Chapter-3

SEDIMENTOLOGY

3.1 General:

In this chapter, various petrographic, viz mineralogical and textural studies of different quaternary sediments representing microenvironments from the area under investigation have been presented. An important aspect of sedimentological studies for depositional environmental analysis is determination of size, shape and mineralogical analysis.

In mineralogical studies, heavy mineral analysis has been carried out; while in textural studies, size and shape analysis have been undertaken to know the interrelationship and variations in these characters, to understand the nature and mode of transport and nature of source rock.

Heavy mineral sands are a class of deposits which is an important source of zirconium, titanium, thorium, tungsten, rare earth elements, the industrial minerals diamond, sapphire, garnet, and occasionally precious metals or gemstones. Heavy mineral sands are placer deposits formed most usually in beach environments by concentration due to the specific gravity of the mineral grains. Heavy minerals have a specific gravity of more than 2.889. They are the secondary minerals, liberated from the primary source rocks by the action of various agents. It is equally likely that some concentrations of heavy minerals (aside from the usual gold placers) exist within streambeds, but most are of a low grade and are relatively small.

The source rocks which provide the heavy mineral sands determine the composition. The source of zircon, monazite, rutile, sometimes tungsten, and some ilmenite is usually granite. The source of ilmenite, garnet,
sapphire and diamond is ultramafic and mafic rocks, such as kimberlite or basalt. Garnet is also sourced commonly from metamorphic rocks, such as amphibolite schists. Precious metals are sourced from ore deposits hosted within metamorphic or igneous rocks.

### 3.2. Sampling:

The sampling stations were fixed by taking forward bearings to the reference stations shown in the Toposheet (Fig: 3.1 and Table: 3.1). The entire length of Karaikal coastal stretch 18 km was traversed for sampling in such a way to obtain 68 samples from layer by layer at, maintaining a sampling interval of about 1 km. Maximum depth of 5.5 feet was covered for sampling and the samples were collected from the trenches excavated at a distance of 150 to 250m from the shoreline (Plate: 3.1 A, B, C, D) and showing various thickness of heavy mineral layers. The sampling interval was changed in some places to collect samples right in the confluence points of the tributaries and rivers. The sediments trapped in the core catcher were transferred to polythene bags and subsequently to cloth bags. The bags were properly labeled at the sampling site itself.

### 3.3. Pretreatment of samples:

The sediment samples brought from the field were subjected to constant temperatures of $60^\circ\text{C}$ in a hot air oven to remove the moisture. In order to ensure the uniformity of heavy mineral distribution, about 100 gm was removed by repeated coning and quartering method while the remaining samples were kept for further studies. Weighed samples were introduced to intensive mechanical stirring to disperse the aggregates and dissociate the clay fractions, if any. The stirred samples were washed with liberal amount of
distilled water and decanted carefully to see that no silt is escaped, until a clear water column is noticed. The process of washing and decantation was repeated. The clay and other mixed up sediments were removed. Apart from this, if necessary, by simple rubbing with hands the remaining clay particles were also removed. After decantation, the samples were kept for drying. The dried samples were weighed and the weight loss was noted down as the weight of silt and clay particles. The 30% by volume of H₂O₂ (Hydrogen per Oxide) was added to the sample to remove the organic debris mixed up in the sediments. It was then washed with distilled water and dried. After drying, its weight was measured and the loss was due to the organic material. The same sample was then treated with 1:1 HCl to remove the calcareous materials present in the sediments. This treatment was repeated until there is no effervescence. After proper washing and drying, the sample was weighed and the weight loss was taken as the weight of carbonates.

If the sands were found to have ferruginous coating at this stage, then conc. HNO₃ was added to the samples till the sands were fully covered. If still the coating was noticed after washing, then Conc. HNO₃ and a pinch of SnCl₂ (stannous chloride) were added and slightly heated. Then the materials were washed with distilled water and dried.

3.4. Grain Size Analysis:

Grain size analysis is used to describe the nature of clastic sediments. It has been considered as a major tool to assess the hydrodynamic aspects of sedimentary system like transformation and environment of deposition of sediments. Since it was first introduced in the sedimentallogical studies, many excellent contribution have been made.
According to Udden (1914) the hydrodynamic conditions prevailing during deposition of clastic sediments control the size and composition of sediment. Passega (1957, 1964) plotted the coarsest one percentile grain size (c) against median size (m) in log paper and obtained a specific pattern characteristic of the agent of deposition. His studies proved helpful to delineate the character of deposition. Visher (1969) emphasized that granulometry of sediments would provide a separate line of supporting evidence for the interpretation of clastic deposits of unknown origin.

Several authors had advocated different graphic methods for the computation of grain size analysis (Trask, 1932; Krumbein, 1936; Inman, 1952; Folk and Ward, 1957), moment measures of Inman (1952) and graphic measures of Folk and Ward (1957) and concluded that while the Inman measure is more satisfactory for poorly sorted sandstone, Trask’s coefficient of sorting is more satisfactory for describing very well sorted sandstone. The Folk and Ward (1957) sorting measures were found to be satisfactory for the entire range of sorting characteristics. Hence, these relationships and trends may offer clues to find out the mode of deposition and identify the environments by size analysis.

ASTM sieves sizes +18 to +120 were taken in such a way as to maintain ¼ phi interval. By using graphic (Folk and Ward, 1957) and moment (Friedman, 1961, 1967 & 1979) methods the grain size data were processed in a computer to get statistical parameter using Grain and Origin 6.1 version.
by Origin Lab Corporation 1991-2000. The statistical parameters (mean, median, standard deviation, kurtosis) were determined. Using the statistical parameters frequency curves, bivariant and visher log probability curves were prepared. Graphic values were used for discussing individual parameters.

Grain size parameters of both graphic and moment methods are given in the table (Table.3.2.a, b, c).

3.4.1. Sieving:

For sieving, ASTM sieves from +7 to +270 mesh sizes were taken in such a way to maintain half phi interval. Ro-tap sieve shaker was employed for shaking. To maintain a constant timing, the shaker was attached to timer and every sample was sieved for about 20 minutes.

3.4.2 Frequency Curves:

Frequency curves exhibit the pictorial representation of actual weight percentage of different fractions of sediments. The peakedness of fractions and uniformity of the sediments can be inferred from it. The frequency curves of sediments of different areas are shown in (Fig: 3.2. a-r).

In the study area, northern sector shows unimodal to bimodal distribution, few locations show polymodal distribution. Well developed peaks are noticed at 1.5ϕ, 2.0ϕ, 2.5ϕ and 3.0ϕ fractions; these peaks reflect an enrichment of beach sands in alternate grain sizes from medium to fine sands. Central and Southern sector shows mostly bimodal distribution and one station has polymodal distribution.

However, about 65% of beach sands concentration is found to be in fine size grade. The polymodality of frequency curves of beach sands indicate the multi source of deposition. When aerial photos and satellite
imagery of the study area are interpreted, it shows the presence of paleo channels in the study area. Hence, the sediments might have been transported by river and deposited under beach environment.

3.4.3 **Mean:**

Mean represents the average size of the total distribution of sediments. It serves as an index to measure the nature as well as the depositional environment of the sediments. It is the function of total amount of sediments available, the amount of energy imported to the sediments and nature of the transporting agent. The energy of transporting agent includes the degree of turbulence and the role played by currents and waves.

The mean size of the beach sand ranges from $1.88 \phi$ to $2.89 \phi$ indicating the presence medium to fine sands. This can be inferred that slightly higher energy condition prevailed in those areas to carry away the finer particles. Further, as some of the locations among the three sector namely, Sinurpet, Mandapattur, Akkaravattam, Vanjur have the accumulations of fines. This indicates the low energy conditions prevailed in those areas. Seralathan (1979) has noted that the increase in mean size to coarse sand around Pondicherry is generally attributed to the removal of fine fraction in high energy condition.

Polymodality confirms a mixed size grade presence in Karaikal beach sand. The depositional environment in Sinurpet and Vanjur are being a river, it is liable to get both the source offshore and inland not only the rain wash but also by the wind, deposits which are likely to get mixed up in the depositional site. The tidal onward push must have brought those coarse sands during monsoonal condition. However, the receding tides present in the
river mouth must have enforced retardation in the energy and allowed the suspension part to go back. The presence of fine and a few medium sized grains of heavy minerals found in some locations near Sinurpet, Thirumalarajapattinam and Vanjur indicate the sudden decrease of the velocity of the transporting agent.

3.4.4. Standard Deviation:

Standard deviation is a measure of uniformity or sorting. It is also the resultant character of sediments controlled by size, shape and specific gravity of sediments and energy and time involved in transporting fine. It is noted that the standard deviation decreases towards the sample of lower mean size. In other words, the sorting improves with the lowering of mean size. As a result, the sediments having fine sand (between $2.25\varphi$ and $4.25\varphi$) exhibit well sorted nature. This phenomenon has also been noted by Inman (1952), Friedman (1967) and Krumbein (1984).

Pheleger (1969) has noted the poorly sorted nature of sediments in the paleo-barriers along the Mexican coast. Zenkovitch (1969) and Reineck and Singh (1986) have also reported the occurrence of poorly sorted sediments and admixture of pebbles in the barriers occurring in front of the coastal lagoons. The presence of minor amount of pebbles in this site may also be accounted for such admixture.

Northern part of the study area, the standard deviation value for beach sands range from $0.33\varphi$ to $0.67\varphi$ indicating moderately well to very well sorted nature. In central region this value range from $0.34\varphi$ to $0.67\varphi$ indicating moderately well to very well sorted nature and one samples has $0.96\varphi$ indicating moderate to moderately well sorted nature.
In southern region this value ranges from $0.37\phi$ to $0.67\phi$ indicating moderately well to very well sorted nature. The moderate sorting in some of the locations in the middle portion is attributed to partial winnowing and addition of sediments in barrier beach environment by aeolian process.

The well sorted to poor sorting nature in few locations like Patinacheri results in a place where there is a continuous, slow deposition of sediments. The presence of minor amount of pebbles in this site may be due to the deposition of the sands of varied sources with varying velocity of the transporting agent.

3.4.5 Skewness:

Skewness is a measure of symmetry of grain size distribution. It is a significant parameter in delineating environment, since it is sensitive to sub-population mixing. Duane (1964) discussed in detail the importance of skewness in studying the modern environment. The beach sand samples showing the skewness values ranging from -0.03 to 0.49 falling within very coarse to very fine skewed. Most of the samples exhibit near-symmetrical character. This can be attributed to the addition of sediments from medium energy conditions. The sands though coarse in the beginning must have slowly lost their dominance due to strong addition of fine sized sand in dried lagoonal portion.

Though the study area is inferred to be a paleo-barrier, formed under marine conditions, it is surprising to note that all the samples are found to be very finely skewed. The analyzed samples indicate the presence of dominantly positive skewness, in other words it is predominantly fine skewed i.e. the tails are skewed better. The skewness directs the attention to the finer
present in the tails. The prominent fine to coarse skewed nature suggests the probability of multi-source and multi-agent role.

3.4.6 Kurtosis:

Kurtosis is a measure of ratio between the sorting in the tails of the curve and the sorting in the central portion. Friedman (1961 & 1967) has concluded that kurtosis is not sensitive for the determination of environment.

Folk and Ward (1957) have explained skewness and kurtosis in terms of the mixing of two normal grain sizes. The graphic kurtosis is a measure of the part of sediments already sorted elsewhere in an environment and later transported and modified by another type of environment. But the moment kurtosis is an index of mixing of two end populations. Jauet and Vernet (1976) have advocated the usage of graphic kurtosis to recognize the inherited characters of population and moment kurtosis for measuring the mixing between the end populations. Sediments with a more or less equiproportionate mixing of the modes show platykurtic distribution whereas the dominance of one mode gives a distribution that is leptokurtic.

Folk and Ward (1957) have inferred that unimodal sediments exhibit mesokurtic and mixing of two populations in sub-equal amount resulting in platykurtic values. The polymodal characteristic is responsible for the platykurtic values. Kapila and Nayomi (2008) studied recognition of diagnostic criteria for recent- and paleo-tsunami sediments from Sri Lanka and resulted Tsunami sediments are less well sorted than storm-surge and nearshore sediments.

The beach sand samples in the study area in northern region exhibit the kurtosis values from 0.78 to 2.35 platy to very leptokurtic; central
region shows the kurtosis values form 0.79 to 2.23 and southern region shows the kurtosis values form 0.84 to 2.11. It shows that medium to high energy conditions must have prevailed in this region. It also supplements the interpretation made earlier, in such a way that the addition of material in both ends. Only a particular size sand of medium in nature must have been added up in due course of time to get accumulated in this region. This is again testified by medium to fine size sediment. This predominantly platykurtic nature of sediments in Akkampettai and Kottucherimedu helps to infer the sorting of tail portions of the sediment population. As finer populations are found to be tidal currents, they show a characteristic very platykurtic nature.

The coarse sediments could not be distributed though; there would have been high energy due to the bar present at the sea mouth. In view of that, poor sorting in the central portion is unavoidable whereas the respective tidal entry must have churned the sediments and must have taken back to the sea, the fines in suspension. Such removal must have enlarged the segregation at a particular fraction in the tails.

3.5. Bi-variant plots:

The inherent relationship between the four size parameters can be well understood, only when they are plotted against each other as scatter diagrams. Researchers like Wentworth (1929), Keller (1945), Inman and Chamberlin (1955), Folk and Ward (1957), Friedman (1961 & 1967), Shepard and Young (1967) have successfully used the scatter plots for understanding the geological significance of the four size parameters. But, they were divided into two schools of thought, one favoring graphic and the other favouring moment method and the controversy is still continuing worldwide.
By using textural parameters, obtained by moment method, Friedman (1961) has differentiated beach and dune sands by plotting mean Vs skewness and beach and river sands by plotting skewness Vs standard deviation. Friedman (1967 & 1979) has prepared bi-variant plots from the textural parameters and proved the sensitiveness of differentiating the depositional environments like beach, inland dune; beach and river sands; river and coastal dune sands and inland dune and coastal dune sands. By using moment measures in the bi-variant plots, Friedman (1961 & 1967) has successfully demonstrated the use of bi-variant plots by utilizing both graphic and moment measures and brought out the dune and river zonation from the plot of standard deviation Vs skewness.

Rajamanickam and Guijar (1985) have attempted to understand the possible changes in the depositional environments within the bays of Maharastra through bi-variant plots ant probability curves. For the present study, the univariant parameters of the beach sands have been used for drawing binary plots. The grain size statistical parameter have been brought in the form of scatter plots showing bivariant distribution.

**3.5.1 Mean Vs Standard Deviation:**

The scatter plot between mean size and standard deviation with normal curve (Fig: 3.3) for sediments samples of the study area indicating beach sediments are moderately to very well sorted with low mean size.

**3.5.2 Mean vs Skewness:**

Mean versus Skewness plots of the beach sediments show a sinusoidal pattern (Fig: 3.4). Most of the beach sediments are very negatively to nearly symmetrical skewed. From the plots study area shows that the
beach sediments are in the range of negatively skewed to very positively skewed.

3.5.3 Mean Vs Kurtosis:

The scatter plot between Mean versus Kurtosis (Fig: 3.5) for beach sediments gives a part of “V” shaped pattern with flattened left limb. It suggests that the majority beach sediments are meso kurtic to very leptokurtic, while few samples are platy kurtic to meso kurtic.

3.5.4 Standard deviation versus Skewness:

The scatter plot constructed using the standard deviation and skewness (Fig: 3.6) for the sediments of beach shows a sinusoidal pattern. Even though, the whole diagram fitted well, the left hand side of the upper part leaves a slight gap due to the fewer amounts of very positively skewed samples with ranges 0.39 to 0.44. Form this plot it can be observed that while the beach sediments are very well to well sorted. This illustrates that majority of the samples are near symmetrical to positively skewed and the corresponding sorting is very well to moderate.

3.5.5 Standard deviation versus Kurtosis:

The standard deviation versus kurtosis scatter plot of beach is casting an inverted “V” shape trend (Fig: 3.7). A “V” shaped pattern is obtained for the deposition of sediments by tidal channel, estuarine and beach sediments. The well to very well sorted sediments shows meso to very leptokurtic nature. The beach sediments are moderately to very poorly sorted with kurtosis value indicting very platy kurtic to extremely platy kurtic nature. On the other hand, majority of the study area in southern are well to moderately sorted with platy kurtic to extremely lepto kurtic nature.
3.5.6 Skewness Vs Kurtosis:

In the scatter plot of skewness versus kurtosis the areas within the range of normal curve are shown by a diagonal line. In the present study, for beach sediments, half of the sample points are present in the “normal” curve, leaving the rest away from normality. But in the case of beach sediments, the plot reveals that (Fig: 3.8) very few samples are present in the “normal” curve.

3.5.7 Visher Diagram:

Visher (1969) has put forward the effective usage of log probability using three types of sub population viz., the traction, saltation and suspension. The environments being known, it is felt that the textural variations may help to infer the micro-environmental conditions prevailing in the study region. The quantification of these three sub-populations from the mode of distribution and from the nature of frequency curve also helped the delineation of environment. Rajamanickam and Gujar (1993) have demonstrated that Visher’s log probability curves can be used to infer the existing depositional environments without any ambiguity in the Ratnagiri nearshore sediments.

The log probability curves prepared using Visher’s (1969) procedure is shown in the (Fig: 3.9. a-r). The Visher diagram of the samples of the study area is characterized by traction, saltation and suspension population. Visher diagrams depict a wave shadow environment for the northern sector, whereas the central sectors show double saltation populations characteristic of beaches, and the southern sector is characterized by a more truncated population characteristic of a plunge zone, which is a high energy environment.
3.5.8 CM Pattern:

In order to find out the mode of transportation and the energy level of the sediments during transportation and deposition, CM pattern was prepared by using Median and First percentile (Passega, 1964 & 1977). The distribution of samples of the present study falls in NOP sector indicating the deposition of beach sands by rolling. As the textural parameters clearly indicate the influence of marine environment in the present study area, the same phenomenon is registered by way of distribution of samples in rolling sector. In the CM pattern (Passega, 1957) samples of the study area clustered distinctly in NOP segment. This distribution supports the textural evidences that there must have been a strong winnowing action leading to the transportation of sediments by rolling (Fig: 3.10).

Along the study area the sediments are concentrated at PQ and QR segments. This illustrates the mode of deposition of sediments by means of graded suspension and rolling. The presence of graded suspension has been attributed to the major role played by the relief. Here the samples show a clear scattering at PQ and QR segments, indicating a type of deposition by beach with fluvial influence.

3.6 Light - Heavy Mineral Studies:

Heavy minerals are characterized as having a specific gravity greater than 2.89, which includes many kinds of opaque and transparent minerals consist of oxides, sulfides, and ore minerals. The economically valuable heavy minerals transported and concentrated as stream sediments or beach materials are called as ‘Placer Deposits’. Once the material is taken out, from a parent source then the same is transported to the basin of
deposition redistributed according to their specific gravity, size, shape, etc. The distribution of heavy minerals is controlled by so many factors like destruction by wear and tear, stability of the mineral, density, grain size, water motion and energy at the depositional environment (Choudhri and Grewall, 1985).

Heavy minerals are studied to establish stratigraphy. They can be useful to track the source rock lithologies dispersal patterns and to evaluate the diagenetic history. They can also be used as tool to find out the weathering and tectonic history of the source area. The heavy mineral analysis is primarily used to understand the nature of source from which the sediments are derived. Large number of workers (Krumbein and Pettijohn, 1984; Okade, 1960; Folk, 1980; Pettijohn, 1984; Blatt, 1985; Russel, 1937; Mallik, 1972, 1986; have studied the heavy minerals of different environments. The density and grain size of the heavy minerals place them in the “hard to move” category of minerals. For, the transportation and concentration of heavy minerals, current velocities greater than the normal are needed since the heavies are not hydrodynamically equal to the light minerals. The heavier minerals like zircon, rutile, kyanite, topaz and garnet used to get settled fast, when there is a little reduction in the velocity of transporting media during the course of transportation.

The sieved fractions of beach sands have been made into light and heavy mineral fractions by following the procedure mentioned in the Muller (1967). The individual fractions have been grouped into three different fractions coarse, medium and fine for heavy mineral separation. The set method has been carried out using bromoform as shown in the Milner (1962).
For those fractions likely to be clogged in the standard separating funnel, filtering funnel fitted with transparent non-corrosive tube clipped by pinchcock is used. After the settlement of heavies pinchcock has been opened to drain them into filter paper kept on the funnel. Then the lighter grains have been washed into another filter paper provided with separate funnel. Bromoform has been filtered in the separate container for further use. Then the grains have been washed first by using methyl alcohol and then with distilled water. Then each and every fraction has been dried in a hot air oven with a mild temperature of 60°C until the moisture has been fully removed. The dried fractions have been weighed and the weights have been noted down.

The shorelines of these areas have been experiencing both accretion and erosion. The beaches have enriched with economic minerals such as ilmenite, garnet and zircon Rajamanicakam et al (2006).

Bhaskar Chandra Acharya et al (2009) have analyzed that Heavy Mineral Placer Sand Deposits of Kontiagarh Area, Ganjam District, Orissa, India. Light minerals decrease in size from the beach to the back dunes, whereas the size distribution of heavy minerals in the beach and dunes is more or less uniform. The average heavy mineral content in the beach and dunes vary from 9.38% to 24.20%. It has good economic potential for commercial exploitation of ilmenite, rutile, sillimanite, monazite, zircon and garnet.

3.6.1. Mounting:

Before entering into slide preparation, the heavies and lights were subjected to coning and quartering, until the required amount was obtained. Keeping in mind that the minimum number of grains per slide was
expected to be 54; the slides were prepared using canadabalsam of refractive index 1.513. While preparing the slides, care was taken to have an uniform spread of grains over glass slides.

3.6.2 Counting:

The prepared grain mounts of light and heavy minerals were studied under refracted light of the microscope. From the mounted slides the individual (>300 grains) minerals were counted by using the line method described by Galehouse (1969). The different counts had, then been converted into percentages and the values were tabulated in Table.3.3.

Various diagnostic properties of heavy minerals provided in the Milner (1962), Ford (1951), Rothwell (1989), are utilized for the easiest identification. From the results of line counting method, the general distribution pattern of heavy minerals all over the study area has been obtained. It is seen that the heavy mineral suite consists of opaques, zircon, tourmaline, garnet, rutile, sillimanite, pyroxene and amphibole.

Heavy mineral percentages of the study area at each location are indicated in (Figure: 3.11. a-r). The petrographic characters of each heavy mineral as observed under microscope are described in the following paragraphs:

3.6.3. Description of the Light Minerals:

3.6.3.1. Quartz:

Quartz is easily identified by its characters like low relief, lack of perfect cleavage, concentric ring of interference figures, straight extinction and uniaxial positive. The quartz grains are comprised of both monocry staline
and polycrystalline and are dominated by dust like inclusions. The grains show a straight to wavy extinction.

Monocrystalline is a single grain of generally fairly of large ones. Polycrystalline quartz is formed out of the fusion of different quartz grains separated by either planar or irregular boundaries. The grains do not have optical uniformity. They are expected to have different level of crystallographic axis orientation. Inclusions also identified within the quartz grains. Generally all the quartz grains are sub-angular sub rounded.

3.6.3.2. Feldspars:

The feldspars in the beach sands are weathered in nature and are easily identifiable under microscope. The feldspars are found to be comprised of orthoclase and microcline.

a) Orthoclase:

The grains are prismatic, sub-rounded to sub-angular in nature. It is seen with characters of low relief, weak birefringence, two directional cleavages at right angled nature i.e. one perfect and other imperfect, straight extinction, colourless under polarized light, first order interference colour and biaxial positive.

b) Microcline:

It is observed by its prismatic nature, parallel and distinct cleavages. It also shows low birefringence, relief, oblique extinction of $5^\circ$-16$^\circ$. The characteristic cross hatched twinning is observed.

3.6.4. Distribution of Light Minerals:

The study area is covered mostly by quartz sand, feldspar present in meager amount. The presence of feldspar also varies from one
location to another. The monocrystalline quartz variety is found to be of a dominant one 80-90 %. Polycrystalline quartz is present 3 - 10 % and feldspars to 2 – 4 %.

The quartz sands are found to be manifested with ferruginous coatings. Even before the treatment the total sands were counted for the coated and non-coated grains. Almost 40 - 60 % of the sands are found to be covered with ferruginous coatings, inferred to have been the direct supply of these sands from the hinterland, probably the Cuddalore sandstones which supply the sands with ferruginous coatings. These sands are scanned under microscope for their distribution of monocrystalline and polycrystalline grains. It is noticed that poly- crystalline quartz is less in the study area.

3.6.5. Description of the Heavy Minerals:

In the mounted slides, the individual (>300 grains) minerals were identified and counted by using the line method described by Galehouse (1969). Various diagnostic properties of heavy minerals provided in the Milner (1962), Phillips and Griffen (1986), Ford (1951), Rothwell (1989), are utilized for the easiest identification. Table.3 2 shows the Heavy mineral weight percentage of the study area. Plate 3.2.a, b, c and d shows that different heavy and light mineral shapes and colours like, euohedral, subhedral, overgrown, outgrown, brown, pink and colorless. The properties of identified heavy minerals are as follows:

3.6.5.1 Actinolite:

It has been easily distinguished by its fibrous and flaky nature, medium relief, high R.I., yellowish and light green in colour, moderate pleochroism (Yellowish green to dark green), irregular fracture, low extinction
angle \( (Z^\wedge C = 6^\circ -15^\circ) \), length slow, strong birefringence and biaxial negative. Some of the grains contain common inclusions of chloride and iron oxide. The grains are found to be prismatic having a state of sub-angular to sub-rounded nature.

### 3.6.5.2. Biotite:

In the study area Biotite occurs mostly as dark green in colour with basal cleavage and flakes having jagged edges. It also posses low R.I., light to dark brown pleochroism, straight extinction and biaxial negative. Pleochroic holoes are sometimes seen in some grains. The etching marks along the margins are well pronounced in few grains and sub-angular in nature.

### 3.6.5.3. Chlorite:

Chlorites are flaky, prismatic and sub angular in nature. They resemble mica. Chlorites are generally, found in dark green and brown colours. Chlorites are found to be strongly etched. The ultra blue interference colours are found to be distinct. Micaceous cleavage, low RI, greenish pleochroism and inclined extinction are some of the general properties of Chlorite.

### 3.6.5.4. Epidote:

It occurs mostly as platy, irregular, equant and rather angular grains. Some grains show etched surface. The important properties noticed here are higher relief, high R.I., pale green to dark brown pleochroism, unidirectional extinction angle \( (X^\wedge C = 1^\circ - 5^\circ) \), ringed interference figure and biaxial negative. The broken minute chips of epidote show bottle-glass like transparency with pistachio green colour.
3.6.5.5. Garnet:

Garnet is found as inequigranular grains with well developed features. Crystal faces are hardly noticed in detrital grains. Garnet is identified by its high relief, isotropism and lack of cleavage properties. On the basis of colour of the garnets, they are recognized in three forms (i) colourless (ii) light pink (iii) dark pink. Colourless garnet is also seen with specks of opaques inclusion. Some elongated colourless garnets exhibit well developed cracks. The inclusions like opaque, rutile, apatite and argillaceous materials are more commonly noticed in light pink garnet. Some of the grains are etched, pitted, and grooved due to the action of intrastratal solution.

3.6.5.6. Glaucophane:

Commonly occurs as irregular grain with lavender blue colour. It is strongly plechroic with colours changing from blue to lavender blue. Oblique extinction but of low extinction angle of $3^{0}-10^{0}$, weakly developed cleavages, striations parallel to principal axis, length slow and strong dispersion are some of its characteristic properties. Few grains show high order of etching and inclusion of opaques, rutile, etc.

3.6.5.7. Hornblende:

It occurs mainly as dark green, or brown or black in colour. It is prismatic and elongated. Hornblende grains show perfect amphibole cleavage and high relief under microscope. Plechroism is usually seen as pale green to straw yellow colour. In crossed nicols, they are optically biaxial negative, having characters of inclined extinction (angle $20^{0}$), and length slow, second order interference colours. Inclusions of magnetite and rutile are commonly noticed. Few varieties show etching marks on the surfaces and boundaries.
3.6.5.8. Hypersthene:

Prismatic or tabular in size, distinct cleavage, uneven fracture, pale pink or red to yellow or green in colour, high refractive index, straight extinction, varied optic axial angle, marked pleochroism from pink or red to yellow-green, minute inclusion, length positive and biaxial negative are some of the significant properties used here to recognize this mineral.

3.6.5.9. Kyanite:

It is identified by its bladed form and high extinction angle. The grains are either colourless or blue coloured. They occur as prismatic but edges are smoothened. High relief, high refractive index and oblique extinction with 35° are significant. Few varieties show etching marks on the surfaces and boundaries. Optically biaxial negative and well developed cleavages are the diagnostic optical characters.

3.6.5.10. Rutile:

It possesses reddish brown colour, high relief, very high R.I., weak pleochroism (various shades of reddish brown) imperfect cleavage, deep red interference colour, and straight extinction. It is prismatic in habit but, the broken pieces are found with rounded faces, length slow, uniaxial positive sign, twinned grains are also present. It occurs as subhedral prismatic forms and in broken type, too.

3.6.5.11. Sillimanite:

It is of fibrous, slender and prismatic in nature with fractured or irregular terminations in nature. It is colourless and shows straight extinction. It is biaxial, length slow and optically positive. Inclusions are rarely noticed in sillimanite.
3.6.5.12. Staurolite:

Prismatic, subconchoidal or hacky fracture, reddish brown or brownish yellow in colour, good cleavage, straight extinction, pleocroism yellow to yellowish brown, high refractive index, birefringence moderate, biaxial positive, dispersion weak and common inclusions with quartz, garnet and carbonaceous materials are some of the significant characters.

3.6.5.13. Topaz:

It is generally prismatic in nature and it also possesses high relief, glassy appearance, colourless, absence of pleochroism, cleavage, irregular fracture, straight extinction, biaxial positive and higher order interference colour. It shows bluish tinge in the fractured edges. Grains are manifested with fluid inclusions and opaque dusts.

3.6.5.14. Tourmaline:

It is identified by its broken terminal faces due to parting, prismatic nature. Sometimes it may be irregular and rounded. It possesses moderate relief, high R.I., brown colour, brown to maximum absorption of dark dichroism, imperfect cleavage, and straight extinction, length fast and uniaxial negative characters.

3.6.5.15. Tremolite:

It is diagnosed by its fibrous, colourless with rugged end in nature, high refractive index, amphibole cleavage, strong birefringence, non plechoic, low extinction angle, length slow, second order interference colours and biaxial negative characters.
3.6.5.16. Zircon:

There are some forms of zircons namely prismatic, euhedral, broken (irregular), oval (elliptical) and rounded found in the sediments. But, all the zircons having the common characteristic properties like, high relief, very high R.I., colourless nature (sometimes various shades of pink colour), absence of pleochroism, imperfect cleavage, conchoidal fracture, higher order interference colour and strong birefringence. The core of the zircon is foggy and cloudy in appearance due to clustering of inclusions. The inclusions found in zircon are opaques. The zircons show the presence of pleochroic haloes. The shattering of zircon grains due to stress are also observed. Though there are euhedral zircons giving the pyramidal faces.

3.6.6. Distribution of Heavy minerals:

Though the study area, in general, the beach sands are pure and devoid of any heavy mineral, an attempt has been made to find out the presence of heavy mineral in the study area. The results show the presence of heavy minerals of minor concentrations. Among the sample locations Karukalacher, Arasalar (river mouth) and Tirumalairajanar River records the highest percentage of 8.868 %, whereas the lowest amount, that is 0.007 %, is recorded in Kalikuppam and heavy mineral weight percentages at each location are shown in Fig: 3.11 a-r and Table 3.3.

3.7 Heavy mineral assemblages of the study area:

In the study area the average heavy mineral assemblages are represented by Zircon (10.07 %), Garnet (10.80 %), Kyanite (3.02 %), Actinolite (3.00 %), Biotite (1.64 %), Chlorite (24.99 %), Epidote (8.91 %), Glauophane (0.66 %), Hornblende (0.47 %), Hyperstherne (0.86%)
Muscovite (0.51 %), Rutile (1.77 %), Sillimanite (0.53 %), Staurolite (1.42 %), Topaz (2.70 %), Tourmaline (0.82 %), Tremolite (0.52 %) and opaque minerals has (27.33%).

In these assemblages, few locations nearer to Akkaravatam which lies in middle portion of the study area represent the typical granular minerals, having higher density. So, the heavy minerals in that region must have been subjected to strong winnowing action, which accounts for the absence for flaky minerals like actinolite, boitite, hypersthene etc. The result of grain size studies has also substantiated a higher energy condition for those areas. The suite of heavy mineral found in the Keezhayur region again reconfirms this inference. Fig: 3.12 and Table: 3.4 shows the individual heavy mineral assemblage (%) in the study area.

Heavy mineral assemblages nearer to Sinurpet which falls in the Northern part of the study area represent a partial mixture of flaky and granular minerals. However, here the flaky minerals like actinolite and glaucophane are totally absent. The presence of biotite along with the granular minerals indicates that this area must have had a mixture of high and low energy condition. The southern part of the study area, Arasalar and Thirmalarajanar river mouth are observed with high garnet, zircon and some opaque mineral concentrations.

Similarly the samples of few locations which cover the northern and central portion, the presence of flaky minerals indicates a low energy condition in these regions. The grain size results have also substantiated the prevailing low energy conditions.
The zircons also carry the assemblage of outgrown and overgrown. The outgrowth and overgrowth has also obtained smoothened nature in few zircons indicate minor amount of etching also.

Kyanites show even fully rounded nature. But for few grains, most of the kyanite possesses smoothened edges; few garnet grains are also present. They indicate the etched nature. The way in which more rounded nature of heavy minerals with etching and overgrowths, they direct the possibility of derivation of these minerals of multi-cycle nature mostly the contribution from the earlier sediments.

Hornblende, garnet, opaques and pyroxens are the dominant constituents in the heavy mineral assemblages with minor amounts of zircon, epidote, sillimanite, rutile, monazite, kyanite, biotite and altered minerals. In all the environments, the fine size grade (125 to 62 micron) contains a higher proportion of heavy minerals compared to medium and coarse size grades.

3.8. Resources:

In the beach and nearshore environments, the variations in heavy mineral concentrations are mainly due to their hydraulic equivalence, longshore currents and the source rocks. Based on the mineralogical study, it is suggested that the chief contributors of these minerals are mainly high grade metamorphic rocks and basic igneous rocks. Based on this conclusion it is proposed that the sediments may be derived from by fluvial input, wave dynamics, and littoral transport, where the rock types mainly consist of biotite gneisses, hornblende gneisses, magnetite, quartzite, charnockite, granite, ultrabasic and basic intrusive.