kanjamalai) and this was observed from the top of the shevaroys. Hence it is assumed that the north western part of the hill around Siddhar Koil was uplifted by the dunite intrusion. In this process the plunging structure of Kanjamalai seems to be disrupted but broken up owing to faulting. The absence of the iron band in this area is easily explained as due to the erosion of the uplifted masses.

The evidence for the dunite intrusion was also very well observed in Nagaramalai, northeast of Kanjamalai. The dunite of the southern portion of the Chalk Hills (near Nagaramalai) has been reported to cut across the country rocks including the garnet pyroxene rock bands. The separation of originally adjacent point on the bands is now more than half a kilometer apart separated by the dunitic intrusion.

The gneisses occur extensively in the plains and often carry variegated lenticular, patches of older rocks and often show interaction along their contacts with older rocks which has given rise to migmatites. The formationof these peninsular gneisses have brought about certain retrogressive changes in all the older igneous members of Dharwars.

Granites, pegmatites, and aplite veins are very scarce and outcrop predominantly along the disturbed zone of the North-Western portion of Kanjamalai. The intrusion of these youger granites further induced retrogressive changes in older Dhaarwarian rocks. Dolerities are very rare and petrologically unimportant by the absence of its differentiated members. The general structure of the study area is doubly plunging syncline fold with the fold axes F1, F2 and F3.The associated rocks characteristically exhibit “Ptygmatic fold” compression structure. Fold and faults often occur together, and small folds often related to drag effects along the faults in this area, most of these combinations occur in the area near Veerapandi, Sevampalayam, and near Perumampatti.

1) The maximum stress axis is in the N-S direction and intermediate, minimum stress axes are E-W and vertical downwards.
2) The later folding activity is directed in SE and SW directions, which is the direction of maximum stress axis.
3) F3 fold axis is represented in the same direction as the F2 axis, this type of folding activity is responsible for the ptygmatic folding commonly found in both BIF and associated rocks.

VII. STRUCTURAL PATTERN ALONG FAULT:

The characters of many strike slip and normal faults are visible in the areas, in and around Veerapandi, Sevampalyam, and perumampatti. Establishment of strike-Slip displacement on faulting is most conclusive when linear features are cut and displayed by the fault. The movements have taken place near Sevampalayam, Veerapandi, and perumampatti. Lateral displacement in the BIF is noted by physiographical effects i.e., Stream terrace deposits.

VIII. KINEMATIC ANALYSIS OF MYLONITE

The discipline of structural geology harnesses three interrelated strategies of analysis: descriptive analysis, kinemetic analysis, and dynamic analysis. Descriptive analysis is concerned with recognizing and describing structures and measuring their orientations. Kinematic analysis focuses on interpreting the deformational movements responsible for the structures. Dynamic analysis interprets deformational movements in terms of forces, stress, and mechanics. The ultimate goal of these interdependent approaches is to interpret the physical evolution of crustal structures, that is, tectonic analysis. A major emphasis in modern structural geology is strain analysis, the quantitative analysis of changes in size and shape of geologic bodies, regardless of scale.

A. Field observation

The Kanjamali area is 15 Km away from Salem town in SW direction. The traverse was taken along the northern and southern sides of Kanjamalai. The mylonite shows well developed stretching lineation which is down dipping. Along the foothill, lineation measured shows amount 650-850- towards NE-SW direction. At another location on the easternside of the hill pitting for water storage has exposed mylonites with southerly dip. The foliation plane shows NE-SW trend rather than plunging as described by previous workers. Many sheath folds were observed lying parallel to the original strike of the foliation.

Mylonites are highly weathered, sheared and intruded by pegmatite& quartz veins, one has trend nearly E-W & another N-S direction. The mylonite contains porphyroclast of quartz & feldspar with quartz ribbons. In this outcrop, small pyroxene porphyroclast occur within the mylonites shows right lateral shearing. The S-C angle measured 320 towards SW direction. One set of joint are observed, shows trend 350-400 dipping 700- 720 towards SE.

B. Small scale structures

The mylonites are marked by penetrative ENE-WSW Gneissic fabric (S1) which is axial planar to a set of isoclinals recumbent folds (F2) that have folded the primary foliation (layering). Another set of recumbent folds, though more open than the former, have folded the gneissic foliation within the shear zone and shear fractures (C- fabric) are developed parallel to the axial plane of such recumbent folds along ENE-WSW directions. These folds are identified as SF1 folds and explained to be developed on the gneissic bandings of the geneisses during shearing. The gneissic fabric (S1) and the C-fabric are involved in open to tight upright F2 Folds along E-W direction. The mylonitic foliation is marked by lineations in the form of grooves and ribs which are more akin to ductile slickenside striae (Lin et al.2007) than stretching lineation. However, the trend of the ductile slickenside striae and the stretching lineation is parallel in the study area. Hence the term mylonitic lineation is used hereafter to describe these linear features. The mylonitic lineations have a low plunge towards NW are subhorizontal in that direction on subhorizontal C-surfaces or parting planes. However, where the linear features are folded by F2 folds, the lineations plunge down dip on F limb in these situation, the F2 fold axis and intersection lineation produced from the intersection between S2 and S1, S2 and C fabric are subhorizontal. Thus two types of lineation namely mylonitic lineation and intersection lineation, coexists at several places. F2 folds show plunge reversal and at places they are vertical. In such localities, the intersection lineation and fold axis become vertical while mylonitic lineation remains horizontal. Therefore it is quite difficult to distinguish these two sets of lineations purely based on orientation. At several localities, *pseudotachylites* occur as millimeter to centimeter scale dark coloured bands or veins along fractures in the mylonite. At places they occur as angular patches and are cut by; close spaced fractures. In handspecimen and at the outcrop scale angular clast fragments of charnockitic composition set in a dark colored matrix could be identified within the pseudotachylyte. Under the microscope microlites are identified. Formed the bulk chemistry determined by XRF, the pseudotachylites are inferred to have been formed as a result of nearly complete melting of the former quartz, feldspar, pyroxene and mica dominated rock.

C. Micro fabric study of Mylonite

The microfabric analysis of the mylonites was carried out on thin sections oriented parallel to the mylonitic lineation and perpendicular to the foliation, which is referred as the "*Vorticity Profile Plane*" (Passchier and Coelho, 2006). The clasts are dominantly alkali feldspars, which have undergone both plastic-cataclastic deformations. Hence many feldspar porphyroclasts are observed along the mylonitic foliation. The porphyroclasts show rotation indicative of dextral top-to-the-NE sense of shear. Microfaults inside the feldspar porphyroclast, as they are at high angle to "C" planes, show sinistral shearing antithetic to main shearing. In phyllonites, hornblende fish are observed showing distinct tails that also suggests dextral top- to- the- NE sense of shear. In addition to these, S-growth of mica and polygonized thin quartz ribbons while the S-fabric is defined by an oblique growth of quartz and biotite to C-fabric. The angularity between S- and C- suggests a thrust slip shearing. This is further sustanined by asymmetric folds developed in the quartz ribbons where the S-fabric remains axial planar to the folds.

D. Large scale structures

The Salem- Attur shear zone has been mapped in detail in Kanjamalai area. The Salem- Attur shear zone passes within the mylonite and trends in an E-W direction. Due to extremely weathered character, the shear zone occupies low lying topography. A stereogram of foliation poles shows the E-W strike distributed on a girdle. This is because of F2 folding which has anaxial plane striking E-W and a^-axis plunging to WSW. The lineations plunge due E or W. This suggests that in this area, the lineations are more uniform.

E. Tectonic Implications

Considering all these observations, an attempt has been made to interpret the kinematics of the Salem-Attur shear zone. Where the mylonitic foliation is subhorizontal, it shows northeasterly oriented lineations. This implies that the Salem-Attur shear zone is a northeasterly verging subhorizontal thrust (Biswal et al.2010). The overprinting of the gneissic foliation by a mylonitic fabric suggests that the thrusting event postdates the granulites facies metamorphism, so that the mylonites were uplifted due to thrusting. The thrust zone is fairly wide with splays that branch and rejoin, encompassing lenses of low strain myloniteic blocks within the mylonites. Since the thrusting developed on a well banded mylonitee, Shear Folds (SF1) are developed on the bandings due to buckling instability followed by shearing, and subhorizontal shear fractures are developed parallel to the axial plane of the folds . Subsequently, the thrust plane was folded by E –W trending upright fold (F2) which had resulted in variation in attitude of the thrust plane and mylonitic foliation. Thus the mylonitic foliations show dip variation from north to south, the mylonitic lineations are also folded to show down dip plunge where the myloniric foliation is steep. Superimposition of F2 fabric on mylonitic zones has complicated the interpretation of shear sense indicators. This is reflected in the earlier work where various models have been suggested for the Salem- Attur shear zone. In our work we have attempted to isolate the effect of late stage folding, in order to interpret the early structural history.

IX. CONCLUSION

The Salem granulite terrain is unique by its location on the transition of greenstone belt of Dharwar and younger granulite terrain. The complexity of the structure arises since the region has undergone many phases of deformation. Still the clear field observation with substantial petrography study will through light on the nature of shearing involved. The region is mainly covered with mylonite and banded iron formation. The mylonites contain very good porphyroclasts. The clasts are‘d’ type and clearly indicating a dextral sense of shear. In light of this finding it is proposed that the Salem-Attur shear zone probably represents a basal devolvement along which the Southern Granulite Terrane or Pandyan Mobile Belt was thrust over the Northern Granulite Terrane. The large scale folds observed on the overlong mylonitic rocks around Salem area are produced during thrusting. The underlying granulites have also deformed, thus suggesting a thick skinned fold thrust belt model for the thrust front. This study has considerable tectonic implications because the Salem block is considered to be a foreland fold-thrust belt created during collision of northern and southern granulite blocks. It is possible that the Salem-Attur thrust front joints with Terrane Boundary shear zone of the Eastern Ghats Mobile Belt in the east, thereby forming a continuous thrust front for the Proterozoic mobile belts in the Indian Peninsula. This boundary may belong to Pan-African age as indicated by the nepheline syenite plutons of the Terrane Margin of the Eastern Ghats. Moreover the Kanjamalai formation has been dragged and stretched by the dextrally sheared Moyar-Bhavani Shear zone. Where the eastern side iron ore bands are thrown into boundins the thickness expected by the earlier workers may vary. The general trend in the eastern side also was not plunging as if it was reported. Still tracing a marker bed would clearly give an idea on structure of Kanjamalai.

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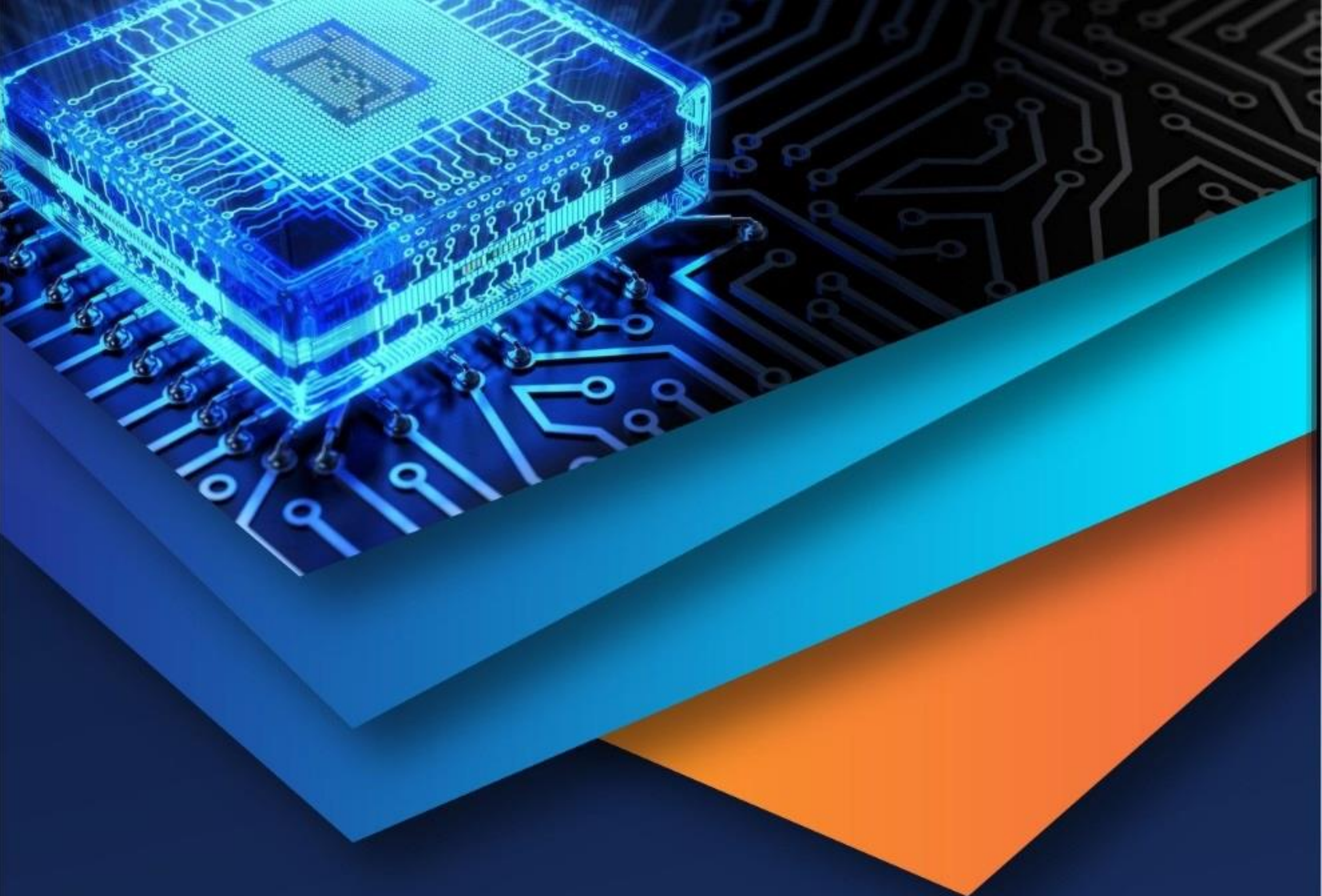

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