UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROJECT REPORT
Ceylon Investigations
(IR) CE-3

ILMENITE BEACH PLACER, PULMODDAI, CEYLON
AND ILMENITE RESOURCES OF THE
PLEISTOCENE AND HOLOCENE FORMATIONS OF CEYLON

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William C. Overstreet
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ABSTRACT

The ilmenite beach placer at Pulmoddai on the northeast coast of Ceylon about 35 miles northwest of Trincomalee has been mined by the Ceylon Mineral Sands Corporation since 1958, when 2000 tons of ilmenite concentrate was exported. The Corporation, an enterprise of the Government of Ceylon, produced between 4,220 and 82,851 metric tons of ilmenite annually, 1960-69; the by-product output of rutile was 1100 metric tons in 1969. The deposit is 4.5 miles long, about 150 feet wide, at least 6 feet deep and consists of a natural black beach sand containing 95 percent of fine-grained heavy minerals of which about 75 percent is ilmenite and 20 percent is zircon and rutile. The balance is chiefly quartz. This remarkable concentration permits the natural sand to be treated directly by electromagnetic separation, after drying and screening but with no preconcentration, to produce a commercial ilmenite separate.

The geology and origin of the deposit are largely unknown. Early proposals suggested that ilmenite was originally deposited in the Bay of Bengal by streams flowing off the weathered plutonic rocks of Ceylon, and the placer was formed by the action of monsoon storm waves casting ilmenite upon the beach from the bed of the Bay. Recently the role of Pleistocene and younger coastal sedimentary rocks as an intermediate host for the detrital ilmenite has been recognized, and the concept has been developed that destruction of this host by storm waves under appropriate conditions led to the formation of the deposit. The actual natural conditions of the coast are recognized in both views as important in the original deposition of the placer and in its renewal.

Long-term exploitation of the Pulmoddai placer and improvement of the facilities require sound knowledge of the origin of the placer, wave energy patterns, and distribution of reserves by grade, both onshore and offshore. Therefore, a two-year research project to solve these unknowns is proposed jointly for the Ceylon Mineral Sands Corporation and the Geological Survey Department of Ceylon with technical direction by a senior marine geologist from one of the foreign assistance programs aiding the Government. Specialized equipment supplied through foreign assistance would be used in other major programs of exploration for ilmenite placers after the project is terminated.

The role of the Pleistocene and younger coastal sedimentary formations as an intermediate host for ilmenite offers the attractive possibility that these formations may locally contain large-volume, low-tenor ilmenite placers resembling three deposits mined in Florida, U.S.A., at the rate of 40,000 cu. yds. per day each. Should similar placers be present in Ceylon, they might be minable in 10 to 20 years time when sufficient cheap electricity is available to exploit them. Long-range plans for the economic development of Ceylon should provide an evaluation of this possible resource. Therefore, it is proposed that a 12-year program be inaugurated in the Geological Survey Department of Ceylon to evaluate ilmenite in the Pleistocene and Holocene sedimentary formations along the coasts of Ceylon. The proposed project would consist of four phases to run consecutively for 2 years, 4 years, 2 years, and 4 years.

Phase I would be concurrent with the proposed study of the Pulmoddai deposits. Aeroradioactivity and airborne infrared surveys would be made of the beach areas northward from Colombo to Jaffna thence southeastward to Pulmoddai. Geomorphological investigations of the Pleistocene and younger formations would begin at Kudremalai Point, and personnel would receive training in the Pulmoddai project in marine geology and in the use of special equipment. Phase II would be a major geologic mapping and sampling program from Kudremalai Point to the Jaffna District to evaluate the Pleistocene and Holocene sedimentary rocks as sources for ilmenite. During Phase III two field parties would complete the geologic mapping and sampling of the Pleistocene formations southward from Kudremalai Point to Colombo and southward from the Jaffna District to Pulmoddai. In Phase IV aeroradioactivity and infrared surveys would be made of the remainder of Ceylon's shoreline, the coastal sedimentary formations showing greatest radioactivity would be evaluated for ilmenite and other heavy minerals, and an offshore marine geological survey would be made of the Ceylonese parts of the Gulf of Mannar, Adams Bridge, and Palk Strait. The purpose of the aeroradioactivity survey would be to detect surface concentrations of zircon which could be used as a pathfinder mineral for ilmenite, because zircon contains small amounts of uranium and thorium that are lacking in ilmenite. Use of color infrared aerial photographs in conjunction with the survey is recommended as an aid to the photogeological interpretation of the sedimentary formations. Little foreign assistance would be needed after Phase I.

INTRODUCTION

Placer mining in Ceylon

Placer minerals of various sorts are an important natural resource of Ceylon. Some minerals, like exotic gemstones, have been mined from stream channels and valley floors since antiquity. Other placer minerals of a more prosaic use have been recovered from the beaches of Ceylon since the early 1900's with increasing output and continuity of exploitation since the 1950's. The earliest mineral to be mined in Ceylon from beach placers was monazite, an ore of the cerium earths and thorium (Overstreet, 1967, pp. 58-60). The main Ceylonese sources for this mineral have been the south and southwest coasts of the island (figs. 1 and 2); the principal source presently is at Beruwala. In processing monazite-bearing sands from the beach at Beruwala, zircon and baddeleyite (ores of zirconium and hafnium) are by-products (see appendix). The largest beach placer exploited in Ceylon for ilmenite and rutile (ores of titanium) is on the northeastern coast in the vicinity of Pulmoddai (fig. 2); other ilmenite

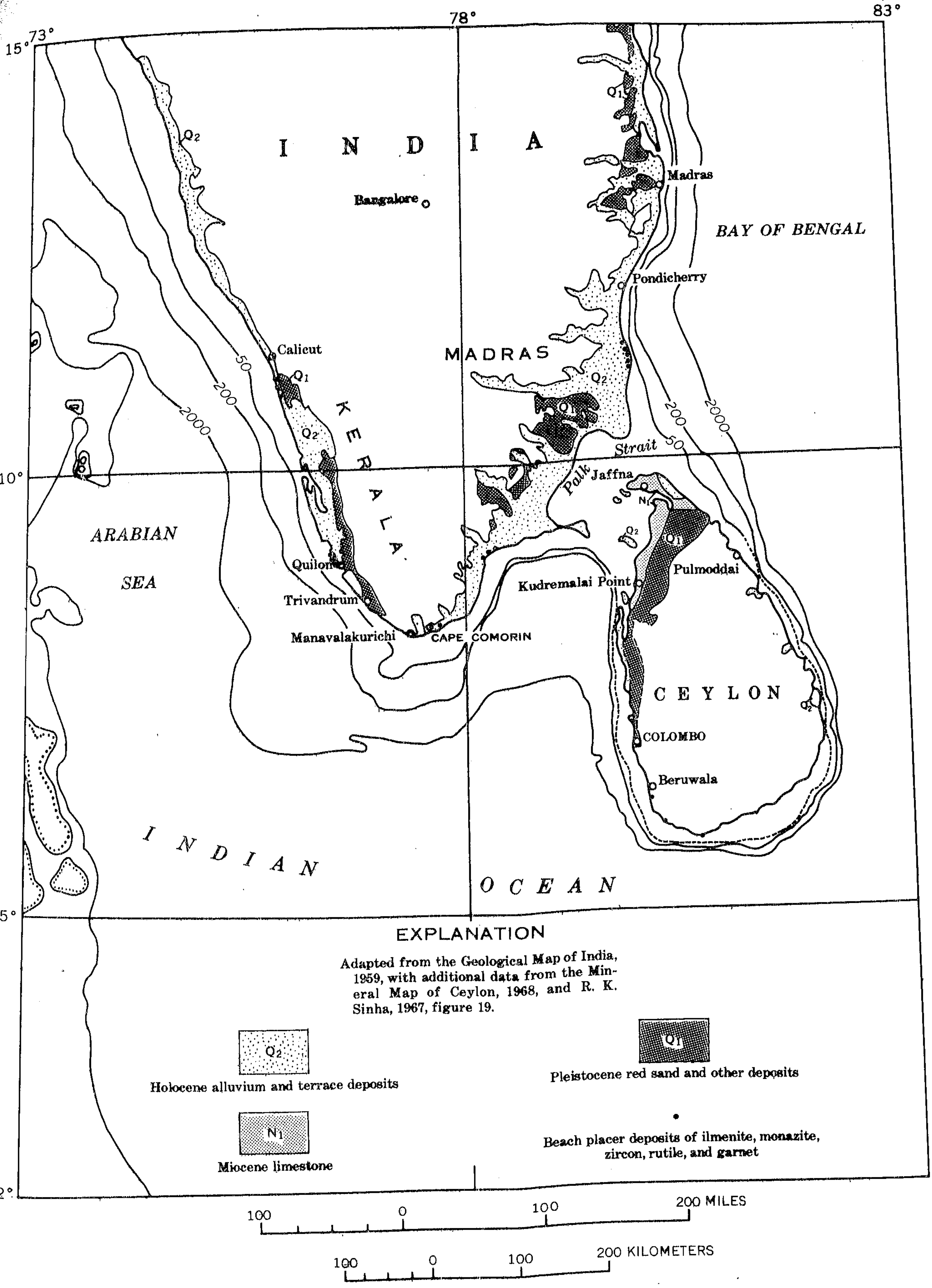


Figure 1.—Map showing distribution of heavy-mineral-bearing Pleistocene sand in northern Ceylon and southern India.

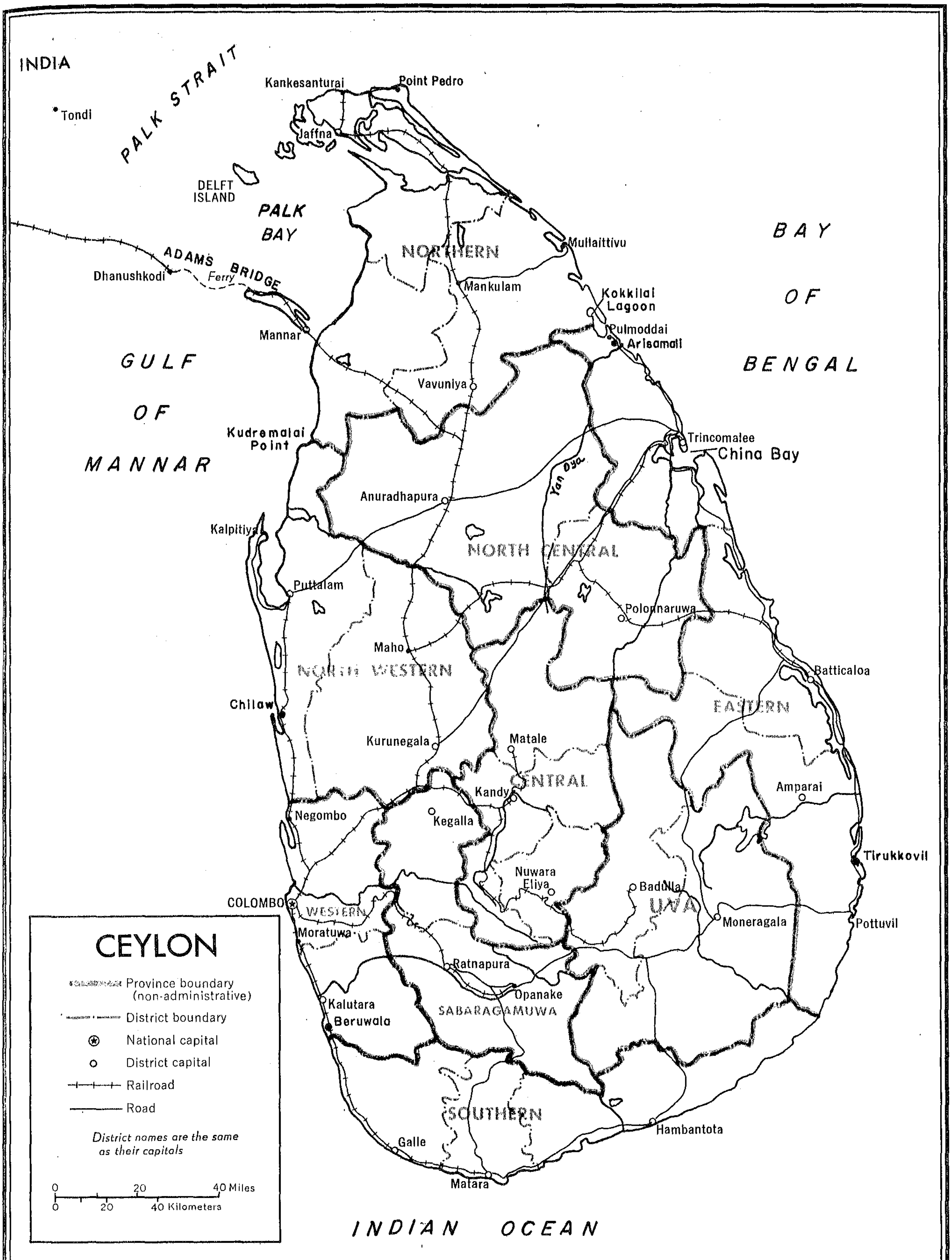


Figure 2. Index map of Ceylon showing location of places referred to in text.

placers are known farther south on the east coast, and on the southern and western coasts. Ilmenite is sufficiently common in most of the beach placers to give a black color to the heavy sands (Coates, 1935, pp. 183-185; Wadia, 1944, p. 8; Fernando, 1948, p. 320; Davidson, 1956, p. 202). Small amounts of sillimanite, thorianite, spinel, and other mineral species characterized by chemical stability and resistance to abrasion are also present (Fernando, 1970, pp. 26-27), but they are not recovered. The ultimate sources of the placer minerals are the deeply weathered plutonic rocks of the Precambrian complex making up most of Ceylon (Fernando, 1970, p. 26).

Mining and sale of Ceylon's beach placer minerals is conducted by a Government-sponsored company, the Ceylon Mineral Sands Corporation, which in 1970 was producing monazite, zircon, and baddeleyite near Beruwala and ilmenite and rutile at Pulmoddai.

Technical cooperation between the staffs of the Ceylon Mineral Sands Corporation and the Geological Survey Department of Ceylon in investigations of the geology and mineralogy of the deposits, the chemical composition of the mineral products, and techniques for mineral separation has been advantageous to the operation of the Corporation. This cooperation has been achieved through the initiative of Mr. L. J. D. Fernando, former Director of the Geological Survey Department, who was responsible for calling Government attention to the ilmenite deposits at Pulmoddai. For several years prior to his retirement in late 1970 from the Geological Survey, Mr. Fernando served as Chairman of the Ceylon Mineral Sands Corporation. Since retirement from the Survey he has devoted full attention to the Corporation.

The Ceylon Mineral Sands Corporation is training two men for geologic investigation of the Pulmoddai placer, but owing to the close association with the Geological Survey Department of Ceylon, has not maintained a staff for other geological exploration. Such long-range exploration for other deposits can be best conducted by the Geological Survey Department, which has the trained personnel, equipment, and experience for this work. In the early spring of 1970, an investigation by the Geological Survey for cement raw materials in northern Ceylon yielded samples from Pleistocene formations which Mr. Fernando considers to have major geologic implications for future exploration of ilmenite.

Purposes of report

This report was prepared to serve three purposes. The first purpose is to mention the discovery of ilmenite in the Pleistocene formations by the Geological Survey Department of Ceylon, and to evaluate this resource with the presently mined beach placer at Pulmoddai. Descriptions of the Pulmoddai placer and the Pleistocene formations are given. Preliminary evidence indicates that the Pleistocene formations were the intermediate host for the ilmenite mined at Pulmoddai, and that similar formations in northern Ceylon and south India may constitute one of the world's great titanium resources.

The second purpose is to recommend the need for a detailed study of the Pulmoddai beach placer to evaluate grade and reserves of onshore and offshore deposits. Such a study would give a sound basis for the planning of future mining at Pulmoddai, and would be an important contribution to the knowledge of the formation of beach placers and of the marine geology of coastal areas subject to monsoon storms.

The third purpose is to recommend the need for a long-term research project to evaluate the Pleistocene formations in Ceylon for possible large-volume, low-grade ilmenite placers suitable for exploitation beginning about 1980-90 when the island's capacity for generation and distribution of electricity might support low-cost, large-scale mechanized mining, and, possibly, a titanium and zirconium metallurgical industry.

Acknowledgments

It is a pleasure to acknowledge the aid given me by the staff of the Geological Survey Department of Ceylon during three visits to the island. In January 1965 Mr. L. J. D. Fernando, then Director of the Survey, showed me the Beruwala beach placer at which time we discussed the possible modes of origin of the baddeleyite (see appendix) he had discovered in the concentrates and had successfully separated on a commercial scale. In April 1970, while I was in Ceylon to plan a United Nations Seminar on Geochemical Prospecting to be held at the University of Ceylon, Peradeniya, 10-20 September, 1970, Mr. Fernando and Mr. D. B. Pattiaratchi, then Deputy Director of the Geological Survey Department of Ceylon (Director since January 1971), discussed the discovery by the Survey of ilmenite in the Pleistocene formations of northern Ceylon. Following the Seminar, Mr. Fernando kindly conducted me, as a guest of the Ceylon Mineral Sands Corporation, to the beach placer at Pulmoddai on September 28-29, 1970, to review briefly in the field the geologic relations of this deposit. These courtesies are most sincerely appreciated.

ILMENITE PLACER AT PULMODDAI

Geographic setting

Location and accessibility

The Pulmoddai ilmenite placer (fig. 2) is on the northeast coast of Ceylon and extends southeastward for 4 1/2 miles from the mouth of Kokkilai Lagoon (fig. 3A) to the ridge of Arisamali (fig. 3B) which forms a promontory projecting northeastward into the Bay of Bengal. Lower-grade ilmenite sands are found along the beach for 0.5 mile north of the mouth of Kokkilai Lagoon.

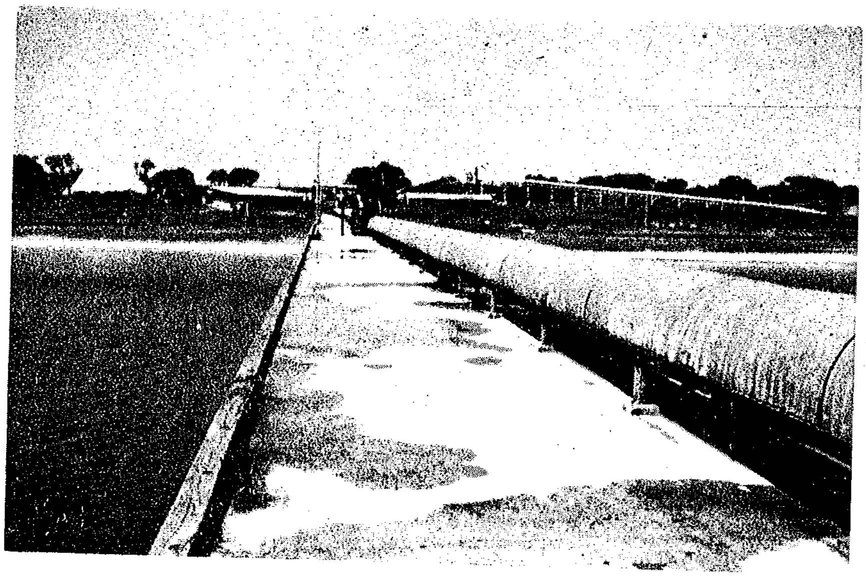
The placer is named for the former fishing village of Pulmoddai, where the loading dock, dry concentrating plant, electrical generating plant, and residential community of the Ceylon Mineral Sands Corporation are located (fig. 4A). The road linking Pulmoddai with the main northerly and northeasterly routes radiating from Anuradhapura and Vavuniya was constructed to supply the mine. A road leads along the coast southeastward from Pulmoddai about 34 miles to the major port of Trincomalee.

Pulmoddai affords an open road instead of a protected harbor. Owing to the gentle shelving of this part of the coast, ships must lie 1 1/2-2 miles offshore to receive or unload cargo for Pulmoddai (fig. 4B). The Ceylon Mineral Sands Corporation operates a shallow-draft tug and lighters to haul bulk ilmenite from the end of the loading dock to the waiting freighters. Clamshell-type grabs of about 1 cu. yd. capacity are lightered out to the freighters to assist loading the bulk ilmenite from the lighters to the freighters.

A. Mouth of Kokkilai Lagoon and Kokkilai village as seen looking north from the northern end of Pulmoddai placer.

B. View southward of Arisamali ridge from the southern end of the Pulmoddai placer. Note black sand on beach.

Figure 3. Northern and southern limits of the Pulmoddai beach placer.



A. Loading dock in foreground; in right background the dry concentrating plant; in left background the storage sheds for ilmenite concentrate.

B. View northwestward from foot of Arisamali ridge toward loading dock and facilities at Pulmoddai, showing navigation beacon on extreme left to aid freighters in anchoring off Pulmoddai

Figure 4. Installations of Ceylon Mineral Sands Corporation at Pulmoddai.

The port at Pulmoddai is closed for about 5 months per year, between October and March, when the full blast of the northeast monsoon strikes the coast. During that period the storm waves are too high to permit the mining of the beach, the lightering and transhipment of ilmenite concentrate, or the anchoring of freighters.

Climate

Pulmoddai is in the dry zone of Ceylon (Soil Survey Staff, 1967) which receives less than 75 inches of rainfall per year (Kalpagé, 1970, p. 1). Most of this precipitation is between October and March during the northeast monsoon. The remainder of the year tends to be dry; thus, water conservation and rationing become necessary at Pulmoddai. Warm, tropical weather prevails, but because of the seasonal distribution of the rain, dense forest conditions are not common.

Discovery, development, and output

The ilmenite placer at Pulmoddai has been known to the profession since the 1920's from descriptions by Adams (1929) and Coates (1926; 1935). Attention was again called to the deposit in 1943 by Wadia (1943, p. 10), who estimated that the Pulmoddai placer contained 3 1/2-4 million tons of ilmenite, a figure that does not include the resources in lower-grade deposits backing the beach (Fernando, 1948, p. 321). In 1948 the Geological Survey Department of Ceylon began more detailed work on the deposit, and Mr. Fernando commenced to promote its possibilities for exploitation. Through his efforts the placer was opened by the Ceylon Mineral Sands Corporation as a Government enterprise, and production began in 1958 with a shipment of 2,000 tons of ilmenite. Production and exports from 1960-1969 are given in table 1. In 1970, between 75,000 and

Table 1. Ilmenite produced at and shipped from the Pulmoddai beach placer, Ceylon, between 1960-1969. (Metric tons).

Year	Production	Exports
1960	a/ 6,096	No data
1961	a/ 10,161	No data
1962	a/ 4,220	a/ 2,794
1963	a/ 19,088	b/ 20,176
1964	b/ 46,158	b/ 37,575
1965	b/ 49,200	No data
1966	c/ 41,198	c/ 41,200
1967	c/ 52,298	c/ 54,476
1968	c/ 74,605	No data
1969	d/ 82,851	No data

a/ Kimbell, 1964, tables 1 and 2.

b/ Shekarchi, 1967, tables 1 and 2.

c/ Staff, Division of International Activities, 1970, tables 4 and 5.

d/ Cole, 1971, table 11, preliminary data.

80,000 tons of the more than 80,000 tons of ilmenite produced during the year was shipped in 11 Japanese freighters. Ceylon's position in world production can be seen by comparing the data in table 1 with data in table 3.

The area first mined is south of the plant at Pulmoddai and extends nearly to Arisamali. Later, areas north of the plant were worked, and in September 1970 the main mining activity centered about 2 1/2 miles north of the plant. Raw sand is scooped from the beach by mechanical loaders and put in 4-wheel trailers hauled by farm tractor southward down the beach to the dry plant where an ilmenite concentrate is obtained by electromagnetic separation without prior treatment except air drying and screening to remove shells and other trash. During the monsoon season when the plant processes stockpiles of raw sand, it is necessary to use a rotary kiln to dry the sand before screening and magnetic separation. Direct dry processing of the raw beach sand by electromagnetic separators without a preliminary wet concentration stage is made possible by the extraordinary original concentration and uniform fine size of the raw sand: virgin sand in the placer contains about 73-75 percent ilmenite, 10 percent rutile, 10 percent zircon, less than 1 percent combined monazite, sillimanite, and spinel, with the balance quartz. The ilmenite is reported (Fernando, 1948, p. 321) to contain 52 to 52.8 percent of TiO_2. This is about 8 percent less TiO_2 than that in the ilmenite product sold by Travancore Minerals Limited, of Quilon, India, which exports ilmenite having 60 percent TiO_2 from a deposit 14 miles long, 0.5 mile wide, and 22 feet deep reported to contain 35 percent of ilmenite (Travancore Minerals Ltd., 1964). However, the Indian production in recent years has been less than that at Pulmoddai.

Tailings from the electromagnetic separation of the ilmenite are rich in rutile and zircon. In 1970 these tailings were still being shipped by Corporation barge and tug, between March and October, southward 42 miles along the coast to China Bay where the Corporation has an electrostatic dry concentrating and bagging plant. This plant is a holdover from management prior to Mr. Fernando's chairmanship, and is necessitated by a shortage of electric power at Pulmoddai. At the China Bay plant the tailings are separated into a rutile concentrate and a zircon concentrate. These products are packed in 8-ply paper bags weighing 112 pounds each for shipment. China Bay is an open port year-around, in contrast to the 7-month open shipping at Pulmoddai; thus, rutile can be exported any time of year on any available carrier. However, the cost in 1970 to haul the tailings to China Bay was 43 rupees per ton, which is uneconomical. Inasmuch as about 200 tons per month of rutile was being produced in 1970, and the annual production of rutile in 1968 and 1969 was respectively 1152 and 1100 metric tons (Cole, 1971, table 11), plans were being made in 1970 to abandon shipping to China Bay and to move the electrostatic separators and bagging equipment to Pulmoddai to achieve integrated and less expensive processing and distribution. The move will probably need to be delayed until 1972 or 1973 when Pulmoddai will be linked to the national electrical distribution grid, because the Diesel generating plant at Pulmoddai cannot accomodate the additional load of the electrostatic separators. It is expected that the sacked rutile and zircon can be exported on the same ships that take the bulk ilmenite concentrate from Pulmoddai.

An increase in the capacity of the Pulmoddai plant to 130,000 tons per year of ilmenite concentrate is planned for completion by 1973 to take advantage of the proposed tie-in of Pulmoddai with the national electrical distribution grid. In 1970 the plant housed 14 Japanese-made electromagnetic separators which had been completely rebuilt locally to meet the special requirements of the Pulmoddai ilmenite sands following 6 months of study by Mr. Fernando of the performance of the separators. This study was made at the heavy-mineral laboratory of the Geological Survey Department of Ceylon, situated near Beruwala south of Colombo, on sands shipped from Pulmoddai.

In order for the Ceylon Mineral Sands Corporation to enter competitive international trade and to have an assured early market for the small quantities of ilmenite first produced, the Corporation negotiated contracts with one main Japanese buyer, and several lesser buyers, for the sale of concentrates at slightly less than yearly average world prices. This achieved purchaser interest and gave the Corporation needed market penetration. At subsequent renewals of the contracts the differential between world average prices and the prices asked by the Corporation have been reduced, although they were still lower than world price in 1970. These early decisions on price policies have given the Corporation an entry which its small annual production could not otherwise have found.

As early as 1943, Wadia (1943, p. 10) in calling attention to the Pulmoddai ilmenite placer and Ceylon's other titanium resources, foresaw the benefit to Ceylon in processing the ilmenite locally as far as possible: "...The [titanium pigment] industry is guarded by patent rights, but as the possessor of large reserves of ilmenite, yielding 62 percent of titanium oxide, it behoves Ceylon chemists to apply themselves to finding out a feasible economic process for industrial making of titanium dioxide. The Ceylon ilmenite after careful magnetic separation is free from chemical or mineral interfering substances and the local production in bulk of titanium dioxide fit for the highly remunerative pigment industry, appears an attractive possibility."

The concept of exporting a finished product instead of a raw material or semi-finished product is, of course, fundamental to thoughts of economic development. However, the state of the titanium pigment industry is such that the ilmenite production at Pulmoddai has been, and is, too small to support economically the local manufacture of internationally competitive titanium pigment.

Similar ideas were raised in discussion on 20 September 1970 by two members of the Faculty of Engineering of the University of Ceylon at Peradeniya: Dr. A. R. T. De Silva and Dr. D. J. Hughes. The issue discussed then was the possibility of founding an indigenous titanium metal industry on the ilmenite and/or rutile at Pulmoddai. De Silva and Hughes were concerned with the extent to which a possible local titanium manufacturing industry would need to be supported by special courses for students at the University. Inasmuch as the production of titanium metal is more costly than the manufacture of titanium pigment, I expressed the opinion that the Pulmoddai placer, as presently known and exploited, was too small to support a local titanium metal industry.

The most important present economic role for the Pulmoddai placer, and one that it might well occupy throughout the next decade, is a source for ilmenite, rutile, and zircon concentrates for export. During the next few years some detailed studies of the origin, grade, and size of the deposit must be made in order to modify and enlarge the physical facilities of the plant for mining the sand. Comment on these studies is given below, but it should be noted here that they are of utmost immediate need as the following two examples will show.

Plans for a jetty and protected loading dock at Pulmoddai are said by the local manager to have been abandoned because it was thought that they would interfere with the transport of ilmenite by monsoon storm waves from the bed of the Bay of Bengal to the beach, where the ilmenite is annually replenished by wave action. The concept that storm waves fling up ilmenite onto the shore from underwater deposits discharged by streams is widely held, but no study of the actual movement of the ilmenite grains has been made, although the offshore deposits have been spot sampled. Doubtless it is not a bad idea to delay this construction until the wave-energy pattern and the movement of ilmenite on the beach from Kokkilai Lagoon to Arisamali is actually known. Whether or not the replenished ilmenite comes from the offshore area or is recycled on the beach is of less immediate importance to the evaluation of the effect of a jetty on local wave action than the certain observation that wave action renews the placer. Modification of the pattern and energy of the waves by a jetty or other construction would certainly change conditions on the beach.

The aforementioned professors expressed a concern over ideas they had heard that the Pulmoddai placer was washing away into the Bay of Bengal, and that if something wasn't done to prevent this loss, Ceylon's resource in ilmenite would be foreclosed. The source of this idea was not identified, nor was any evidence marshalled to support it, but these concerned engineers wondered if the Government wouldn't be better advised in the near future to move the whole deposit above the reach of the waves than to sell it off in small amounts annually while greater quantities, supposedly, were being forever lost to the Bay. Natural anxieties of this sort over the fate of this resource will persist and possibly magnify, until the geologic facts are known. Once these facts are available, the options and activities open to the Government in the exploitation of the deposit can be evaluated. Inasmuch as the beach has been known to the profession since the 1920's and probably has been known as far back as any written record or local tradition, it is unlikely that the placer would be eroded away during the time required for a geologic study. Furthermore, the high cost of transplanting the deposit would prohibit the profitable sale of the ilmenite.

Geology

Shape and stratigraphy of the placer

Detailed geologic mapping of the Pulmoddai placer had not been undertaken by September 1970. However, two young men were being trained by Mr. Fernando in the Ceylon Mineral Sands Corporation to study the mineralogy of the deposit, to conduct chemical and sieve analyses of the sand, and to work on the geology of the placer. A large amount of mineralogical and chemical data have been acquired as part of process control during the separation of ilmenite from both virgin sands and the replenished sands deposited by monsoon wave action in areas already mined. Such records are filed, and splits of raw sand, ilmenite concentrates, and tailing have been retained. Thus, a good deal of information about the composition of the beach sand at various mined areas could be recovered from company records.

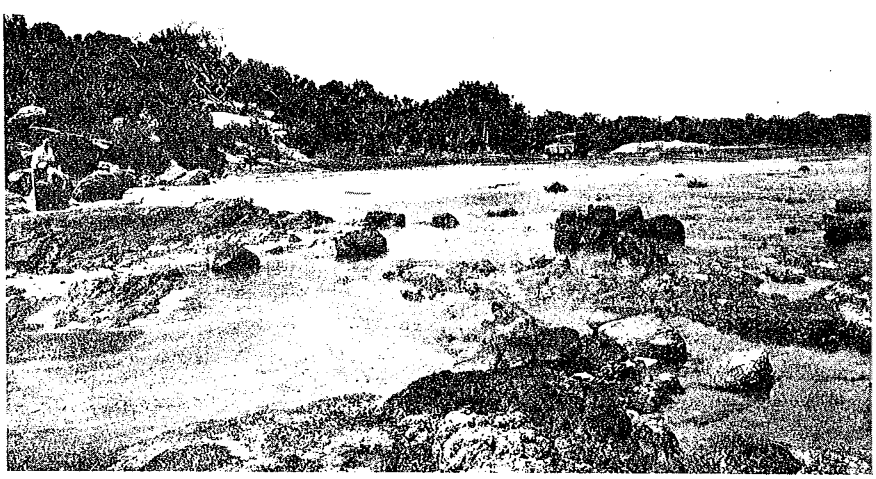
Holes have been drilled to bedrock at 1/2 mile intervals along the Pulmoddai placer at Mr. Fernando's direction. He also directed programs of spot sampling offshore, and of pitting or drilling behind the beach. Mr. Fernando believes the Pulmoddai beach placer originated through the erosion of pre-existing Pleistocene red-sand deposits along an emerging coast line; the normally low concentrations of ilmenite, zircon, and rutile in the red sand were reconcentrated into the present high-grade deposit through wave action during the northeast monsoon (Fernando, L. J. D., oral commun., Sept. 29, 1970). In his view, the angle of the shore line to the storm waves, the gentle off-shore slope, and the promontory of Arisamali are factors in the localization of the placer.

Another current idea is that ilmenite and other heavy minerals are raised from the Bay and deposited on the beach by waves of the northeast monsoon. Similar ideas were long held for certain ilmenite- and monazite-rich beach sands on the southwest coast of India, but offshore sampling failed to bear them out (Gillson, 1950, p. 689; 1959, p. 428).

The main black-sand beach extends from the low-tide line to a low berm marking the normal high-tide or storm limit of wave action (fig. 5A). Probable fixed dune and monsoon storm deposits succeed the berm inland. The rocky north shore of the Arisamali headland proper, forming the southern terminus of the placer, lacks black sand (fig. 5B), but from the north groin between the headland and the beach, black sand deposits resembling those of figure 5A are continuous and uniform in composition but of somewhat variable width to Kokkilai Lagoon. Several small estuaries formed by intermittent streams that flow during the northeast monsoon season, and are partly flooded by high tide, cut across the placer, but their channels are small compared to the size of the placer.

Even following the heaviest storms, the rocky north shore of the Arisamali promontory is said never to display any concentration of heavy minerals. This feature in itself is notable and needs explanation, particularly if it is thought that the floor of adjacent parts of the Bay of Bengal is the source of the black sands on the beach north of Arisamali. Between the low-tide line and the high-tide berm the beach ranges in width from about 100 feet to about 300 feet and may have an average width of about 150 feet.

A. View looking southeastward from a point 0.5 mile south of the mouth of Kokkilai Lagoon; Bay of Bengal on left; high-tide berm on right succeeded inland by fixed dune and storm deposits covered with low brush and vines.



B. Rocky north shore of Arisamali in foreground; south end of Pulmoddai placer in background.

Figure 5. Black-sand beach of Pulmoddai placer.

The holes drilled at 0.5-mile intervals along the beach were said (Fernando, L. J. D. oral commun., Sept. 29, 1970) to have yielded a remarkably consistent pattern for the placer sands. Precambrian crystalline rocks are buried 15 to 20 feet under the beach sands. The upper 6 feet of the natural beach sand consistently contains 95 percent of heavy minerals, which are very fine-grained (150 mesh or less). From 73 to 75 percent of the heavy minerals is ilmenite; the balance is mainly rutile and zircon with a little monazite. Rutile tends to be more abundant than zircon, and locally may make up as much as 15-20 percent of the balance. Thirty percent of the monazite is less than 240 mesh in size. Minerals like sillimanite and hypersthene, which are common in the khondalites and charnockites of the Precambrian rocks of Ceylon, are entirely absent, and garnet is well less than 1 percent. Thus, ilmenite can be separated easily from the natural black beach sand without the need for preconcentration in a wet plant, or for elaborate circuits in the dry concentration plant.

Pieces of Miocene limestone are found as rare, scattered cobbles and pebbles in the heavy sand. Similar scarce cobbles and pebbles of Precambrian plutonic rocks and Pleistocene ferruginous conglomerate are also present in the heavy sand (fig. 6A). The limestone is known in the northwestern part of the island, but it has not been found in the vicinity of the placer nor does it underlie the sand. The Precambrian rocks represented among the cobbles resemble rocks exposed near the beach or found under the beach sand. The Pleistocene ferruginous conglomerate found as cobbles in the black beach sand appears to be identical to the ferruginous conglomerate that crops out as

A. Cobbles of Precambrian gneiss (back), Miocene limestone (middle) and Pleistocene ferruginous conglomerate (front).

B. Reçent seashells (white fragments in black sand piled during mining).

Figure 6. Coarse debris found in the black sand at the Pulmoddai placer.

displaced boulders and relict capping on the Precambrian basement exposed along the north shore of the Arisamali headland (figs. 3B and 7A) and identified locally under the beach deposits and over the Preçambrian rocks behind the beach in several estuaries south of Kokkilai Lagoon (figs. 7B and 8A-B). The Precambrian rocks make well-rounded cobbles, but the limestone is less well rounded. The large blocks of Pleistocene ferruginous conglomerate at Arisamali are nearly in place and tend to be subangular to subrounded, but the cobbles of ferruginous conglomerate in the black sand are well rounded.

The 6-foot thickness of black sand at the Pulmoddai placer is underlain by normal beach sand containing some heavy minerals but lacking the enrichment in ilmenite of the black sand. Some thin layers of fine red sand are present in the section below the black sand. They may be remnants of old subaerially weathered beach deposits, now buried, but they have not been studied (Fernando, L. J. D., oral commun., Sept. 29, 1970). Should they represent episodes of subaerial weathering then intervals of submergence in a generally emergent pattern would be indicated. Perhaps they represent aeolian deposits formed during a dry cycle.

Seashells are present throughout the 6-foot thickness of black sand (fig. 6B); the shells and cobbles of older rocks necessitate sieving of the sand prior to magnetic treatment.

Organic layers are absent, and humic cement, such as is known in the glass sands on the west coast of Ceylon, and the coastal sands of northwest Florida, U.S.A. (Swanson and Palacas, 1965), is not present in the Pulmoddai beach sands (Fernando, L. J. D., oral commun., Sept. 29, 1970).

The grade of the black sand decreases away from the high-tide berm in those places where the deposit has been mined into the fixed sand behind the berm (figs. 9A and B). There the grade drops to about 65 percent heavy minerals. This sand is lighter colored than the sand on the active beach, and is distinctly brownish black in contrast to the intense black of the sand on active beach. The fixed heavy sand behind the berm also appears to be somewhat finer grained than the black sand on the active beach.

A. Dislodged boulders (behind figure) and relict capping (background) of Pleistocene ferruginous conglomerate on the north shore of Arisamali.

Figure 7. Ferruginous conglomerate in basal part of Pleistocene red sand.

B. View toward the mouth of estuary near Kokkilai Lagoon showing outcrops of Precambrian gneiss (foreground) overlain to center rear by Pleistocene clay and ferruginous gravel.

Figure 7. Ferruginous conglomerate in basal part of Pleistocene red sand.

A. Surface exposure on gentle slope seen in figure 7B of Pleistocene ferruginous gravel and other sediments.

Figure 8. Details of Pleistocene ferruginous gravel and other Pleistocene sediments in estuary south of Kokkilai Lagoon.

B. Weathered gneiss overlain by gravelly yellowish-green clay succeeded upward by ferruginous gravel with lenticles of gravelly clay.

Figure 8. Details of Pleistocene ferruginous gravel and other Pleistocene sediments in estuary south of Kokkilai Lagoon.

A. View looking west at vegetation-covered fixed black-sand deposits mined about 150 feet inland from high-tide line. Grade decreases from 90 percent of heavy minerals in foreground bank to 65 percent at back of cut.

Figure 9. Fixed black-sand deposits inland from the high-tide line.

B. Fine-grained sand with 65 percent of heavy minerals at back of cut shown in figure 9A.

Figure 9. Fixed black-sand deposits inland from the high-tide line.

Very little of this brush-covered, lower-grade, finer-grained, fixed black sand had been mined as of September 1970, because adequate higher-grade sand is available on the open beach, and the process used at the dry concentrating plant was evolved to handle the richer natural sand. Ultimately, the 65 percent material will be mined, but a map of its distribution has not yet been made.

Backing parts of the active beach from Pulmoddai northward, or backing or overlying the fixed black sand behind the high-tide berm, is a strongly rubified sand the depositional history of which is unknown. This rubified sand may be fixed old dune deposits. Where tested, this rubified sand is said to contain from 10 percent to as much as 60 percent of heavy minerals (Fernando, 1948, p. 321). Several ages of rubified sand are present. These include younger sands that immediately back the active beach at Pulmoddai (fig. 10) and northward (fig. 5A) and overlap the fixed black sand; red sand interbedded under the beach sand; rubified sands of somewhat greater age that back the fixed black sand or are overlain by it; and the older red sand of Pleistocene age. Evidently, the role of these units must be determined if the depositional history, source, and origin of the Pulmoddai beach placer is to be thoroughly understood.

South of the Pulmoddai placer, elevated coral reef material and shell beds stand as much as 3 feet above present high tide level. The presence of these raised marine deposits are viewed by Mr. Fernando as part of the evidence for his interpretation that the east coast of Ceylon is rising and the west coast is sinking (Fernando, L. J. D., oral commun., Sept. 29, 1970).

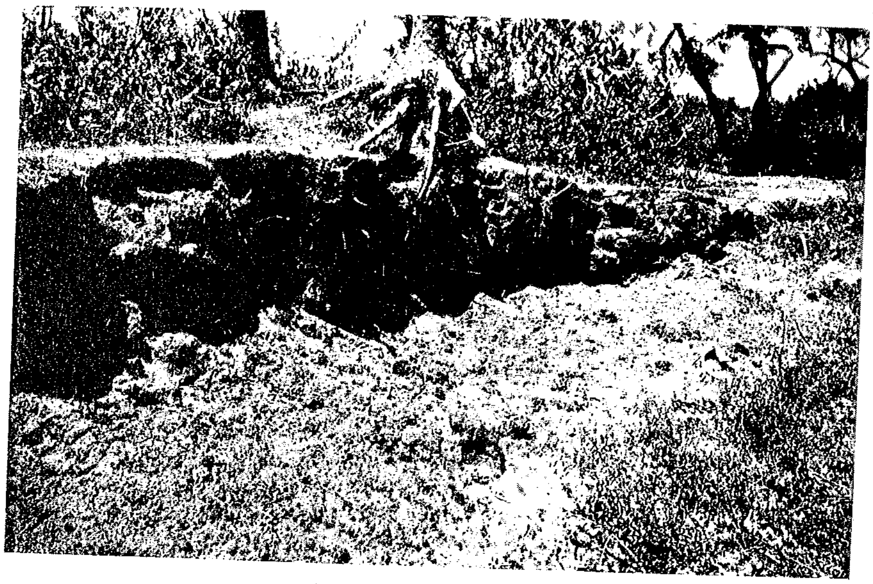
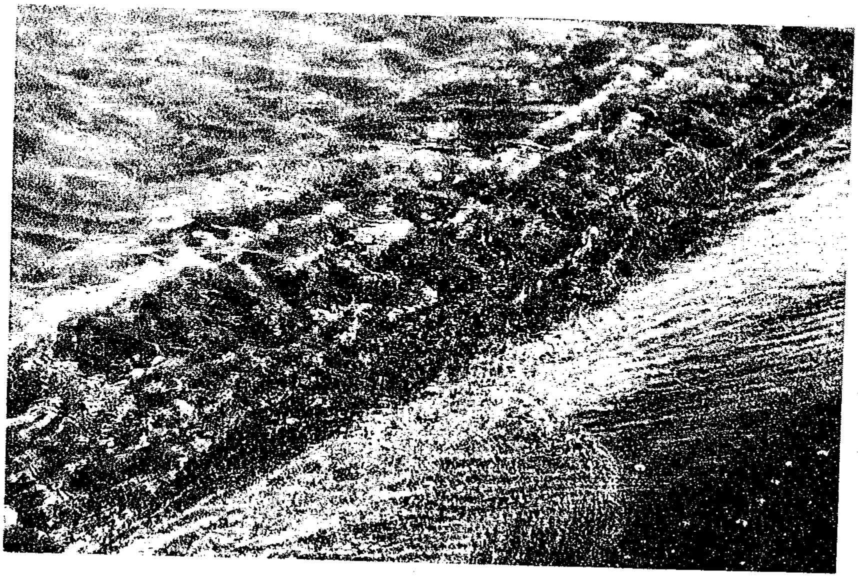


Figure 10. Rubified fixed sand lean in heavy minerals that backs the beach at Pulmoddai.

Offshore from the Pulmoddai placer the water of the Bay of Bengal deepens very gradually to 7 fathoms at about 1 1/2 miles distance. This gentle underwater surface has been spot sampled by Mr. Fernando and found to be mantled by abundant quartz sand and heavy minerals (Fernando, L. J. D., oral commun., Sept. 29, 1970). The percentage of heavy minerals in sand on this gentle surface is not as high as in sand on the beach, but the same species of minerals are present at both localities in the same relative abundances and in the same size range (fig. 11A). Actual tenors of the offshore sands were not stated by Mr. Fernando. The presence of these heavy minerals in the immediate offshore environment gives rise to the concept that the northeast monsoon exhumes heavy minerals from the floor of the Bay of Bengal and deposits them on the beach. The presence of concentrations of heavy minerals immediately offshore is in striking contrast to the offshore condition along the southwestern coast of India, where the bottom sediments are said to be lean in heavy minerals (Gillson, 1950, p. 689; 1959, p. 428).

During the 7-month period between seasons of the northeast monsoon, a thin film of quartz sand grains is deposited over the black beach sand (fig. 11B). Those persons who favor the floor of the Bay of Bengal as the source of the ilmenite attribute this layer of quartz to the waves having too little energy to move heavy minerals out of the Bay and onto the shore during this quiet season. Here, then, is a most interesting problem. What are the sources and the directions of movement of these quartz grains? Have they come from the bottom of the immediate offshore? Have they migrated along the coast, and if so, from what direction? Are the quartz grains being gently winnowed out of the existing black beach sand and accumulating on the surface because they are moved away more slowly than they are during the northeast monsoon?



A. Black sand and quartz riffles under 1-1 1/2 feet of water on the south side of the entrance of Kokkilai Lagoon.

B. Layer of quartz grains deposited on black sand beach between northeast monsoon seasons; gentle slope of beach with quartz continues offshore into Bay of Bengal; view looking north about 2 miles south of Kokkilai Lagoon.

Figure 11. Mineral distribution on the immediate offshore, Pulmoddai placer.

The coastal currents around Ceylon change in direction every season owing to a reversal of the wind systems at the end of the northeast monsoon (Somerville, 1908, p. 71; Cotter, 1966, p. 271; Neumann, 1968, figs. 25-26). According to Somerville the currents circulate around Ceylon in a clockwise direction during the northeast monsoon and counter-clockwise during the southwest monsoon. Somerville (1908, pp. 71-78) also notes that the greatest coastal currents along Ceylon are those on the northeast coast during December and January (in the northeast monsoon season), when the velocity southward is 1 1/2 to 4 knots per hour. The velocity of the currents is greater to the south along the east coast than to the north along the west coast. Thus, the growth of lagoons along these coasts is caused by the formation of offshore bars, which accrete southward on the east coast and northward on the west coast, because of currents associated with the northeast monsoon on the east coast and the southwest monsoon on the west coast (Somerville, 1908, pp. 76-78). The bars at the mouth of Kokkilai Lagoon, for example, show a greater extension to the south than to the north. Countercurrents are common, and the complexity of currents around Ceylon, which are influenced by the energy systems of the Bay of Bengal, the Indian Ocean, and the Arabian Sea, has long been noted by mariners. Thus, the thin films of white sand deposited over the black sand on the Pulmoddai beach may have drifted up the coast from relatively barren beach sand south of Arisamali ridge between northeast monsoons, or it may have come from the coast north of Kokkilai Lagoon during the northeast monsoon.

Another explanation for the film of quartz sand needs testing. The rise of the quartz sand to the surface of the beach and remaining there during the season between northeast monsoons, might be compared to a mineral beneficiation process involving contrasts of specific gravity in water, like panning or jigging. The mobile grains with the highest specific gravity would have the highest settling velocity. They would move downward from the grains of lower specific gravity with lower settling velocity during agitation of beach sand by waves. In this instance the ilmenite and other minerals of relatively high specific gravity would move downward away from associated grains of quartz, resulting in a surface layer enriched in quartz. At seasons when wave energy was too little to shift the quartz off the beach, it would accumulate in the kind of layer shown in figure 11B. At seasons when the wave energy was greater, the quartz would be moved away.

During the period of the northeast monsoon, mined parts of the beach are replenished with black sand said to contain 85 to 90 percent of heavy minerals, thus being a little leaner than the virgin beach (Fernando, L. J. D., oral commun., Sept. 29, 1970). These renewed heavy sands are usually thought by persons familiar with the placer to be deposited on the beach by the storm waves which lift the heavy sand from the immediate offshore area where ilmenite is known to be present. Perhaps the difference in tenor between the virgin sands and the replenished sands is a function of the length of time the process of gravity separation, mentioned above, has operated. Long-term winnowing of the replenished sand might remove the excess quartz grains and leave a product indistinguishable in mineral composition from the virgin sand of the Pulmoddai placer. The source of the replenished sand would then not be so much a factor in its final composition as the extent of reworking. No test of the source of the sands deposited in the old workings during the northeast monsoons has been made.

The shapes of the coastal lagoons, the extent of their closure from marine water and hence the variation in the salinity of their waters from saline to brackish to fresh were remarked upon by Somerville (1908, p. 69-79) in his study of the coast of Ceylon. An investigation of the filling of these lagoons, including the fossil evidence for changing salinity, might provide a fruitful line of research toward the geologic history of the development of shoreline features and of the Pulmoddai placer. For example, the mouth of the Yan Oya, immediately southeast of the Pulmoddai placer, seems from the kinds of soils (Soil Survey Staff, 1968) to be a completely filled lagoon, but the Kokkilai Lagoon north of the placer, except for its northwestern shore, appears to be largely unfilled. What depositional processes cause this difference in so short a reach of coastline? How does the time of the possible filling of a lagoon at the mouth of the Yan Oya relate to the beginning of the deposition of the 6-foot layer of black sand at Pulmoddai that overlies normal beach sand?

Relict Pleistocene sediments

The Pleistocene sediments of Ceylon, first recognized by Wayland (1919), have been described by Fernando (1970, p. 4) as consisting of two formations. The upper unit is called the Red Earth deposit. It is underlain by a lower gravel deposit. Fernando notes that the two units are fairly well defined, but that locally they tend to coalesce vertically and horizontally. The Red Earth unit is said by Fernando to vary in thickness from a few feet to more than 100 feet, being thickest on the west coast about 75 miles north of Colombo. It consists of bright-red stained quartz grains and ferruginous clay in which up to 12 percent of heavy minerals have been found locally. The bright-red color is modified to buff in some exposures. The lower gravel unit is not everywhere present in association with the Red Earth unit (Fernando, 1970, p. 4), and where it is absent the Red Earth unit rests directly on Miocene limestone or Precambrian rocks. The lower gravel is made up mainly of quartz grains up to several inches across bound in ferruginous cement and clay. Generally the gravels are mottled in various shades of red and brown, and the clayey part of the matrix is said to be gray (Fernando, 1970, p. 4).

The geologic map of Ceylon doesn't show Pleistocene formations in the vicinity of Pulmoddai (fig. 1), but, interestingly, the soil map of the island (Soil Survey Staff, 1967) shows a unit called red-yellow latosols, which elsewhere parallels the distribution of the Pleistocene formations, extending southward to the northern end of Kokkilai Lagoon.

Relicts of the lower gravel unit and the Red Earth unit of Pleistocene formations are, however, exposed in estuaries west of the beach south of Kokkilai Lagoon (figs. 7A-B, 8A-B) and on the north shore of the Arisamali promontory. The former presence of the Pleistocene formations is further confirmed from a physical feature that inspired the name of the promontory. Arisamali is a Tamil name made of the words arisa (rice) and malai (hill), and is used by local people who observed a cover of sand grains the shape, size, and color of rice on the south base of the hill (Fernando, L. J. D., oral commun., Sept. 29, 1971). Such sand grains were said by Mr. Fernando to be quite typical of parts of the Red Earth unit of the Pleistocene formations, but none of the original sand is left in place on Arisamali ridge.

Remnants of the Red Earth unit were observed over thin units of gravel west of the placer in estuaries between Pulmoddai and Kokkilai Lagoon. At these exposures a yellowish-green clay up to 2 feet thick rested on layered gneiss. This clay was overlain by several feet of ferruginous fine gravel over which coarse gravel composed of rounded fragments of quartz, gneiss, and Miocene limestone graded upward to red sand. The total thickness of gravel and yellowish-green clay under the red sand is at most about 6 feet. The yellowish-green clay immediately overlying bedrock was said by Mr. Fernando (oral commun., Sept. 29, 1971) exactly to resemble clay in the basal unit of the Pleistocene formations on the west coast of Ceylon, as does the ferruginous fine gravel and the coarse gravel. The red sand seen above the coarse gravel exactly resembles the Red Earth unit of the Pleistocene formations on the west coast. Only a few feet of this red sand was seen. It is here thought that much of the original sequence of the Red Earth unit has been eroded away in the vicinity of the Pulmoddai placer, but owing to the presence of red sands of several ages in the area, careful mapping will be needed to separate the Pleistocene Red Earth unit from the younger red sand deposits. All the various red sands seen in the Pulmoddai area are unconsolidated, as is the Pleistocene Red Earth unit on the west coast of Ceylon.

Strong streaks of heavy minerals, consisting dominantly of ilmenite with rutile and zircon, are washing out of the relicts of the Red Earth unit and the lower gravel units. These heavy minerals can be seen in every exposed relict of the Pleistocene formations in the vicinity of the Pulmoddai placer.

Origin

Too little is known of the geology of the Pulmoddai placer to ascribe with any certainty an origin to the deposit. Clearly, formation of the placer was more complicated than simple stream erosion of ilmenite from the weathered Precambrian complex of the island to the Bay of Bengal and redeposition of heavy minerals upon the beach during monsoon storms. No large streams enter the coast between Kokkilai Lagoon and Arisamali.

The Pleistocene formations must have been an intermediate host, or protore, and, although now largely removed, the formations formerly extended at least as far southeast as the south side of Arisamali ridge; relicts contain possibly 4 to 8 percent of heavy minerals. Erosion of the Pleistocene formations along an emergent coast might have led to major underwater concentrations of heavy minerals. Continuous uplift of the coast is contraindicated by the buried red sands in the Pulmoddai placer. If they represent stillstands and subaerial weathering, then it is possible that the period required for their formation was also a time when beach placers, now buried under water on the shelf offshore, were formed eastward of the present placer. Net uplift of the coast is shown by the raised coral and shell beds, and by the removal of the Pleistocene formations.

Coastal currents and energy levels, wave action and wave energy, need to be correlated with wind directions and force, and these factors correlated with various angles of the coast line and slopes of the beach and offshore areas to evaluate movement of sand at the placer. Perhaps the Pulmoddai placer as presently constituted is essentially a closed system instead of an open system. That is, there may be neither natural net annual loss nor net annual gain in the amount of heavy minerals in the placer: sand on the beach may not suffer a net loss to the Bay of Bengal during monsoons, nor, perhaps, does the beach gain heavy minerals from the Bay. The apparent natural destruction and replenishment during monsoons may be only a re-cycling of ilmenite already in the placer but moved to newly formed low spots by coastal currents when sufficient energy is attained during monsoons. The sources for replenishment would be up-beach assuming a southeastward drift during northeast monsoons, and a northwestward drift between northeast monsoons. Thin sheets of sand only need be removed from broad areas to supply the heavy minerals to fill natural lows. Mining would accelerate the process by making large new lows in the beach. The smaller percentages in heavy minerals reported for the replenished sand compared with the virgin sand may reflect lack of sorting between monsoons similar to the layer of white quartz sand of the beach (fig. 11B).

The role of the Arisamali promontory in changing the directions or strength locally of these seasonal currents, and the contribution such change makes to the deposition and replenishment of the Pulmoddai placer needs study. Headlands and elevated sea cliffs are evidently factors in the formation of beach placers at Beruwala, Ceylon, and Kovalam, India (Narayanaswami and Mahadevan, 1964).

Whatever the factors that were at work, their ultimate combination at Pulmoddai produced a placer of a size and grade not known to be equalled elsewhere in Ceylon. Sound knowledge of these factors would contribute to the long-range exploitation of the placer and provide valuable marine geologic data. Observations at Pulmoddai could provide a geologic basis for the search for similar preserved beach placers elsewhere along the coasts of Ceylon, possibly now hidden under fixed dunes and brush where the coast might have been raised, or under shallow offshore water where the coast had been lowered.

Recommended detailed study

It is herewith recommended that a two-year detailed geologic study of the Pulmoddai placer area be carried out between Kokkilai Lagoon and Arisamali at least, and possibly to the Yan Oya, inland for about 2 miles and offshore for at least an equal distance. Because results of this study would be valuable for planning future mining, beneficiation and shipping at Pulmoddai, it is recommended that the proposed study begin as early as practicable. Hopefully, some results would be available in order to plan further exploitation of the placer following the proposed connection of Pulmoddai with the national electric power distribution grid in 1973.

It is further, and most strongly, recommended that the proposed study be undertaken as a joint investigation involving personnel of the Ceylon Mineral Sands Corporation, the Geological Survey Department of Ceylon, and specially qualified experts obtained through one of the foreign assistance programs which is being used, or could be used, by the Government of Ceylon. The recommendation for foreign assistance is made because technical skills in the relatively new science of marine geology are needed, and specialized equipment and supplies of types not available in Ceylon are required for the investigation. Cooperation between the Ceylon Mineral Sands Corporation and the Geological Survey Department of Ceylon is recommended because it would continue a fruitful pattern that has existed since the organization of the Ceylon Mineral Sands Corporation, and because the project would train personnel from the Survey who would assist the Survey in organizing and conducting a long-range exploration program for other marine placer deposits. A by-product of this cooperation would be that the Geological Survey Department of Ceylon would become the Government's exploration arm in the search for and evaluation of heavy-mineral deposits, and the Ceylon Mineral Sands Corporation would continue as the Government's exploitation arm to mine and process the heavy minerals.

The proposed detailed study would introduce the methods of marine geology to identify the stratigraphic sequence of the sedimentary units making up the placer and its environs to show the relations of these units to the underlying rocks and adjacent sedimentary materials, to determine the grades and reserves of ilmenite, rutile, and zircon in the various lithologic units in the onshore and offshore areas, to determine the processes involved in the formation of the placer and its replenishment, and to elucidate the movement of sediment in the Pulmoddai area in relation to the winds, waves, currents, shore angles and slopes and vegetation. The results of this study would be used to guide the staged construction of new mineral processing facilities and loading facilities, the opening and mining of placer ground, and the negotiation of sales contracts for the Pulmoddai operation. The project would train appropriate personnel in the Ceylon Mineral Sands Corporation and the Geological Survey Department of Ceylon, who would, by the close of the project, be prepared respectively to manage development sampling to guide mining at Pulmoddai and to manage exploration for new placers.

It is recommended that the proposed project be completed two years after the field work is begun. Headquarters for the project should be at Pulmoddai, where it is recommended that housing for project personnel, laboratory space, and small boats and barges would be made available by the Ceylon Mineral Sands Corporation. Work would be done in two years with emphasis on field work during March to October and laboratory work during October to March. It is recommended that two professional employees of the Mineral Sands Corporation and one professional employee of the Geological Survey Department be attached full time to the project for field and laboratory work. It is also recommended that laborers, drivers, drillers, boatmen and other help as required, be supplied by the Ceylon Mineral Sands Corporation, and that surveyors and drillers as required be supplied by the Survey. Special skills needed for marine placer exploration would thus be acquired in both organizations. One senior specialist in marine geology and beach placer evaluation would be provided by a foreign assistance program for two years to direct the project, conduct the work, train the counterpart personnel, and prepare with counterparts the final reports on the results of the project.

Equipment and supplies not now available in Ceylon or not surplus to the on-going needs of the Ceylon Mineral Sands Corporation and the Geological Survey Department, would have to be budgeted for by the cooperating foreign assistance agency as part of the costs of the project. Included should be a special 1:5,000 scale base map, special aerial photographs, onshore and offshore drilling equipment suitable for placer investigations in fine sand--particularly, a modern mobile jet drill for onshore work, specialized marine geophysical equipment for shallow water, outboard motors, onshore and offshore surveying instruments, two four-wheel-drive Landrover-or Jeep-type vehicles and a 3/4-to 1-ton four-wheel drive flat-bed truck, specialized laboratory equipment including chemical hoods, electromagnetic and electrostatic mineral separators, separatory funnels, heavy liquids and other reagents, filter paper, sieves, microsplit, petrographic and binocular microscopes, drying oven, plastic sample vials, and sample envelopes.

A detailed topographic map at 1:5,000 scale with 5-foot contours and equivalent offshore bathymetry should be prepared to present the main syntheses of the geology. Onshore parts of the map should be made by photogrammetric procedures from new aerial photographs acquired for the purpose. The Royal Ceylon Air Force might agree to make the photographs, and ground control might be established by the Survey Department of Ceylon. At the same time as black-and-white photographs are acquired for the base, it would be extremely valuable to have color infrared aerial photographs made of the same area. The data for the bathymetry should be acquired by the offshore investigations of the marine geology.

Highly specialized and effective mobile jet drills have been developed by the Carpco Engineering Corporation of Jacksonville, Florida, U.S.A., for the evaluation of ilmenite beach placers like the Pulmoddai deposit and for materials like the Pleistocene Red Earth unit. One of these drills should be used on the proposed project to evaluate its capability in these materials in Ceylon and to train local drillers in its use, because this type of drill could greatly reduce the cost of the exploration drilling in Pleistocene formations recommended below in a separate project proposal for the Geological Survey Department of Ceylon.

The foreign assistance contribution to the proposed project should also include the temporary duty assignment to Ceylon of other specialists as needed up to a project maximum of 6 man years, and an agreement for submitting to commercial laboratories outside of Ceylon about 20 specimens for carbon-14 isotope age determinations.

Reports of the investigations should be prepared in two categories: (1) geologic syntheses having specific values to the local and international geologic community for their contributions to the science, particularly for Pleistocene and Holocene geology, the origin of placers, and the marine geology of monsoon coasts; and (2) detailed resource surveys of a company-confidential type useful in the Ceylon Mineral Sands Corporation and the Government of Ceylon for management of the Pulmoddai placer. The first type of report would be prepared for public release in the professional publications of the Geological Survey Department of Ceylon or other suitable scientific outlets. The second category of report would be prepared for transmittal only to designated agencies of the Government of Ceylon.

ILMENITE IN THE PLEISTOCENE AND HOLOCENE FORMATIONS

Descriptions of the formations

Pleistocene

The general distribution of the Pleistocene and Holocene formations and major Holocene beach placers in Ceylon and southern India are shown on figure 1, adapted from the Mineral Map of Ceylon (Geological Survey Department of Ceylon, 1968) and the Geological Map of India (Geological Survey of India, 1959) with additions for India from Sinha (1967).

As previously stated, the Pleistocene of Ceylon is divided into two formations, a lower gravel unit and an upper Red Earth unit (Fernando, 1970, p. 4) which extend as a broad, well-defined but intermittent (Fernando, 1948, pp. 306-307) mappable unit along the northwest side and northern end of the island and remnants are found at least as far southeastward as Arisamali ridge on the northeast coast.

Their present distribution is also well reflected by a specific soil, a red-yellow latosol, formed thereon (Soil Survey Staff, 1967). Wayland (1919), in the first description of these deposits, thought that they were the erosional remnants of a once far more widely distributed unit that covered most of lowland Ceylon. Not a very great deal of study has been accorded these deposits, because the main thrust of geologic investigations in Ceylon has been in the heavily populated central and southern parts of the island (Pattiaratchi, 1970, fig. 3). Seemingly, most of the work on the Pleistocene of Ceylon relates to evidence for early man outside the coastal belt of sand (Deraniyagala, P. E. P., 1937; 1940a; 1940b; 1943a; 1943b; Deraniyagala, S., 1971).

A correlation between the red sand in Ceylon and the Warkalli sedimentary rocks of southwestern India appears to have been suggested on a basis of color, texture, and content of heavy minerals by Coates (1935, p. 186). The original description of the Warkalli beds (King, 1882, p. 96) makes it plain that the upper part of the sequence is lateritized and overlain by superficial ferruginously cemented debris and reddish sands almost indistinguishable from surficial deposits found inland and not associated with the Warkalli. In recent years the distinction between the Warkalli beds proper, the laterite developed on them, and the overlying Pleistocene red sands has been made in India, and the Warkalli beds have come to be regarded as of probable Upper Miocene age and are overlain by younger red sand (Narayanaswami and Mahadevan, 1964, p. 2), although as late as 1944 the beds were described as Pleistocene (Pascoe, 1964, pp. 1881-1882). Descriptions of the Pleistocene formations in Ceylon, and the small exposures of the Red Earth unit I have seen near Pulmoddai, resemble closely the Pleistocene formations of southern India shown on Excursion C-23 of the International Geological Congress, XXII Session, India, 1964 (Narayanaswami and Mahadevan, 1964). The Pleistocene formations in Ceylon do not resemble the Warkalli beds in India.

Discontinuous areas of Pleistocene sedimentary rocks are exposed along the southwestern and southeastern coasts of southern India (fig. 1). These rocks occupy positions similar to the Pleistocene sediments of Ceylon, except that in southern India, particularly along the southeastern coast, a continuous belt of Holocene sediments is between the Pleistocene outcrops and the coast. These Indian Pleistocene deposits are described (Narayanaswami and Mahadevan, 1964, p. 2, 7-8) as including beach sands and aeolian deposits consisting of both white and red sands. They are separated from the Upper Miocene Warkalli beds, consisting of sandstone, clay, and lignite, by a thick capping of laterite. The red aeolian sands make a conspicuous form of sandhill, called a teri (Pascoe, 1964, pp. 1917-1918), composed of rounded grains of quartz sand stained red to bright red by a thin film of ferruginous material. They are thought to have formed in a manner similar to red Holocene dunes built up from quartz sand and red laterite dust blown by the southwest monsoon off the bare red soil plains toward the coast. Where the wind meets the sea breeze it is slowed, and the sand and dust fall to make the teris (Pascoe, 1964, pp. 1917).

Many examples of raised beach and dune deposits are known, and Holocene littoral shelly limestone has been found at heights of at least 60 feet above mean sea level at Cape Cormorin at the southern tip of India (Narayanaswami and Mahadevan, 1964, p. 1).

Present beach sands at Cape Comorin locally contain sand grains resembling rice thought to be derived from eroded Pleistocene sands. The similarity of the rice sand at Cape Comorin and the rice sand at Arisamali has yet to be compared.

Holocene

The Holocene deposits shown on figure 1 north of Colombo on the northwestern coast of Ceylon are reported by Fernando (1948, p. 306) to be coarse-to medium-grained, current-bedded sandstone with calcareous cement. Locally the sandstone has a banded appearance owing to layers of ilmenite. The ilmenite may increase in abundance until the sandstone becomes an ilmenite rock. Scattered deposits of similar sand are known on the eastern coast of Ceylon.

The much larger extent of the Holocene deposits on the coasts of India (fig. 1) includes a wider variety of formations than are known in Ceylon, including beach sands and soils, aeolian deposits, white calcareous sandstones, loose shelly sands, shell limestones, coral reefs, and teris (Narayanaswami and Mahadevan, 1944, p. 2). Lagoonal and estuarine deposits are particularly common on both coasts of India.

Content of ilmenite

Very little appears to have been done as yet to evaluate the content of ilmenite in the Pleistocene formations of Ceylon. Coates (1935, p. 186) pointed out that the formations were ilmenite-bearing, and that the deposits of heavy minerals on the present beaches are a product of the erosion of these sediments. The Pleistocene Red Earth unit was found in 1970 by Mr. Fernando (oral commun., April 24, 1970) to have as much as 8 percent heavy minerals at a site in the northern part of the island where the Geological Survey Department of Ceylon was investigating sources of raw materials for the cement industry. Bore holes through the Red Earth unit to underlying Miocene limestone showed that the heavy minerals in the Pleistocene formation consisted mainly of ilmenite but contained about 10 percent of zircon and 0.5 percent of monazite. The shape and size of the grains closely resembled the ilmenite, zircon, and monazite in the black beach sand at Pulmoddai. Relicts of the Pleistocene formations in the Pulmoddai area contain ilmenite.

The Holocene beach sands and associated aeolian deposits in Ceylon have been known to contain heavy minerals since the earliest work of the Ceylon Mineralogical Survey (Dunstan, 1905; 1906; 1907; 1910; 1914; Coomaraswamy, 1910), the predecessor organization of the Geological Survey Department of Ceylon. Fairly systematic reconnaissance of the coastal deposits of monazite was completed by the time of World War I, and a beach at Induruwa about 40 miles south of Colombo, was mined for monazite between 1918-1922 (Chem. Trade Jour. and Chem. Engineer, 1917; Imp. Inst. [London], 1917, p. 346; Soc. Chem. Ind. Jour., 1917; Fernando, 1948, p. 321). Ilmenite was noted at many placers, and Pulmoddai was recognized by the 1930's as the largest and richest Holocene ilmenite deposit. The next largest well-concentrated deposit was at Tirukkovil on the east coast about 150 miles south of Pulmoddai (Fernando, 1948, p. 321). The Tirukkovil placer (fig. 2) was estimated to contain 0.5 million tons of ilmenite. A number of small Holocene deposits were noted for 200 miles along the western and southern coasts between Chilaw (fig. 2), 45 miles north of Colombo, and Hambantota, half-way around the south side of the island, where the placers were generally associated with the mouths of rivers, but the largest, at Kudremalai Point, was associated with the Red Earth unit. The west coast deposits show a variation in mineral composition reflecting different kinds of rocks in the basins of rivers leading to the coast (Fernando, 1970, p. 28). Fernando noted that the west-coast deposits are strictly local, have no great depth, and are largely seasonal, forming during the southwest monsoon. He also pointed out a further important difference between the west coast placers and those of the east coast; that the western placers generally lack an intermediate host like the Pleistocene Red Earth unit, which he identified as an important factor in the development of the extremely rich ilmenite placers on the east coast at Pulmoddai and Tirukkovil (Fernando, 1970, p. 28). However, an exception is at Kudremali Point (fig. 1) on the west coast where Red Earth deposits are an intermediate host for ilmenite concentrated on the beach (Fernando, 1970, p. 28).

Wind-blown sands are a common part of the Holocene sediments beginning about 20 miles north of Colombo on the west side of the island. Sand dunes extend inland for many miles, but deposits of heavy minerals are not known to be associated with them.

Ilmenite has been known in the Pleistocene and Holocene unconsolidated sedimentary rocks of the southwestern and southeastern coasts of India (fig. 1) at least since monazite was discovered in 1909 by C. W. Schomberg in beach placers between Cape Comorin and Quilon (Krishnan, 1951, p. 298; Brown and Dey, 1955, p. 279). The Indian beach placers have been cited to illustrate the role of the Pleistocene sediments as intermediate hosts for the ilmenite, and to show the geomorphic processes leading to the formation of ilmenite beach placers (Gillson, 1959, pp. 427-429). The Holocene deposits, including elevated offshore bars, spits, estuarine and lagoonal deposits, teri sands, beach sands, and sand dunes, are noted in many reports for their content of ilmenite which reaches its highest percentages in places where storm waves attack preconcentrated deposits (Narayanaswami and Mahadevan, 1964, p. 8). Some preconcentrated deposits, like sand dunes north of Quilon, before wave attack are reported to contain as much as 50 percent of heavy minerals, and the monsoon-enriched beaches made by their destruction may contain up to 70 or 80 percent of ilmenite. Although many investigations of these deposits have been made--those published through 1962 are reviewed elsewhere (Overstreet, 1967, pp. 70-73)--actually very little has been published to show the range in tenors of ilmenite in rocks similar to Pleistocene and Holocene sedimentary rocks in southern India. Estimates of 4 to 12 percent heavy minerals, mainly ilmenite, have been made by Indian geologists familiar with the deposits, but these estimates seem to be for selected areas only. As of 1957 no systematic sampling had been done at the main commercial deposits near Quilon, and the problems of sampling, owing to the sandy nature of the deposits and the presence of ground water at shallow depth, required the use of special jet drills developed in the United States but not then available in India (Viswanathan, 1954; 1957).

Geomorphological control of the development of the various Pleistocene and Holocene formations was stressed by Gillson (1959, pp. 425-429), who showed that the physiographic history of the region in which the deposits are located is a controlling factor on the amount of ilmenite in the sand.

The amount of TiO_2 in ilmenite from different sources in the Pleistocene and Holocene deposits of India is known to vary. The greatest percentages are reported for Quilon (table 2).

Table 2.--Titanium oxide in ilmenite from India, in percent

	Source	TiO_2	FeO	Fe_2O_3	Other
a/	Theoretical ilmenite	52.7	47.3	-------	-------
a/	Quilon	58.2	10.2	24.3	7.3
b/	Quilon	60.0	Some	25	No data
c/	Cochin	47.0	No data	No data	No data

a/ Lynd and others, 1954, table 2.

b/ Travancore Minerals Ltd., 1964.

c/ Viswanathan, 1957, p. 314.

The older and more weathered ilmenites, particularly those reworked from old intermediate hosts, tend to have the most TiO_2.

Ilmenite mining in India began near Quilon in 1922, and rutile was first produced there in 1936. Despite a long period of mining and large deposits, Indian production of ilmenite from 1964-68 (table 3) was less than that of Pulmoddai, Ceylon (table 1).

Large reserves of high-grade sand in India--for example, the deposit mined by Travancore Minerals Ltd. north of Quilon was reported to contain 159 million cubic yards of sand averaging 35 percent of ilmenite (Travancore Minerals Ltd., 1964)--combined with low annual production, has tended to cause local geologists to ignore the possibly immense resources in parts of the Pleistocene and Holocene coastal deposits having perhaps 4 to 12 percent of ilmenite. Even the tailings cast back into the Arabian Sea

Table 3.--Indian production of ilmenite and rutile compared to world production. (Metric tons).

[Adapted from Parker, 1969, table 10.]

	1964	1965	1966	1967	1968
			Ilmenite		
India	12,041	30,057	30,167	41,586	58,726
World	2,349,555	2,454,362	2,619,029	2,738,604	2,917,612
			Rutile		
India	1,870	1,317	1,816	2,538	2,686
World	194,826	222,499	249,660	305,787	313,582

at Quilon by Travancore Minerals Ltd. were said (Viswanathan, 1957, p. 315) to contain 20 percent of unrecovered ilmenite, a percentage 5 times as great as the ilmenite content of sands mined on a vast scale in Florida, U.S.A. Recently, however, the possibility of exploiting large-volume, low-tenor dune sand on the southeast coast of India was said to have been recommended by a United Nations expert. Doubtless in India, as in Ceylon, the exploitation of such deposits will require a major increase in the generation and distribution of electrical power. In Florida, for example, the availability of cheap electricity and water makes possible the successful exploitation of Pleistocene sands having about 4 percent of ilmenite. These sands are mined at the rate of 40,000 cu. yds. per day at each of three plants (Calver, 1957, p. 19; Carpenter and others, 1953). In 1969-70 additional placer mines were opened in the Florida-Georgia area on a similar grade of sand to help meet the rising demand for titanium.

Available resources of ilmenite in India at the 4 percent grade, or greater, must be immense. The Indian and Ceylonese Pleistocene and and Holocene ilmenite-bearing sands may well constitute the world's greatest titanium resource at grade of 4 percent ilmenite or greater. Long-range investigations of these deposits to find the most favorable low-grade, large-volume placers can be regarded as an appropriate investment for a plan of national economic development. Thus, when electric power is available, the best sites for a large-scale ilmenite industry will be known.

Recommended study

A long-range study of the Pleistocene and Holocene formations along the coast of Ceylon to locate and evaluate sites having 4 percent or more of ilmenite is recommended as part of the economic development plan of Ceylon. The agency best prepared to carry out the investigation is the Geological Survey Department of Ceylon, but special training of selected personnel in new aspects of marine geology and placer evaluation is necessary, and some specialized equipment and services will need to be purchased to support the study. The proposed study should be planned in phases, and the total time allotted should be on the order of 12 years. The suggested phases are:

Phase I. Aeroradioactivity survey, airborne infrared survey, and carborne radioactivity survey of the area of Pleistocene and Holocene formations extending northward from Colombo through Kudremalai Point to Jaffna, thence southeastward to Pulmoddai; training of Survey personnel in marine geology and use of jet drill in Pulmoddai investigation; introduction of geomorphological investigations in the Pleistocene formations of the Kudremalai Point area. Duration: 2 years.

Phase II. Stratigraphic and geomorphologic studies of the Pleistocene and Holocene formations northward from Kudremalai Point to the Jaffna District; correlation of aeroradioactivity anomalies with stratigraphic and geomorphic features; drilling and mineralogical sampling of aeroradioactivity anomalies and special stratigraphic and geomorphic features; analysis of ilmenites from various geologic units to determine range in percentage of TiO_2 compared to geologic features; geologic mapping of the Pleistocene and Holocene formations on 1:63,360-scale topographic maps; geologic mapping at appropriate scales to show topography, geology and drilling on the features richest in ilmenite; evaluation of the heavy-mineral potential of the Pleistocene and Holocene formations in the area from Kudremalai Point to the Jaffna District. Duration: 4 years.

Phase III. Using the same methods followed in Phase II, with modifications and improvements developed during phase II, and making use of two field parties, extend the investigation by one field party southeastward from the Jaffna District to Pulmoddai, and by the other field party southward from Kudremalai Point to Colombo. Duration: 2 years.

Phase IV. Extension of the survey to the remainder of the coastline of Ceylon, emphasizing an interpretation of an aeroradioactivity survey and airborne infrared survey of these coastal areas, and an offshore marine geological survey of the Ceylonese parts of the Gulf of Mannar, Adams Bridge, and Palk Strait. Duration: 4 years.

The importance of the previously recommended detailed study of the Pulmoddai ilmenite placer as a training ground for personnel to prepare for this much larger regional survey is seen. The two programs are planned here to overlap during Phase I, so that the airborne and carborne radioactivity surveys can be made and the data reviewed while the investigation of Pulmoddai is under way. Detailed concepts of geology evolved at Pulmoddai can be applied in all phases of the regional investigation, and jet drills and marine geological instruments used at Pulmoddai can be transferred to the regional study.

The aeroradioactivity survey should be contracted, and the contract should also specify that the area covered by the aeroradioactivty survey at a flight height of 300 ft. be reflown at about 10,000 ft. to give complete coverage, including coastal waters, on color-infrared film. The purpose of the aeroradioactivity survey is to define surface concentrations of zircon, a weakly radioactive mineral that accompanies ilmenite in the Pleistocene and Holocene formations. Parts of these formations enriched in heavy minerals <u>and</u> exposed to surface erosion will be marked by surface concentrations of ilmenite and zircon. The distribution of these surface concentrations, interpreted from the aeroradioactivity maps, will give a first, <u>but incomplete</u>, pattern of the association of heavy minerals with specific depositional and geomorphic features. Completely buried deposits will not show up. A study of the geologic relations of the exposed concentrations will give geologic guides to hidden deposits.

Color-infrared photographs will aid in the geologic and geomorphic interpretations. They also may play an important role in investigations of groundwater hydrology conducted by other agencies. They may be of use in agricultural planning.

A contract should be made to permit carbon-14 type of analyses to be made in a laboratory outside of Ceylon. These analyses are needed to establish ages of well-defined younger geologic mapping units.

The study in Phase IV of the offshore environment in northwestern Ceylon is recommended to learn if marine placers have been formed along Adams Bridge by currents setting northward along the west coast of Ceylon (Somerville, 1908, p. 77), and by the erosion of Pleistocene and Holocene formations on the two sides of the Strait (Olson and Overstreet, 1964, p. 30). Evaluation of possible offshore mining of ilmenite, monazite, or other heavy minerals in this area would need to consider the historic pearl fisheries of the area, the effect of mining on the pearling grounds, national and international laws related to pearling, and the probable future value of the pearl industry to the nation. Although little pearl fishing is now done, the history of the industry can be traced back to the 6th century B.C. in areas to the north and south of Adams Bridge, the Gulf of Mannar, and Palk Strait (Mouton, 1952, pp. 140, 143, 145, 154, and 155). Throughout history pearling appears to have been subject to various contingencies affecting the growth and harvesting of oysters. Perhaps placer mining would affect only relatively small parts of the pearling grounds, and these areas could be replanted with oysters after dredging.

Formal publication by the Geological Survey Department of Ceylon, of the scientific results of this investigation would make a major contribution to knowledge of geologic events in Pleistocene and Holocene time in this area.

Except for the contracted airborne surveys and carbon-14 analyses, little outside help would be needed by the Government of Ceylon to conduct this program. Sources of foreign aid should be sought for these two elements of the proposed regional investigation of ilmenite resources. Foreign assistance in the proposed Pulmoddai project would provide the training in marine geology, stratigraphy, detrital mineralogy, surveying, and drilling needed for the regional investigation.

SUMMARY

Future profitable exploitation of the ilmenite placer at Pulmoddai, and plans for the improvement of the plant and other facilities of the Ceylon Mineral Sands Corporation, depend in large measure on sound geologic knowledge of the deposit. This knowledge could best be acquired through a 2-year study in which personnel of the Ceylon Mineral Sands Corporation and the Geological Survey Department of Ceylon cooperate. Foreign technical assistance should provide an experienced marine geologist to guide the study of the deposit, to train Ceylonese scientists in new techniques of marine geology, and to introduce new instruments needed for an evaluation of the onshore and offshore details of the deposit. Personnel of the Geological Survey Department of Ceylon, trained in the geology of Pulmoddai and the techniques of marine geology should thereafter be used by the Geological Survey Department in a long-term evaluation of the Pleistocene and Holocene sedimentary formations of Ceylon as potential large-volume, low-tenor ilmenite placers. Such placers might be mineable 10-20 years hence when the facilities for electrical generation and distribution on Ceylon can provide cheap power to process large tonnages of ilmenite-bearing sand.

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APPENDIX

APPENDIX

Samples of baddeleyite and zircon from the beach at Beruwala were analyzed in the laboratories of the U.S.G.S. through the interest of Dr. David Gottfried. The Beruwala baddeleyite was reported (Gottfried, David, written commun., 14 May 1965) to have a higher content of hafnium than other specimens of baddeleyite examined to that date by U.S.G.S.:

Table A.--Zirconium and hafnium in zircon and baddeleyite from Beruwala, Ceylon. [X-ray fluorescence analysis by Robena Brown, USGS, 23 July 1965.]

	Percent ZrO_2	Percent HfO_2	Hf/Zr
Zircon	66.00	1.45	0.025
Baddeleyite	98.00	1.95	.023

Table B.--Hafnium and the hafnium-zirconium ratio of baddeleyite from Beruwala, Ceylon. [Quantitative spectrographic analysis by C. L. Waring, U.S.G.S., 23 August 1965.]

Baddeleyite	Percent Hf	Hf/Zr
Analysis #1	1.70	0.024
Analysis #2	1.74	0.024

Table C.--Semiquantitative spectrographic analysis of minor elements in baddeleyite from Beruwala, Ceylon. [Analyst, Helen W. Worthing, U.S.G.S., 23 August 1965.]

Element	Percent	Element	Percent
Si	0.07	V	.01
Al	.007	Y	.005
Fe	.1	Yb	.0003
Mg	.015	Pr	.02
Ca	.001	Nd	.1
Ti	.2	Sm	.3
Mn	.001		
Ag	.0007		
B	.007		
Ba	.02		
Ce	.5		
Cr	.0005		
Cu	.00007		
Hf	1.5		
La	.1		
Nb	.007		
Pb	.01		
Sc	.005		
Sn	.7		
Th	.3		

The amount of tin is notable.