CHAPTER II

REVIEW OF EARLIER WORKS

2.1. Introduction

In this chapter an attempt is made to review some important works related to the present study. A survey of available literature reveals the fact that studies were undertaken to the increasing importance of zircon mineral and many governments and research institutions have sponsored and supported several studies on the different aspects of zircon mineral and its mining. However, in this chapter, some important research works undertaken in recent years which are very closely connected with the present study are reviewed. Here, the past studies are broadly classified into distribution, reserve estimation, mining and extraction and their economics.

2.2 Zircon Mineral Deposits in India and Tamil Nadu

Azam Ali Krishnan and Banerjee (2010) have pointed out that the article entitled inland heavy mineral sand investigations and deposits in India. Inland a coastline of over 6000 km, hosts some of the largest and richest shoreline placers. The beach and dune sands in India contain light Heavy Minerals (HMs) like ilmenite, rutile, garnet, zircon, monazite and
sillimanite. A combination of favourable factors like hinterland geology, coastal geomorphology, sub-tropical to tropical climate and intricate network of drainage, aided by wind and coastal processes like waves and currents, have influenced the formation of beach and adjoining dune sands. The heavy mineral assemblage varies widely from near mono-mineralic near Ratnagiri in Maharashtra to multi-mineral suite elsewhere. The ultimate source for the heavy minerals consists of the Khondalites, Charnockites, granite gneisses (Precambrian) and the Deccan traps (Cretaceous). The intermediate host-rocks are the heavy mineral-laden tertiary and quaternary sediments occurring in the coastal plains. Ilmenite-rich major beach and dune sand deposits occur in the coastal stretches of Kerala (Chavara), Tamil Nadu (Manavalakurichi, Midalam, Vayakallur), Andhra Pradesh (Kakinada, Pentakota, Bhimunipatnam, Konada-Kandivalasa-Mukumpeta-Bendicreek-Donkuru), Orissa (Sanaeka-Sangi-Gopalpur, Chatrapur, Bajarkot, Satpara and Puri) and Maharashtra (Kalbadevi, Newre and Malgund). Rich concentration of almandine-rich garnet (up to 31 per cent in the raw-sand) is observed in the 68 km beach stretch of Navaladi-Periathalai, south of Tiruchendur in Tamil Nadu. The red Teri inland sands occurring in the coastal plains of Southern Tamil Nadu contain HMs up to 10 per cent and occupy vast tracts with large tonnage of heavy minerals. The Indian ilmenite
commonly contain 50 to 65 per cent TiO$_2$ and are suitable for various process-technologies. Zircon, monazite and sillimanite are ubiquitous in both the beach and inland red Teri sands, and constitute potential co-products. The Indian resources of placer minerals are: 348 Million tonnes (Mt) of ilmenite, 107 Mt of garnet, 21 Mt of zircon, 18 Mt of rutile, 8 Mt of monazite and 130 Mt of sillimanite. Indian resources constitute about 35 per cent of world resources of ilmenite, 10 per cent of rutile, 14 per cent of zircon and 71.4 per cent of monazite. India meets about 10 per cent of the worlds requirement of garnet. This unique status is largely due to the exploratory efforts of the Atomic Minerals Directorate for Exploration and Research (AMD) of the Department of Atomic Energy, Government of India, since 1950's. Lastly, it is time to set up down-stream industries for better utilization of and much higher returns from these placer minerals, instead of exporting them in raw form, and this requires development of an integrated infrastructure.

Chandrasekharan and Murugan (2010) have studied out minerals in the beach and the Coastal red Teri sands of Tamil Nadu. Studies on the beach and dune heavy mineral deposits by close-grid sampling in the 508 km long Coastal stretch of the Central and Southern Tamil Nadu, and the red Teri sands of the Southern Coastal plains reveal high concentration of heavy
minerals, most commonly from the surface down to a depth of nine meters. The heavy mineral assemblage in the beach faces consists predominantly of ilmenite, garnet, sillimanite, pyroxenes, amphiboles, zircon, rutile, monazite, kyanite, and less frequently spinal, tourmaline, epidote, apatite, staurolite, etc. The concentration levels of total heavy minerals in the different beach segments show wide fluctuations, whereas the relative abundance of the heavy mineral species exhibits a distinct distribution pattern with the latitude. Thus, the heavy mineral suite in the beach and dune deposits is: (a) ilmenite-dominant in the Southern-most Manavalakurichi sector, (b) almandine garnet-rich in the Ovari sector, (c) a mixed association of ilmenite, garnet and pyribole in the Tuticorin sector, and (d) pyriboles abundant in the northernmost Velanganni - Cuddalore sector and beyond. The Coastal Teri sands contain total heavies of 6 to 13 per cent by weight, with Ti- minerals (ilmenite, leucoxene and rutile) constituting about 75 per cent of the total heavies and garnet being nearly absent. The Teri sands account for nearly 83 per cent of the resources of placer Ti- minerals identified so far in Tamil Nadu. The beach sands of the Ovari sector contain 3.2 million tonnes (Mt) of garnet at an average grade of 10.7 per cent. Zircon, monazite and sillimanite are ubiquitous in both the beach and coastal Teri sands, and hold potential as co-products or by-products. The heavy
minerals in both the environments in most cases are medium-to fine-grained, with the slime content up to 13 per cent. Ilmenite often contains higher TiO$_2$ (54 to 57.8 per cent) than its stoichiometric composition, with the higher values restricted to the Manavalakurichi sector. The high concentration of heavy minerals occurring in the beaches may be ascribed primarily to the reworking of heavy mineral laden quaternary sediments in the coastal plains that probably extend offshore and to the influence of coastal processes involving onshore and offshore movements, and the long-shore currents, with their original source being the granulitic provenance comprising khondalite, charnockite and granitic gneisses.

Duncan et al. (2009) have pointed out the zircon alteration, formation and preservation in sandstones. Zircon textures, chemistry and microstructures have been characterized in situ within Carboniferous sandstones from the Midland Valley of Scotland using back-scattered electron and cathodoluminescence images, electron backscatter diffraction techniques and chemical analyses. It can also be the zircon types including unmodified detrital zircon, zircon outgrowths and different forms of modified zircon that formed in low-temperature conditions within the sedimentary rocks. These rocks have only experienced temperatures of $<100$ °C during burial; however, altered zircon is abundant and characterized by a
low mean atomic number, with relatively high contents of non-formula elements and a nano-crystalline or microcrystalline structure. It forms by replacement of detrital zircon that subsequently became Metamict. Two types of replacement mechanisms are effective in sedimentary environments and involve either dissolution–reprecipitation or solid-state reaction, but both require fluid access to the radiation-damaged areas. The former process appears to become the dominant replacement mechanism as temperature increases and produces highly porous, inclusion-rich zircon. Metamict zircon is extremely reactive in near-surface conditions and the production of low-temperature zircon is sensitive to both parent zircon characteristics and environmental conditions.

Gupta and Johannes (2007) have explained the effect of metamorphism and partial melting of host rocks of zircons. Zircons have been studied from different layers of migmatites (from Arvika, western Sweden and Nelaug, southern Norway) and from a paragneiss (from Arvika) associated with one of the migmatites. The main purpose of the investigation is to establish whether or not information about zircons can help in the elucidation of the parentage and rock-forming processes of migmatites. The elongation ratio of zircons from all layers is small and characteristic of sedimentary zircons. Further, the absence of characteristic colours and the
growth trends of the zircons (indicated by the reduced major axes) observed in the various samples both support a sedimentary parentage for these rocks. The zircons of all layers exhibit secondary growth (overgrowth, outgrowth and multiple growth) due to metamorphism. Compared with the zircons from the paragneiss, those of the migmatite layers are more clouded and less rounded, some of them becoming opaque or even skeletal; this is especially true of the zircons from the leucosomes. These observations indicate an alteration of the original sedimentary zircons in the migmatite, especially in the leucosomes, in response to the migmatization process, previously interpreted as partial melting.

Mikio Umeda et al., (2007) pointed out that the vibration stress and temperature dependence of piezoelectric resonators with lead-zirconate-titanate ceramics it has been shown that the temperature of a piezoelectric ceramic resonator increases, and its electromechanical characteristics vary, when the resonator is continuously driven at a high level of vibration stress in a resonant mode. The effects of temperature and vibration stress on specific electromechanical characteristics of typical piezoelectric ceramics were separated using two measurement methods: the continuous-voltage-wave drive method, which results in increased temperature, and the burst-voltage-wave drive method, which does not. The elastic, dielectric, and
piezoelectric constants were found to be sensitive to temperature but not to vibration stress. The mechanical loss factor, however, was found to be a function of both temperature and vibration stress.

Haridasan et al., (2006) identified the natural radio nuclides in zircon and related radiological impacts in mineral separation plants. The activity concentration of uranium and thorium present in zircon obtained from mineral sand industries are presented. External gamma radiation levels and inhalation of airborne dust are found to be the significant routes of radiation exposure to occupational workers. The annual average dose attributed to zircon processing is estimated to be 2.3 in the plants under study. This paper presents the results of external gamma measurements, estimation of airborne radioactivity in zircon process locations and radon and the occupational environment of two mineral separation plants in India. Analyses of the solid wastes and liquid effluent generated and resultant environmental impacts are indicated.

According to Ralph Cook (2006) properties and uses of several clays in porcelain enamels the comparative effect of several clays on the physical characteristics of typical ground-coat and cover enamels was investigated. In the ground-coat enamels, the effect of the clays on the firing characteristics,
the development of the bubble structure, reboiling, and the set characteristics were studied. Suitable amounts of each of the clays were used as mill additions to the following cover enamels: (1) super opaque antimony frit, (2) zirconium frit, (3) a clear frit as used for colors, and (4) fluoride frit. The effect on reflectance, gloss, and the resistance to gouging was noted on these samples. Spectrophotometer curves were run on selected cover-enamel surfaces. The clays showed a widely varying effect on the set characteristics and the bubble structure of the ground-coat enamels. The different clays with the antimony frit caused a wide variation in the gouging characteristics while, with the zirconium frit, the clays had less effect, the gouging values being uniformly high.

Williams and Steenkamp (2006) have carried out the heavy mineral processing at the rechards bay Minerals Located on the eastern shores of South Africa, 180 km north of Durban, Richards Bay Minerals (RBM) produces approximately 2.0 million metric tonnes of product annually making RBM a leading producer of titania slag, high purity pig iron, rutile and zircon. Heavy minerals are extracted from the nearby dunes by dredging and concentration on a floating gravity separation plant, followed by separation of the ilmenite, rutile and zircon at the mineral separation plant located at the smelter site. The ilmenite is processed through
an oxidizing roast followed by magnetic separation and is then partially reduced to an 85 per cent TiO₂ slag in one of four six-in-line a.c. electric arc furnaces. The slag is milled and then classified into two product sizes suitable as a raw material for both the sulphate and chloride pigment processes. The high quality iron produced during the reduction process is further processed to produce various grades of low-manganese iron. Around 95 per cent of the products are exported, yielding a world market share of about 25 per cent of titania slag, rutile, high quality pig iron, and zircon.

Maria et al. (2005) the discussed about novel technique for zirconia-coated mullite a novel, low-cost, screen-printing route to obtain zirconia coated mullite starting from zircon powder has been proposed. A zirconia thick film of 30-μm thickness with a strong adherence to the mullite substrate has been obtained. The roles of zircon impurities in the coating characteristics as well as the effect of firing temperature.

Jean-Paul Crocombette and Dominique Ghaleb (2005) have studied that the Modeling the structure of zircon (ZrSiO₄): In this paper the ability of two complementary simulation approaches to reproduce the structure of crystalline zircon is assessed. The first approach based on Born–Mayer–Huggins empirical potential reproduces within 5 per cent the characteristics
of each of the zircon phases, but not their relative stability. The second one, namely ab initio electronic structure calculations, reproduces with better than 1 per cent agreement the structural properties of zircon. The relative stability of the phases is correctly simulated as well.

Gillian Dooley and Anthony Leddin (2005) have study the perspectives on mineral policy in Ireland. Mining firms have a greater incentive to invest in a country with effective and efficient mineral policies, given favourable the geological and commodity price conditions. This paper examines and appraises mineral policy in Ireland. The legislative, regulatory and fiscal frameworks for mining are examined. Inherent administrative issues surrounding these policies are also discussed. Despite the positive reviews of Irish mineral policy in the Fraser Institute Annual Survey of Mining Companies 2004/2005, this paper concludes that a number of policy improvements are needed to maximise the industry's potential. The paper suggests that a National Mineral Policy document be produced to provide greater clarity to potential investors through a transparent legislative framework and a balanced fiscal framework.

Agugusamy et al., (2004) has carried out the study on zircon and ilmenite from the beach placers of Southern Coast of Tamil Nadu, East
Coast of India. Zircons were studied from the two different zones of enrichment of placer deposit namely. Kanyakumari-Kuttankuli (KK) along the Southern Coast Tamil Nadu. The average heavy mineral contents were 67 wt per cent in VP region. The heavy mineral assemblage of the two zones was akin to each other. However, monazite was present in the KK region. In KK, zircons were rounded (44.8-63.2 per cent ), overgrown (4.1-16 per cent), and euhedral (9-4.9 per cent).While in VP, they are largely broken (47.8-59.6 per cent), and rounded (22.2-38.9 per cent), and euhedral (7.3-8.1 per cent), mean length and breadth of the zircons of KK and VP ranged from 0.22-0.26 mm and 0.07-0.13 mm and, 0.06-0.16 mm and 0.07-0.11 mm, respectively. The zircons of VP are more fine-grained and well-rounded than in KK. The northerly currents, in the Gulf of Mannar, must have transported and deposited the heavy minerals due to the inflection of the coastline, and down warped the basal structure REE pattern of zircons exhibit Eu and Ce anomalies which could be explained only in terms of crystallo chemical factors and the bulk compositional differences of the melt. In the study area, there is an abundance of rounded zircons. Length/breadth (L/B) ratios, reduced major axis (RMA) angles, indicated that the source rock for the zircons must have been primarily of chamockites. The distribution, composition and REE content of the zircons
compare well with that of other countries where it is currently under exploitation.

Wang et al. (2004) decided in the article entitled laser induced structure changes on a zircon refractory that a zircon (ZrSiO$_4$) refractory was treated by CO$_2$ laser surface melting in order to improve its surface density and to modify the corresponding microstructure in present study. The laser-induced microstructure and phase structure changes and these have been investigated by scanning transmission microscopy incorporating Energy Dispersive X-ray (EDX) technique and X-ray diffraction analysis. Laser surface melting treatment was readily achieved over a wide range of scanning velocities from 4 to 16 mm s$^{-1}$ although the melting temperature of the zircon is very high, and the molten depth was almost linearly decreased with increasing scanning velocity. Cracks and pores could be eliminated at the lowest scanning velocity of 4 mm s$^{-1}$ whereas some pores in the laser-molten zone and cracks only in the overlapped zone were produced at the higher scanning velocities of 8, 12 and 16 mm s$^{-1}$. The microstructure of the laser-molten zone was characterized by a dendrite structure with interdendritic segregation to some extent. Laser-melting treatment led to the decomposition of ZrSiO$_4$ into ZrO$_2$ and SiO$_2$ and thus the selected evaporation of SiO$_2$ during heating process. The consequent rapid
solidification resulted in the formation of the phase m-ZrO$_2$ instead of the phase ZrSiO$_4$ under equilibrium conditions.

Roy Rice (2004) has pointed out in processing of ceramics from a broad perspective, with emphasis on the predominant powder-based methods, but with considerable attention to other methods. The major stages of the powder process, from preparation, modification, and handling, to sintering or pressure densification (or postdensification) are discussed. Nonpowder-based methods, such as chemical vapor deposition, melt, and polymer pyrolysis processing, are also presented. The processing of ceramic composites is reviewed, noting the shifts in processing technology this entail. Practical aspects, such as part size, shape, volume, and the costs of various processes which are also addressed.

Zhangfu Yuan et al. (2004) deal with the production of zirconia from zircon using a plasma-rotating furnace. Desilicated zirconia (88.60–94.21 mass per cent ZrO$_2$) and stabilized zirconia (ZrO$_2$ $\geq$ 91.54 mass per cent, MgO $\leq$ 5.39 mass per cent) have been produced successfully from zircon in a 150 kW plasma facility. Effects of temperature, time and carbon content on the removal of SiO$_2$ from zircon have been investigated. According to preliminary applications in continuous-casting nozzles at a steel works, the
obtained desilicated ZrO₂ can substitute for traditional ZrO₂ made by the chemical-purifying method. The main characteristics of the trial product meet the requirements for industrial production.

Pirkle and Podmeyer, (2000), discuss out the zircon origin and uses the mineral zircon is mined for use as specialty foundry sands, abrasives, ores of ZrO₂ and zirconium metal, refractories and zirconium chemicals. It is produced as one of several products from heavy-mineral sand deposits associated with ancient shorelines. Because of its low coefficient of thermal expansion, its high melting point, its high refractive index and its chemical inertness, it is an attractive refractory material. Zircon varies from deposit to deposit in terms of grain size, grain shape and chemical purity. Thus, there is a wide range of commercial zircon products that differ in impurity levels, particle shapes and grain.

Elangovan, Manickam and Victor Rajamanickam (2000) discuss the “Economic Viability of Placer mining along the Southern Coast between Kanyakumari, and Mandapam, Tamil Nadu, and the world economic experience makes it clear that economic prosperity comes through industrialization. The entire economic edifice of industrial societies is built on the use of minerals and mineral products. So a well developed mineral
industry is one of the most important pre-requisites for attaining self-sustained industrial development for a developing country like India. In the post-independent period, India achieved a significant growth in mineral production. The share of minerals was barely three per cent of the total merchandise and it reached the highest level of 30 per cent in 1983-84 and ranged between 20 and 30 per cent thereafter. In the case of placer minerals 75 per cent of the world’s tin production, 11 per cent of the gold and 13 per cent of the platinum are extracted from placers. About half of the world’s supply of diamonds, titanium, tungsten and tin comes from placers. Even India’s has achieved 100 per cent self-sufficiency in the production of heavy minerals like ilmenite, rutile, kyanite, and sillimanite. Easy mine ability, development of indigenous technology and the market potential provide bright scope for the establishment of the placer mining industry. The main problem based on the low level of economic activity in the placer mining industry is largely due to the lack of awareness on the part of the entrepreneurs about the profitability of the placer mining venture. At this juncture, the exploratory, the geological and scientific studies must be supported by economic viability study of the placer mining for motivating the industrial community to come forward with their investment programmes in this field. The study aimed at the economic feasibility study
of placer mining with special reference to garnet in the coast between Kanyakumari and Mandapam in Tamil Nadu. In this study area, two regions are identified with the enrichment of placers viz., Kanyakumari and Kuttankuli, and the Kallar and the Vaipar regions. The objective of the study was to discuss the economic viability of garnet mining venture, to estimate the capital and operating cost of the garnet mining industry to evaluate the annual revenue of the garnet mining venture and to identify those factors which mostly affect the profitability of the placer mining venture. After Net Present Value, Internal Rate of Return, Simple Payback Period and Sensitivity Analysis the economic return analyses point out that the mining of beach placers in the coastal region from Kanyakumari to Mandapam is economically viable. The profitability may further be raised by allowing the industrialists to mine other less strategic minerals like zircon with some environmental protection measures.

Alan Heap (1999) in this paper explains that the titanium dioxide pigment accounts for more than 90 per cent of the titanium mineral consumption. TiO₂ is the brightest of the white pigments and its main applications are in the manufacture of paints, plastics, and paper consumption is concentrated in North America and Europe which together account for nearly two thirds of the total world demand. The titanium metal
market slowed in 1998. The main cause of the slowdown the purchases by
the aerospace industry which accounts for 65 per cent of demand. According
to him Japan is the world’s largest producer of titanium sponge and output
slid to 1 per cent to 24,200 tonnes. In the US, the world’s largest consumer,
spangle demand declined by 9 per cent to 21,100 tonnes. Being announced
that it expects titanium purchases to fall it has reduced inventories;
competitive pressure is expected to increase from Russian producers after
the lifting of anti-duping tariffs by the US government. In early 1999 the
titanium market continued to weaken, demand in the US fell and producers
see little sign of improving business conditions. This growth mix should be
supportive of demand for titanium products, which is concentrated in the US
and Europe. In addition, the modest increases in expected supply should
reduce downward pressure on prices.

Gujar et.al.,(1998) have stated in that the article entitled
“provenance and distribution of placer minerals in three areas”. That Quilon
deposits of Kerala stretching over 22 km between Neendakara and
Kayakulam are found to contain 60-70 per cent of ilmenite (upto 60 per cent
TiO$_2$ content), 4-7 per cent of rutile, 5-8 per cent of zircon, 0.5-1 per cent of
monazite, 4-8 per cent of sillimanite, 1 -1.5 per cent of leucozene and silica
shell and other minerals amounting to 4-25 million tonnes of rutile and 0.12
million tonnes of monazite. Manavalakurichi deposits of 6 km stretch from the mouth of Valliyar river to Colachal in Kanyakumari district in Tamil Nadu contains an average of 45-55 per cent of ilmenite (4.74 million tonnes), 2-3 per cent of rutile (0.08 million tonnes), 7-14 per cent of garnet, 3-4 per cent of monazite, 4-6 per cent of zircon, 2-3 per cent of sillimanite, 0.5-1 per cent of leucoxene and silica shell and other minerals constitute 10-25 per cent. The area of concentration in Chathrapur Coast stretching for about 18 km over an area of 26 km² in Ganjam district of Orissa has placer deposits with 9.4 per cent of ilmenite, 0.04 per cent of rutile, 3.3 per cent of sillimanite, 6.8 per cent of garnet, 0.33 per cent of zircon, 0.29 per cent of monazite and 0.76 per cent of other minerals.

Pirkle and Podmeyer (1991) explain the zircon origin and uses the mineral zircon is mined for use as specialty foundry sands, abrasives, ores of ZrO₂ and zirconium metal, refractories and zirconium chemicals. It is produced as one of several products from heavy-mineral sand deposits associated with ancient shorelines. Because of its low coefficient of thermal expansion, its high melting point, its high refractive index and its chemical inertness, it is an attractive refractory material. Zircon varies from deposit to deposit in terms of grain size, grain shape and chemical purity. Thus, there is a wide range of commercial zircon products that differ in impurity levels,
particle shapes and grain sizes. Zircon is used in the refractory industry because of its chemical and physical properties.

Randhir Sengupta and Samit Bhattacharyya (1990) reported the preliminary studies of offshore heavy mineral places, Gopalpur Chhatrapur Coast, Orissa. It include individual constituents of heavy placers, sediment chemistry particularly the elements Ti, Zr, Ce, La, Th and V. The sediments are predominantly terrigenous, transported by the river Rushikulya. Twenty one samples were subjected to heavy mineral separation in different size fractions, and balk heavy mineral weight percentages varies from 2.11 to 30.85. The heavy minerals present in the area of study include ilmenite, sillimenite, garnet, rutile, zircon and monazite. Sediment types are fine Sand, medium to coarse sand, admixture of sand silt-clay and silty clay. The distribution of sediments does not show any gradual reduction in grain size with depth, rather having fine sand close to the shore, followed by the coarse sand and admixture zone and finally the clayey blanket which could be a cover on the relict coarse sand. Zircon occurs as euhedral prismatic hue. Rounded grains of monazite are found in most of the samples in varying concentrations. The colour of monazites is usually yellowish, but pale brown and greenish varieties are recorded occasionally. The major heavies has been discuss the hornblende, hypersthene, staurolite, tourmaline, epidote, spinel
and shapphirine are also recorded in very minor amounts. Thirty – eight seabed samples were subjected to chemical analysis to know their trace and few RE elemental concentration. Finally concluded that the studies of grab samples from the Shorface off Gopalpur, Bay of Bengal reveal the presence of a relict sand sediment containing fairly good concentration of heavy mineral like ilmenite, zircon, rutile, sillimenite, garnet and accessories of hornblende, pyroxenes, epidote, tourmaline spinel etc. The bottom sediments of the off – shore areas have heavy mineral contents similar to those found in beach deposits and the heavy mineral placers owe their provenance to the adjacent Eastern Ghat litho-units.

Babruvahan Rao (1989) has estimated the evolution of the sand dune deposits of Ganjam Coast, Orissa, India, the main point of Coastal sand Dunes containing monazite, zircon. The origin and evolution of the deposits are discussed and are traced to (a) the existence of older and deeper bays. (b) progressive silting of the bays owing to marine oscillations resulting in the emergence of land with a gentle seaward slope during the recent recession of sea, and the emergence of sand bar in the trend of the bays to form a lagoon due to the combined effect of the grading of profile and littoral drift of sand by long-shore currents, and merits of dunes. The availability of plenty of sand all along the beaches has naturally led to the development of the
frontal-dunes ridges is prominent along the greater length of the Coast reaching heights up to 18m it is significant to note some gaps with only poor to moderate development as in the vicinity of villages.

(d) growth of the bar into frontal- dunes and further development into ridges parallel to the Coast owing to the continuous and adequate supply of sand by long-share currents and wind action (e) differential growth of recent vegetation resulting in the development of irregular dunes in the inter-dune area. It is concluded that the greater the deviation of the coastline from the North towards the east in the area, the more favorable for the concentration of heavy minerals.

Jeffrey et. al., (1989) undertook a detailed Hydrothermal zircons and zircon over growths. Zircons from the Sierra Blanca Peaks, a group of mildly peraluminous, rare-element enriched rhyolite laccoliths in Trans-Pecos Texas, display textures that indicate formation and/or alteration in a hydrothermal environment. These zircons can be categorized into three types according to host rock, texture, and mineral chemistry: (1) magmatic zircons hosted by intrusive igneous rocks; (2) hydrothermal (or late magmatic) zircon overgrowths on magmatic zircons; and (3) hydrothermal zircons hosted by replacement bodies of fluorite in limestone. Rims of magmatic zircons from the Round Top intrusion generally are enriched in Y, Hf, Th, and U relative to cores. Magmatic zircons from the Sierra Blanca intrusion
show a negative correlation between Y and U contents. Overgrowths from
the Round Top intrusion have generally higher Hf contents (5.1 to 7.6
wto/oH fOr) than do their magmatic substrates (3.9 to 6.3 wo/o). Hydrothermal zircons in replacement bodies contain much less Hf (1.1 to 2.2
wro/oH fOr). Compositions of magmatic zircons vary between intrusions.
Magmatic zircons in most of the intrusions display amoeboid texture and, in
samples from the more the-rich intrusions, host numerous thorite inclusions.
Some magmatic zircon grains from the round top have conspicuously
inclusion-free zircon overgrowths. The round top also has zircon veinlets
and tiny "stringers" that connect to the overgrowths. Zircon overgrowths
also occur in the Triple Hill intrusion, where the magmatic zircons tend to be
less corroded. Hydrothermal fluorspar replacement bodies in limestone that
are associated with the intrusion of the Sierra Blanca laccoliths contain
subhedral to anhedral, commonly corroded, inclusion-free zircon grains.

According to Carolyn Banks Luttrell, (1948) an investigation was
conducted to develop a white opaque low-expansion glaze of suitable gloss
and texture for commercial application on zircon porcelain. A glaze
containing the alkaline-earth zirconium silicates was selected as the base
glaze; batch changes and molecular adjustments were then made. On a
molecular basis the KNaO content should be low (less than 0.20 equivalent);
the alkaline-earth oxides should be used to raise the RO group to 1.00. High MgO (from 0.40 to 0.50 equivalent) definitely reduces crazing tendencies; CaO and ZnO complete the RO group. The most desirable Al₂O₃ and SiO₂ content is 0.3 to 0.4 and 3.0 to 4.0 equivalents, respectively. The Al₂O₃-SiO₂ ratio considerably affects the finish and texture of the fired glaze. From 0.5 to 0.7 equivalent of ZrO₂ gives satisfactory opacity and improves crazing resistance; B₂O₃, although important as a low-expansion constituent, is limited to 0.2 equivalent.

Ralston Russell, and Mohr (1946) explain the characteristics of zircon porcelain. The manufacturing characteristics, properties, uses, and future possibilities of zircon porcelain are discussed. Any of the usual manufacturing processes may be used, but special glazes must be employed because zircon absorbs normal glazes: The typical properties (approximate values) are (a) linear expansion, 4.5 × 10⁻⁶ per °C., (b) thermal conductivity, 0.012 (normal porcelain, 0.004), (c) tensile strength, 13,000 lb. per sq. in., (d) compressive strength, 100,000 lb. per sq. in., (e) modulus of elasticity, 25 × 10⁶ lb. per sq. in., (f) thermal-shock resistance, good, (g) power factor at 1 mc., 0.001, and (h) dielectric constant.
2.3 Other related studies

Manickam et al. (2002) have conducted a geological exploratory study in conjunction with economic feasibility. It has been found out that the beach sands contain 62.83 per cent of heavy minerals in which 52.4 per cent is garnet. Opaque constitute 27.8 per cent, zircon 9.41 per cent, chlorite 2.24 per cent and other heavies constitute 8.15 per cent. The garnet alone constitutes 32.9 per cent in the raw sand. In the baseline model, the capital cost is estimated to be Rs.1187.48 lakhs, for a plant size of 250 tonnes throughput per day with a mineral separation efficiency of 90 per cent. The annual operating cost and annual revenue are estimated at Rs.537.27 lakhs and Rs.196.52 lakhs respectively. The IRR is 21 per cent which is well above the market rate of interest and the pay-back period is 3.5 years. The sensitivity analysis shows that the annual revenue is the more dominating factor in determining the economic return. The study concludes the garnet mining is profitable at the present prevailing market rate of interest in the study area. Further, the separating of other minerals such as zircon will enhance the profitability of the venture to a greater extent.

Manickam et al. (2001) have carried out a geological exploratory study along with economic feasibility study of the garnet mineral, along the
coast between Chennai and Pondicherry. The heavy mineral deposits with higher garnet content are found around Mahabalipuram and Madras. In this zone, about 23.2 per cent of non-magnetic heavies are found, in which one third is garnet. The authors worked out the economic feasibility of garnet mining. The capital cost of a plant with a capacity of 100 tonnes throughout per day is given as Rs.140.30 lakhs. The annual operating cost is Rs.70.01 lakhs, with an annual revenue of Rs.104.3 lakhs. The life of the project for the base case is computed to be 25 years, the internal rate of return and the pay-back period are worked at 18.6 per cent and 4.1 years respectively. The study has concluded that the exploitation of garnet in the coastal area between Chennai and Pondicherry is profitable.

Elangovan (2001) has studied garnet industry in India. Author has pointed out that India has a leading role to play in the future world market for garnet. Linear and Quadratic trends for the Indian garnet production are estimated. These models have projected the production to 1,26,000 tonnes and 3,19,000 tonnes respectively for the year 2010. The log-linear regression equation has pointed out that the production of garnet in India is significantly influenced by its exports and export price of garnet.
Janardhan (2001) has studied beach placers with the concentration of ilmenite (over 50 per cent visual estimate) located along the seashore above the high water line (tide) commencing from two kilometer west of the Vembar and continuous up to Vaippar river mouth. The sand shores of back waters are the repository of ilmenite placers. Besides this, river sands are also highly enriched in ilmenite. The deposit is traced for about 1.6 km in length and 12 to 25 m in width. At some places the width increases to more than 75 m with thickness over 1 m. Ilmenite deposit is also located about 0.5 km north of Valinokkam on the right bank of Palar, extending over 0.75 km eastwards and about 1 km westwards along the coast. The width of this deposit varies from 3 to 4.5 m and the thickness is 85 to 15 cm and the deposits consist of about 40 per cent of ilmenite with garnet. In the coast south west of the Vembar up to the Vaippar river mouth an average of 40 to 70 per cent of heavies of ilmenite, zircon and garnet is found. The chemical analysis of the samples shows an average of 32 per cent TiO₂ and 28 per cent FeO.

Angusamy and Victor Rajamanickam (2000) have surveyed the southern Tamil Nadu coast with a length of about 360 kms. Among the five sectors viz., Mandapam, Valinokkam, Tuticorin, Manappad and Kanyakumari the researchers found that the Kallar-Vaippar region in
Tuticorin sector stretching 20 km is concentrated with heavies to an extent of 64 per cent, in Kanyakumari with 80-86 per cent, in the Manappad sector, 8.46 to 80.72 per cent, and in the Valinokkam sector, 5.05 to 64.4 per cent are in Tuticorin 5.47 to 10.87 per cent in Manappad.

Victor Rajamanickam (2000) has pointed out that in Thanjavur district of Tamil Nadu, titanium rich beach sand area has been identified over a length of 12 km distance, along the cauvery river delta between Sirkali and Kaveripattinam. According to him, this deposit contains a higher percentage of zircon along with monazite and ilmenite, than the deposits of Manavalakurichi.

Mohan et.al., (1999) have surveyed the coastal area between Vedaranyam and Rameshwaram on the east coast of India extending up to 150 km length and one km width the authors estimated the reserves of ilmenite, magnetite and garnet to be 4.9 m.t, 4.3 m.t, and 6.0 m.t respectively. Buried placer deposits are also identified in the same coast with 20 km width. They estimated the probable reserves of ilmenite, magnetite and garnet to be 87.9 m.t, 98.6 m.t, and 120.5 m.t respectively.

Chandrasekaran et.al., (1998) identified heavy mineral concentration at Manavalakurichi near Kanyakumari, Tamil Nadu. The deposits are found
to contain 15.5 per cent of ilmenite, 2.6 per cent of sillimanite, 2.4 per cent of garnet, 1.2 per cent of zircon, 0.9 per cent of rutile, 0.7 per cent of leucoxene, 0.7 per cent of monazite and 0.1 per cent of kyanite. A stretch of the 7 km long bay between Muttam and Colachal has been found with high concentrations of heavies (15.6 to 39.2 per cent with a thickness of 7.5 m) when compared to the other areas of the region.

Dikshitulu et. al., (1998) identified the enrichment of ilmenite, rutile, zircon, garnet, monazite, magnetite and pyrobole in the coastal stretch between the Kakinada and the Tandava rivers in the East Godavari district, Andhra Pradesh. The deposit is found in the sea floor at a depth of 12m. The grade of the ilmenite is favourable for titanium slag production.

Elangovan et al., (1998) have discussed the economic viability of garnet along the coast between Kanyakumari and Mandapam, Tamil Nadu. This study has applied the capital budgeting techniques such as net present value, internal rate of return, simple payback period and sensitivity analysis. The study concludes that garnet mining is economically feasible. The authors have estimated that the capital cost of a garnet mining plant with a capacity of 100 tonnes throughput per day is Rs.2.51 crores. The operating cost is worked out to an extent of 20 per cent of the capital cost. The annual
revenue and net cash flow are estimated at Rs.1.732 crores and Rs.1.232 crores. The pay-back period and the life of the projects are worked out to 2.5 years and 20 years respectively. The results of the sensitivity analysis have shown that a 10 per cent change in capital cost, operating costs and annual revenue does not have any considerable effect on the economic feasibility of garnet mining in the study area.

Murthy et al., (1998) have reported the occurrence and distribution of heavy minerals on the eastern seabords of India (Kooyam deposits) between Mukampet village, in the South, and the Nagavali River, in the North, in Srikakulam district, Andhra Pradesh. The study area stretches a over 20 km distance with an average width of 800 meter. The concentration is 8-22 per cent in the central sector of the study region, and 12-33 per cent in the Southern and Northern sectors, respectively. Of the total Indian ilmenite reserve of about 278 million tonnes, the Northern Coast of Andhra Pradesh alone contain 50 million tonnes. This deposit contains 2 million tonnes of ilmenite with a working grade of 10 per cent, 1.5 million tonnes of garnet, 1.9 million tonnes of sillimanite, 0.15 million tonnes of rutile, 0.15 million tonnes of leucoxene, 0.08 million tonnes of zircon, and 0.62 million tonnes of monazite.
Nagamallawrara Rao (1998) identified a high potential of economic minerals like garnet, ilmenite, zircon, rutile, and monazite in the Visakhapatnam-Bhimunipatnam sector (VB). In this region the heavy minerals content in the beach and dune deposits are 90 per cent and 35 per cent respectively. In the Itamsaladivi-Manginipudi (HM) region, the placer minerals are abundant with magnetite (45 per cent), ilmenite (28 per cent), avgite (19 per cent) and other minor minerals. In the Vashishta Godavari-Upputeru (VGU) region ilmenite and magnetite are in equal proportions (34-35 per cent) and others are to be less than 10 per cent.

Rao et al., (1998) have studied the placer mineral reserves in the coastal area between Machchali-Sunnapalli in the South to the Bendi Creek in the North, Srikakulam district in Andhra Pradesh. This area is estimated to contain 29.78 million tonnes of total heavies. These deposits are estimated to have 10.4 million tonnes of ilmenite (51 per cent TiO₂), 10.04 million tonnes of garnet, 7.37 million tonnes of sillimanite, 0.39 million tonnes of rutile, 0.35 million tonnes of leucoxene, 0.21 million tonnes of zircon, and 1 million tonnes of monazite.

Chandrasekar and Victor Rajamanickam (1997) classified the central Tamil Nadu coast into three sectors according to the level of concentration
of heavy minerals. They are the Northern sector (Pondicherry to Porto Nova), the central sector (Porto Nova to Thirumullaivasal) and the Southern sector (Thirumullaivasal to Nagapattinam). These sectors are endowed with average heavy mineral concentrations of 7.6 percent, 20.5 percent and 25.6 per cent respectively. The authors has estimated the zircon reserves in the study area to be of 1.74 million tonnes in the area of about 45 sq. km in the South Zone. The deposits between Pallithoppu–Rajakkamangalam contain 50 per cent of ilmenite in the heavies followed by sillimanite (28.3 per cent), zircon (4.7 per cent), rutile (3.6 per cent), monazite (1.74 per cent) and pyribole (0.32 per cent). Here the total heavy mineral reserves are estimated at 1.21 million tonnes with an average grade of 6.32 per cent permeated upto a thickness of 6.35 m.

Yugandhara Rao et. al., (1997) have studied the heavy mineral potential of red sediments spreading over 18 km in Chatrapur of Ganjam district, Orissa. The red sediments are divided into two groups. They are semi-consolidated and unconsolidated sediments. The former consists of an average of 35 per cent of heavies, with a thickness of 5 to 30 m. These deposits contain important economic minerals such as ilmenite (15.15 per cent), rutile (4.66 per cent), zircon (4.22 per cent), monazite (2.77 per cent), garnet (1.06 per cent) and sillimanite (11.83 per cent). The latter type
consists of an average of 29 per cent of heavy minerals occurring 3 to 4 m of thickness.

Victor Rajamanickam (1993) has estimated that the Vaippar reserves have a of 0.1 million tonnes of ilmenite, 0.13 million tonnes of monazite, 0.638 million tonnes of zircon and 11.05 million tonnes of garnet.

Augusamy et.al., (1992) have estimated 0.49 million tonnes of zircon, 6.13 million tones of garnet, 6.01 million tonnes of ilmenite, 0.10 million tonnes of magnetite and 0.84 million tonnes of monazite in the coast between Mandapam and Kanyakumari in Tamil Nadu.

Chandrasekar (1992) has identified enrichment of ilmenite, zircon, garnet and kyanite between Nagore and Thirumullaivasal in the central coast of Tamil Nadu, India. He has estimated the heavy mineral percentage to be between 3-56 per cent and the reserves of zircon to be 1.74 m.t, up to a depth of 1m.t.

The Geological Survey of India (1992) has conducted a reserve survey of heavy mineral deposits in the Varkala and Chavara sectors of Kerala, in 0 to 4 m of water depths. The inferred reserve is found to be 0.953 and 0.461 million tonnes of ilmenite, 0.313 and 0.207 million tonnes of
sillimanite and 0.058 and 0.060 million tonnes of zircon in the respective sectors.

The Geological Survey (1992) of India has estimated that along the Orissa coast, at depths of 0 to 1 m, a reserve of 17.28 million tonnes of ilmenite, 6.8 million tonnes of sillimanite, 4.86 million tonnes of garnet, and 1.62 million tonnes of monazite, zircon and rutile occurs.

Sengupta et al., (1992) have estimated placer reserves along the Orissa Coast up to a depth of 1 m. They have estimated 17.28 million tones of ilmenite, 6.8 million tones of sillimanite, 4.86 million tones of garnet, 1.62 million tonnes of monazite and the presence of zircon and rutile.

Gujar (1989) has conducted a survey of shallow seismic profiling and magnetic covering about 90 sq. km the carried out in the near shore area (up to 20 m water depth) of 2 bays, the Pawas and Purangad in the Konkon coast, the west coast of India. The onshore beach placer sands extend offshore to a water depth of 10-11 m beyond which it is covered by clays. The surficial sands in these bays contain up to 93.69 per cent of heavy minerals with an appreciable amount of ilmenite and magnetite. The thickness of heavy minerals rich sand is 2-3 m. In the study area, the heavy mineral concentrations range up to 60 percent in the Pawas bay and 80
percent in Purangad bay. The heavy mineral assemblage mainly consists of ilmenite (up to 22 per cent in the Pawas and up to 17 per cent in the Purangad) and magnetite (up to 47 per cent in the Pawas and up to 43 per cent in the Purangad). The remaining mineral consists of minor quantities of auquite, epidote, tourmaline, hornblende, rutile, zircon and kyanite. The lighter minerals are quartz and feldspar. Chemically these placers contain on an average 34.65 per cent Fe₂O₃ and about 10 per cent of TiO₂ in the Purangad sand. The offshore reserves of ilmenite and magnetite are inferred to be about 1 and 3.2 million tonnes respectively.

Mahadevan et.al., (1958) have evaluated the reserves of the south-west coast of India in the Neendakara region covering 586.6 acres with a thickness of 25 ft and further inland 16 ft. The study area has a reserve of 52 m.t. This area is also found to have 787 m t. of zircon.

The petrographical study conducted by Sri Ramadas (1951) along the Vishakhapattnam beach proved that the bulk of the heavy minerals are distributed at or near the mouths of the streams with the domination of finer grades. Monazite and zircon have striking similarity along with workable quantities of ilmenite, monazite, zircon, etc.
2.30 Overview

Earlier studies discussing the development of zircon mining industries in various aspects at state level particularly at Tamil Nadu level is very much limited. Hence the present study makes an attempt of studying zircon mining industrial development in Tamil Nadu in terms of deposits, sand investigations, processing, and uses of zircon. The researcher hopes that the study will give a detailed picture discussing the marketing and trade performance of zircon industries in Tamil Nadu. Thus the present study is not only an attempt to fill up the above mentioned research gap but it is also a piece of contribution to the existing knowledge about various aspects of zircon mining industrial development. Moreover, this study is both follow-up work and improvements over the previous studies on zircon mining industrial development.

. This research tries to focus on this aspect and in the next chapter concepts and methods necessary for this analysis are discussed.