Geomorphological Field Guide Book

on

TAMILNADU COAST

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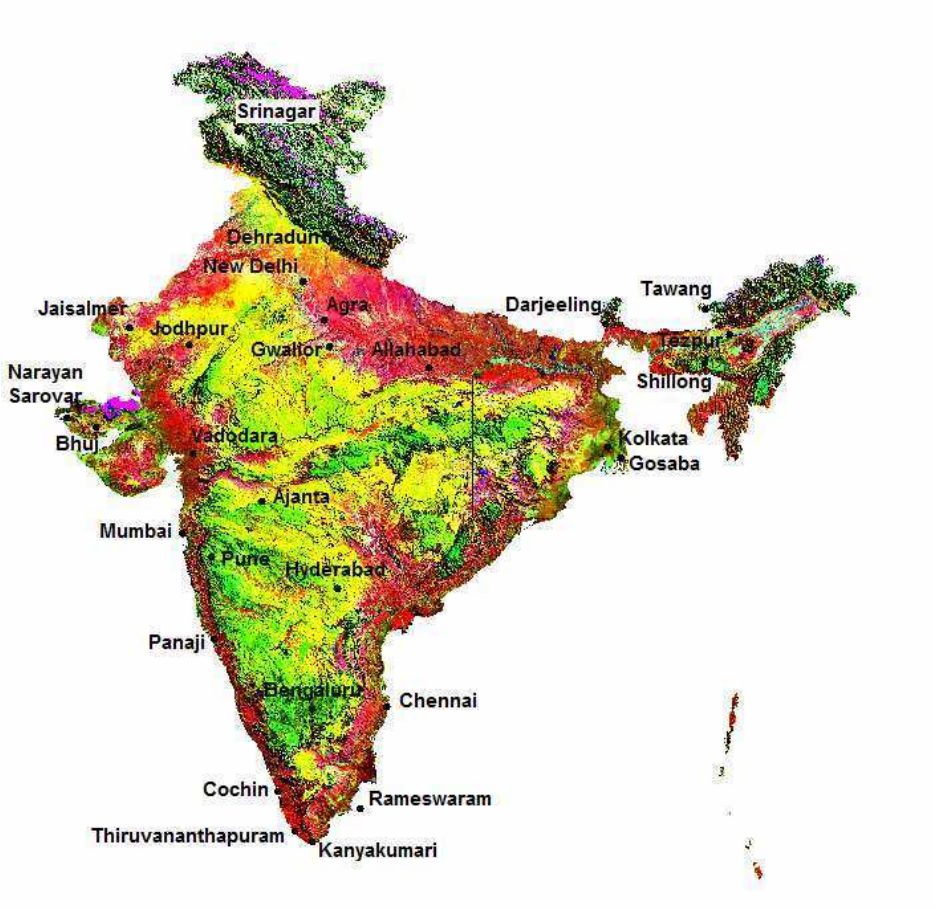

Fig. 1. Image-map of India, showing some places of interest for the 9th International Conference on Geomorphology, 2017 (Map prepared by A. Kar through processing of relevant ETM+ FCC mosaics and SRTM 1km DEM, both sourced from the US Geological Survey site). Boundaries are approximate.

Geomorphological Field Guide Book on Tamil Nadu Coast

Itinerary

Day	Places from - to	Stay
Day 1	Arrival at Chennai Briefing and discussion	Chennai
Day 2	Chennai to Velankanni Field visit to Mahabalipuram beach, panoramic view of ancient sculptures, Pancha Rathas at Mamallapuram, Dansborg Fort at Tarangampadi, Poompuhar beach	Velankanni
Day 3	Velankanni to Tuticorin Field visit to Rameswaram ancient coral reef terrace, Dhanuskodi sand pit (emerged coast), Coral and marine terraces at Mamdapuram	Tuticorin
Day 4	Tuticorin to Kanyakumari Field visit to Thiruchendur sea caves and rocky shore, Manapad sand dunes, Vattkottai Fort and beach morphology	Kanyakumari
Day 5	Kanyakumari to Inayam & back Field visit to Kanyakumari rocky coast at sunrise, Manakudy estuary, sand dunes and beach rocks, Periyakadu beach nourishment, Muttom terrace and Red Sand topography, Placer deposit concentration and coastal structure, Midalam, Inayam beach erosion	Kanyakumari
Day 6	Kanyakumari to Thiruvananthapuram Depart from Thiruvananthapuram.	

A. TAMIL NADU COAST: AN INTRODUCTION

Sea coast is one fascinating area where man interacts with Nature for a large number of activities on daily basis. Considering the coastal environment as a Common Property Resource (CPR), human societies have started using the different facets of coastal landforms for numerous kinds of activities, and without any restriction. This has resulted in several types of land degradation along some of the coasts, with implications for socio-economic activities along them. Even otherwise, the coastal strip is an assemblage of several dynamic landforms, resulting from the actions of marine, estuarine, aeolian and fluvial processes, etc. Observation of these landforms and interpretation of data collected from them provide us insight to their origin and evolutionary trends, as well as the processes involved in their making and the likely changes in them under induced pressures. In view of this, it is important to study, record, document and disseminate all the physical and socio-cultural details of the coastal belts, as well as the resource potentials of the coastal tracts and their vulnerabilities to pressures. Such studies at suitable spatial and temporal scales can help proper use, management and conservation of the coastal belts. It is important to apply certain standards for the use of coastal CPR, so that it can sustain its attractiveness through improved management. India has a coastline of about 7,800 km, but in many areas the coast is now under a phase of vigorous erosion and subjected to adverse changes. The length of the coastline in Tamil Nadu state is about 1076 km.

Weather and Climate

Tamil Nadu, as also the rest of India, is dominated by monsoon climate. The normal annual rainfall of the state is about 945 mm. Unlike north India, which receives its maximum rainfall during the period of Southwest monsoon, large parts of south India, including Tamil Nadu state, receives almost half of its rainfall during the Northeast monsoon. The state, in fact, has three distinct periods of rainfall. About 48% of the total annual rainfall is received from the Northeast monsoon (in November-January), 32% from the Southwest monsoon (mostly in June-September), and the rest during the retreat of the Southwest monsoon in October, when tropical cyclones emerging in the neighbourhoods of the Andaman Islands bring some rains (October to mid-November). The dry season is from the end of February to June.

The hot weather begins in mid-March and lasts till June. The hot winds start blowing from April, with an average velocity of 8–16 km/hour. The highest temperature is often registered in May, when different meteorological stations often record a maximum of 40-45°C. From June onwards the humidity increases significantly, which increases the discomfort level manifold due to the hot weather. The cold weather commences early in October and comes to an end in the middle of January. The climate during cold weather is pleasant. The days are bright and warm but the

sun is not too hot. As soon as the sun sets, the temperature falls, and makes it more comfortable.

Since the state is entirely dependent on rainfall for recharging its water resources, monsoon failure leads to acute water scarcity and severe drought. Tamil Nadu is classified into seven agro-climatic zones: north-east, north-west, west, southern, hilly (high altitude; high rainfall), and Cauvery Delta (the most fertile agricultural zone). Southern Tamil Nadu is usually more dry than the northern part, necessitating the construction of thousands of tanks for drinking and irrigation purposes. The Ramanathapuram-Tirunelveli coastal segment is one of the driest areas.

Geology and Geomorphology of the Tamil Nadu Coast

Geology

The southern part of Tamil Nadu state, which includes the coastal tracts to be visited, has three major lithostratigraphic units. Major part of the area comprises Precambrian granitic rocks, charnockites, granulitic retrograded products and basic intrusive, which are overlain by the Tertiary calcareous sandstone and recent coastal sediments. During the Proterozoic, several major shear zones dissected the granulitic terrain, and the granulitic facies assemblages suffered retrogradation. The crystalline charnockitic rocks are exposed in the western part of Ramanathapuram district and adjacent areas (Chandrasekar et al., 2005). In Kudankulam area, foliations are very distinct, and at places of weathering charnockites, biotite and garnet have become segregated along the foliated planes.

Coastal tectonics of Southeast coast of Tamil Nadu: In the tectonically active coastal tracts, marine notches are considered as one of the indicators of rates and pattern of uplift. Indian coasts are subjected to tectonic movement in the Quaternary period. A simplified tectonic map of southern Tamil Nadu and Kerala, as well as a map of the types of major faults aptly summarises the geology of the area (Fig. 2; after Drury et al., 1984).

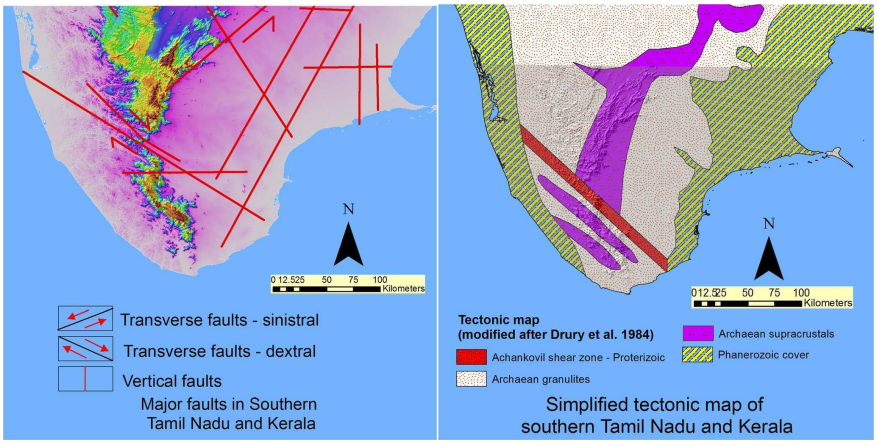

Fig. 2. Tectonic features of southern Tamil Nadu and Kerala.

Based on the variations in landforms and occurrece of lineaments, the southeastern coast of Tamil Nadu between Rameswaram and Kanyakumari has been classified into seven major blocks. It has been suggested that the seven blocks form the planes of weaknesses and cause the continuity of strike slip faults along the lineaments. The sharp triangular shape of Rameswaram Island might have some genetic link with tectonic activities during its evolutionary stages, especially the activities of the Vaigai Fault. Loveson et al. (1996) identified the following major blocks: (1) Mandapam – Valinockam block, (2) Valinockam – Vaippar block, (3) Vaippar – Thiruchendur block, (4) Thiruchendur – Navaladi block, and (5) Navaladi – Kanyakumari block (Dajkumar et al., 2015).

A study by Chandramohan et al. (2001) has revealed that the average annual rate of sediment deposition in the shallow marine shelf areas adjoining the Tamil Nadu coast is 0.01 m in Gulf of Mannar, 0.006 m in Pak Bay, and 0.003 m at Sand Heads. The study also reveals that the sands are coarse to fine grained, and the fineness increases towards Kovalam (between Chennai and Kalapakkam), possibly due to higher fluvial deposition in that direction.

Coastal Geomorphology of Southern Tamil Nadu

The coastal tract of southern Tamil Nadu extends for about 1075 km from Pazhaverkadu in Thiruvallur district to Ezhudesam in Kanniyakumari district. Kanniyakumari forms the southernmost tip of the Indian subcontinent where Indian Ocean, Bay of Bengal and Arabian Sea meet. Pamban Island and Rameswaram form part of the Ramanathapuram district, separating Gulf of Mannar and Palk strait from Sri Lanka, except a string of tiny islands called the Ram Setu (earlier known as Adam's Bridge).

About 46 streams originating from the hilly Pre-Cambrian granite-gneiss terrain of the Eastern Ghats and the Nilgiris drain through the Tamil Nadu coast to meet the Bay of Bengal through small estuaries and lagoons. Among these, six are the major ones. The streams are the Palar, the Cauvery, the Vaigai, the Vaippar, the Tambaraparani and the Nambiyar. Apart from the Cauvery, which has a wide deltaic plain with appreciable sedimentary contribution of alluvium, all the other streams have smaller sedimentary loads along them, and narrower associated plains. The sandy beaches are dominant especially along the coast near Ennore, Chennai, Mahabalipuram, Manakkanam-Pondichery, Cuddalore, Rameswaram, where fine to medium sand is mixed with broken shell fragments, shingles, etc. In the southern part, the beaches at Vattakatti, Rasthakadu, Muttam, etc., have high percentage of black sand, especially consisting of heavy minerals like monazite, garnet, ilmenite, magnetite, etc. Coral reefs are numerous in Pamban-Rameswaram-Palk Bay sector, where several small islands (Tivus) have reefs of thriving coral colonies. The coastal tract of Pichavaram (near Cuddalore), Vedaranyam, Pt. Calimere, Muttupet and Tuticorin have mangrove forests along a muddy coast. A number of lagoons, fronted by spit, have also developed along the coast. The largest of the lagoons is at Pulicot,

which is the second-largest lagoon in India. Overall, the coastline along Tamil Nadu is straight and narrow, except near Vedaranyam where the coastline takes a sharp westward turn and becomes indented. The mean sediment drift appears to be from south to north, as the Northeast Monsoon (November-January) is more vigorous along this coast than the Southwest Monsoon (June-September). Littoral drift during the Southwest monsoon is weak.

The southeastern coast of Tamil Nadu provides numerous examples of erosional and depositional landforms. Among the depositional landforms, prominent features are beach ridges, swales, spits, and estuaries. The major erosional landforms are wave-cut platforms, cliffs, marine terraces, sea caves, etc., which can be seen in and around Rameswaram, Mandapam, Valinockam, Kannirajapuram, Thiruchendur, Manapad, Idinthakarai and Kanyakumari (Chandrasekar et al., 2005). At places, marine notches have developed in coastal beach rocks that run parallel to the coast. Beach grooves, containing rock outcrops and exposures with fossil assemblages, are also exposed along the present strand lines (Fig. 3). Coastal cliff rocks at places provide signatures of palaeoclimate and the prevalence of past shallow marine environmental conditions, as attested by a series of eight beach ridges in curvi-linear fashion between Mandapam and Valinokkam, as well as 2-3 well developed sub-ridges. All these beach ridges occur sub-parallel to the present coastline.

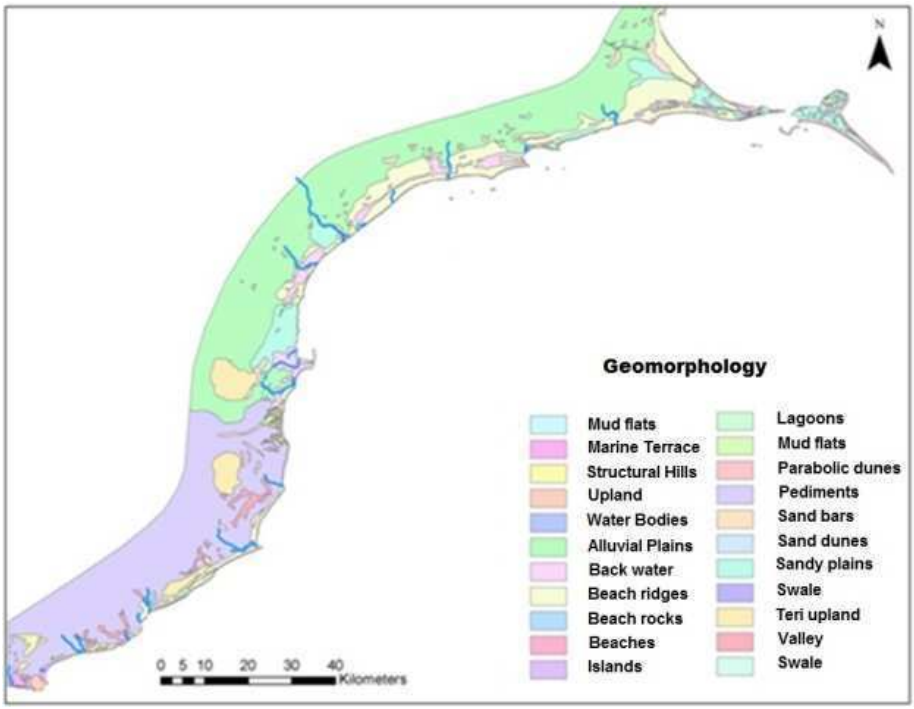

Fig. 3. Landforms along the Tamil Nadu coast.

Tsunami and Cyclone effects: The devastating Indian Ocean Tsunami that was generated after a major 9 Mw earthquake near Banda Ache in Indonesia on 26

December 2004, caused not only loss of humans and properties along the coast of Tamil Nadu, but also modified the coastal landforms to some extent. Nagapattinam coast was most severely affected, where the maximum water level rose to 4-5 m, and the inundation reached 3 km inland. The beaches became flatter as the backwash of the plunging waves swept away the smaller undulations of backshore region. The sediments at many places became enriched with re-worked foraminifera fragments, which led researchers to assume that a palaeo-strandline, now at a depth of 30-40 m in the sea in shallow shelf region, was exploited by the tsunami waves to bring up the fragments. At places the beaches also became enriched with heavy minerals.

The inundation was more in the areas between the fore dunes and the back dunes, and the waves swept away most of the temporary hutments of fishermen in between the two dune systems. About 700 persons died in Nagapattinam district, followed by 250 in Kanyakumari district and 200 in Cuddalore district. About 125 persons perished in the state capital, Chennai. In Kerala, 86 persons were reported as dead, out of which 67 death was reported from Kollam district and 16 from Alappuzha district.. Hundreds of people were also injured and many livestocks perished as seawater surged through the fishing hamlets and entered the village settlements. The previous notable tsunami along this coast was recorded during 1881 as the consequence of a major earthquake in the Andaman Islands.

Apart from the tsunamis, the coastal configuration and the life and properties in coastal zones are also greatly affected by the cyclones. Several cyclones, originating in the Indian Ocean or in the Bay of Bengal, regularly sweep across the Tamil Nadu coast, their average number per year being 16. The large waves generated during the Super Cyclone of 1999, as well as the accompanying strong winds, modified the beaches to a large extent, while the gusts of wind and the incessant rains caused extensive damage to life and properties in the coastal belt and inland areas of Tamil Nadu.

Socio-economic Aspects

There are 13 districts in Tamil Nadu that share the coastline. These are: Thiruvallur, Chennai, Kanchipuram, Villupuram, Cuddalore, Thiruvarur, Nagapattinam, Thanjavur, Pudukottai, Ramanathapuram, Thoothukudi, Tirunelveli and Kanyakumari. About 300 villages and 25 urban centres thrive on the land resources of the coastal resources of these districts. The density of population is more than 400 per square kilometer, which is high. Among the coastal towns and cities, Chennai is a megalopolis, with several smaller town clusters around it. Tuiticorin-Tiruchendur, Thiruvottiyur-Pulicot, Cuddalore-Portonovo, Nagapattinam, Rameswaram-Mandapam, Vedaranyam and Kanyakumari are the other major urban centres. All these urban centres are currently witnessing moderate to high population growth, driven especially by expansion of trade and commerce, as well as in marine salts-based industries and fishing, while some are also witnessing considerable tourist influx (e.g., Mamallapuram, Poompuhar, Nagore, Rameswaram-Mandapam,

Tiruchendur, Kanyakumari). Chennai and some major cities are also engaged in harbour works, oil refineries and associated chemical industries like fertilizer, pesticide, as well as phermaceuticals, etc. The coastal towns and cities inhabit roughly 6 million people, which account for about 10% of the total urban population of the state.

The rural land use is dominated by agriculture, where the croplands occupy more than 40% of the total coastal area. Sand dunes with or wthout vegetation, salt marshes, mangroves, as well as barren rocky areas, which together cover a class of land use tradtionally termed as 'wastelands', cover about 4% area.

The state has a fishermen population of 1.05 million. The coast consists of 3 major fishing harbors, 3 medium fishing harbors and 363 fish landing centers. The marine fishing output from the state contributes to 10-12% of the total marine fish production in India, which is estimated at 0.72 million tonnes. Aquaculture includes shrimp, sea weed, mussel, clam and oyster farming.

Tamil Nadu has four major sea ports at Chennai, Ennore, Tuticorin and Nagapattinam. There are 11 other minor ports. Chennai Port is an artificial harbor and is India's second busiest container hub. Because of its shallow waters, Sethusamudram, the sea separating Sri Lanka from India, presents a hindrance to navigation through the Palk Strait. Though trade across the India-Sri Lanka divide has been active since at least the first millennium BCE, it has been limited to small boats and dinghies.

The coast of Tamil Nadu was along the ancient Silk Route and, hence, played an important role in spice trade with the western empires. Roman and Greek traders frequented the ancient Tamil country, securing trade with the sea-faring Tamil states of the Pandyan, Chola and Chera dynasties. Since the time of the Ptolemaic dynasty (i.e., a few decades before the start of the Common Era) the traders established trading settlements along the coast to strengthen trade between South Asia and the Greco-Roman empires. Even after the fall of those empires, the trading continued due to the operations from the settlements. Major ports included Uraiyur, Korkai, Poompuhar and Kaveripattinam. The ancient city of Poompuhar was destroyed by the sea around 300 BC.

During the reign of Raja Raja Chola I and his successors Rajendra Chola I, Virarajendra Chola and Kulothunga Chola I, the armies of the Chola Dynasty invaded Sri Lanka, Maldives and some parts of Malaysia, Indonesia and southern Thailand (Sri Vijaya Empire), especially in the 11th Century. In 1025, Rajendra Chola launched naval attacks on the ports of Srivijaya and against the Burmese kingdom of Pegu. Through this operation he conquered parts of Malaysia and Indonesia and Thailand and occupied the areas for some time.

Fig. 4. Tamil Nadu state, showing major sites to be visited.

B. DESCRIPTION OF THE FIELD SITES

The field visit will begin at Chennai in Tamil Nadu state and end at Thiruvananthapuram in Kerala state. The major sites proposed for visit are shown in Fig. 4.

Day 1
Arrival at Chennai
Stay at Chennai.

The first day will be spent on briefing about the field visit and a short visit to Chennai's Marina Beach.

Day 2
Chennai to Velankanni
Stay at Velankanni.

On day-2, the coastal features between Chennai and Velankanni will be explored. The coastal tract from Chennai southward is also known as Coromandal Coast. Following is a description of the sites to be visited.

Stop 1: Mahabalipuram Beach

Mahabalipuram beach is located 58 km to the south of Chennai, lying at the shore of Bay of Bengal (Fig. 5). This 20 km long beach came into notice for tourism purpose during the 20th Century. The beach is thronged by tourists mainly during the months of November and February.

Fig. 5. Mahabalipuram beach.

Beach morphology: Beaches, beach ridges, backwaters, mudflats, palaeo-tidal flats and palaeo-barriers form the coastal landscape at Mahabalipuram. These landforms are bordered in the west by Mio-Pliocene Cuddalore Sandstone and the pediplains developed in the Charnockites of Archaean era. The prevalent wave action and the large amount of sediments derived by littoral currents make the beaches highly dynamic. Although beach accretion is noticed along the entire length of the coast, erosion is also observed around Ennore. Two beach ridges can be observed along many parts of the coast, which exhibit strandline characteristics. The maximum height of these beach ridges is 5 m above MSL.

Panoramic view of the sculptures: Mahabalipuram is an ancient historical town. It has a group of beautifully carved structures in granite, which were carved out from a single rock in 7th Century AD, especially during the reign of King Mahendravarman I and his son Narasimhavarman I (630–680 AD; also known as "Mamalla", the Great Warrior) of the Pallava Kingdom (Fig. 6). These monuments are an example of the age-old monolithic rock-cut architecture of India, and are now a part of the UNESCO World Heritage sites, providing excellent exposure to the Pallava Art. Archaeology Survey of India (ASI) maintains the edifices.

Fig. 6. Panoramic view of the sculptures at Mahabalipuram.

The monuments are mostly cut along the faces of a cliff and are monolithic, constituting the early stages of Dravidian architecture wherein Buddhist elements of design are prominently visible. The intricately designed edifices include Rathas (temples in the form of chariots), Mandapas (cave sanctuaries), and giant open-air relief. The pillars are of the Dravidian order. Although sometimes mistakenly referred to as temples dedicated to the five kings of Pandava clan in the epic Mahabharata, namely, Yudhishthira, Bhima, Arjuna, Nakula and Sahadeva – and their common wife, Draupadi, the structures were never consecrated because they were never completed, and were left un-finished after the death of Narasimhavarman (Fig. 7).

It is believed by some experts that this area served as a school for young sculptors. The different sculptures, some half finished, might have been examples of different styles of architecture, and were probably sculpted by the young students as per demonstration by their instructors. This can be guessed from the sculpture "Pancha

Rathas" (five chariots), where each Ratha is sculpted in a different style, although all the five were carved out of a single piece of in situ granite. The carvings at Mahabalipuram might have required hundreds of skilled sculptors (Iniyan, 2015).

Fig. 7. A glimpse of the Pancha Ratha (five chariots) at Mahabalipuram.

The tsunami of 26th December 2004, although a devastating one, exposed some beautifully carved structures in the near-shore zone of Mahabalipuram, especially as the backwash from the tsunami waves scooped out considerable thickness of sand from the lower beach. The structures included a granite lion and an elephant relief. Mahabalipuram beach is also famous for activities like sunbathing, diving, wind surfing and motor boating (https://en.wikipedia).

Stop 2: Dansborg Fort in Tarangampadi

Tharangambadi, located in the southeast of Tamil Nadu, is famous for its 17th Century Danish fort with a breathtaking view of the Bay of Bengal (Fig. 8). The site is still largely unspoiled by destructive tourism, and retains its natural scenic beauty due to less crowding.

Fig. 8. Dansborg Fort and Bungalow on the beach at Tharangambadi.

The Fort Dansborg was built in 1620 by Ove Gjedde, Commander of the Royal Danish Navy, when he was 26 years old. The Fort was built on the orders

from Danish King Chrisitan IV of Denmark and Norway. A treaty was signed on November 20, 1620 between King Raghunatha Nayak of Thanjavur and the King of Denmark, by which the Danes were given permission to build the Fort at Tarangambadi (Tranquebar) for trading. The Fort faces the Bay of Bengal and the sea is just 200 m from the Fort.

The Fort has two levels. The lower level was used to accommodate soldiers and horses, as also to store materials used for trading and as a prison. The upper level was used as residence of the governor and the priests. Presently, a museum at this upper level exhibits Danish era artifacts at Tharangambadi. Although Tharangambadi was a busy port during the 17th century, it is no more a port now. Some fishing activity can, however, be noticed.

Stop 3: Poompuhar Beach

The coastline between Nagapattinam and Poompuhar is almost straight with a high energy zone at a depth of 8 to 9 m (Jeena et al., 2001). Poompuhar is an ancient port city, and was built on the north bank of Cauveri River, close to the site where the river flows into the sea. Its beach is often crowded with local tourists (Fig. 9). Puhar in Tamil language means an estuary. This ancient port city used to be called earlier as Kaveri Poompattinam, and was the capital of the early Chola rulers. The town had two distinct clusters, Maruvurpakkam near the sea and Pattinappakkam to its west (Iniyan, 2015). These two clusters were separated by a stretch of gardens and orchards where daily markets used to be held under the shade of trees. The market place was known as ‘Naalangadi’ during the day and as ‘Allangadi’ by night. It is learnt from ancient literature that Maruvurpakkam was near to the beach and had several terraced mansions and warehouses with windows shaped like the eyes of the deer.

Fig. 9. The Poompuhar beach.

The ancient town was destroyed by the sea and was submerged, presumably in 500 AD. It was rebuilt thereafter. According to the National Institute of Marine Archaeology, much of the town was washed away by progressive erosion of the sea and by floods. Ancient pottery and figurines dating back to the 4th Century AD were recently found by ASI during some excavations. Submerged wharves and lengths of

pier walls have also been excavated in recent times. The findings confirm the antiquity of the town as found from literary sources (Sundaresh et al., 2004).

Buddhism flourished in Poompuhar two thousand years ago. Some pillars erected during the 2nd Century BC have inscribed on them “Kangitha Somaya Pikunia Thanam”, meaning “this pillar was donated by Somaya Pikkuni of Poompuhar”. Two other tourist attractions at Poompuhar are: (1) the Masilamani Nathar Koil, which was built in 1305 by Maravarma Kulasekara Pandiyan, and which bore the sea erosion; and (2) a seven-storied structure called the Silapathigram Art Gallery that focuses on Sangam literature. Poompuhar is known as the oldest continuously inhabited place in Tamil Nadu.

Day 3
Velankanni to Tuticorin
Stay at Tuticorin.

Stop 1: Rameswaram - Ancient Coral Reef Terraces

Rameshwaram, a strategically and socially important island along the east coast of India, is excellent for the study of coastal evolution during the Quaternary period. The island has landforms like beaches, beach ridges, mudflats, raised coral terraces, lagoons, spits, etc., along with living corals (Fig. 10). The evolution of coastal landforms could very well be reconstructed through integration of the landform distribution with the available carbon-14 dates. There are indications that sea level has played a major role in the evolution of landforms in the island. The raised terraces that are dated to 125000 years BP were formed as fringing reefs during that period. The emerged reef-corals during the subsequent regressive phase of the sea served as places for marine sedimentation, as indicated by the mudflats and beach ridges of later period. The spit is a recently-formed landform in the island (Rajamanickam and Loveson, 1990).

Marine/ coral reef terraces: In the northeast of the island the beaches get terminated by a cliff, which is formed of coral reefs as well as exposed Cuddalore Sandstone, both appearing along a terraced landform. The marine terraces are exposed at few places in the island. Commonly, the terraces are composed of corals with calcareous, evaporite deposits; the deposits get easily eroded by sea wave to form sea caves and notches along the Mandapam coast. The average height of the exposed terraces is about 3.5 to 3.8 m (Chandrasekar et al., 2002). The mineralogical composition in the northern sector differs from that in the eastern sector. Near Valinockam the notches are well-developed, and are made up of consolidated hardened sandstone. The Rameswaram Group of sediments was deposited under marine condition more than 28,000 years before present (BP). Probably between 12,000 and 18,000 years ago the bottom part of the deposits got elevated to a level of the present beach line. Marine terraces located at Valinockam, south of Mandapam, are made up of calcareous sandstone and are significantly covered by sand dunes

(Krishnakumar et al., 2011). In this terrace, hard marine calcareous sandstones, comprised of heavy and light minerals, are observed. The rounded notches are developed above the mean sea level due to wind activities. In this sector, two marine transgression and regression took place within a short period of 30,000 years.

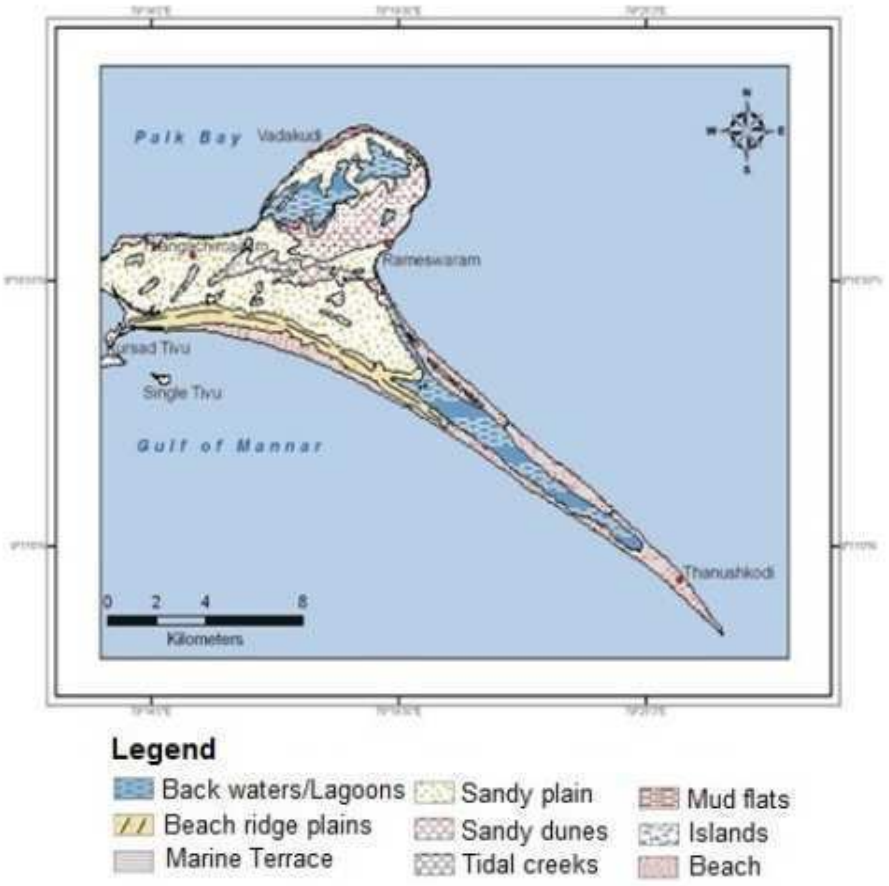

Fig. 10. Geomorphological map of Rameswaram.

Stop 2: Dhanushkodi Sandpit (Emerged Coast)

Dhanushkodi has the only land border between India and Sri Lanka, and is one of the smallest international boundaries in the world (45.7 m in length), located on a shoal in Palk Strait. A number of small, emerging spits can be identified near the land's end at Dhanushkodi (Fig. 11). Beyond lies a group of tiny coral islands, arranged almost linearly in a roughly WNW-ESE direction, which together are known as Ram Setu (also called the Adam's Bridge), and lead to the land's end of Sri Lanka at Talaimannar (Fig. 12).

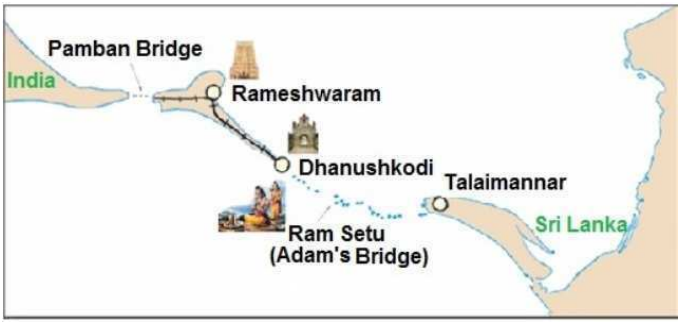

Fig. 11. Location of Ram Setu (Adam's Bridge) between Dhanuskodi (India) and Talaimannar (Sri Lanka).

Fig. 12. An emerging spit at Dhanuskodi.

Fig. 13. View towards Ram Setu from Dhanuskodi.

Before the 1964 cyclone, Dhanushkodi was a flourishing tourist and pilgrimage town. It had then a railway station, a small railway hospital, a higher secondary school, a post office, customs and port offices, etc. The 1964-cyclone swept away a part of the railway tracks at Dhanushkodi. A number of buildings in the southern

part of Dhanushkodi, including some temples, also got submerged in the sea. In 1965, the town was declared unfit for habitation. At present only a small group of fisher folks resides in Dhanushkodi. Haunting yet appealing, deserted but still full of life, eerie but fascinating, Dhanushkodi, with a population of less than 500, attracts many tourists (Fig. 13). Its breathtaking natural beauty, away from the worldly connections (the nearest telephone booth is about 20 km away), makes it a place truly less-travelled (https://en.wikipedia).

Stop 3: Mandapam Beach

The coastal landforms between Devipattinam and Mandapam can be grouped under depositional and erosional features. Sandy beaches and rocky beaches are dominant between Mandapam and Rameswaram. At Mandapam rocky beaches abound (Fig. 14). The lush green vegetation seen on the hills beyond the Bay of Bengal here is on the Eastern Ghats (Fig. 15). The rocky beach hosts a rich marine fauna, including live corals (Fig. 16).

Fig. 14. A shallow rocky beach at Mandapam, with breaker waves at a distance.

Fig. 15. Another view of the rocky beach at Mandapam.

Fig. 16. Corals forming a part of the rocky beach at Mandapam.

For people interested to see the life in the shallow sea beyond Mandapam, the Forest Department of Tamil Nadu runs the services of some glass-bottomed boats. These allow the tourists to see beautiful coral reefs and even live corals under the sea, as well as numerous other fauna and flora. An amusement park along the Mandapam beach, measuring about 16 ha, keeps the children engaged, as it is home to man-made coral reefs, fountains and hillocks.

Day 4
Tuticorin to Kanyakumari
Stay at Kanyakumari.

Stop 1: Tiruchendur Beach and Sea Caves

Tiruchendur is situated in Thoothukudi district of Tamil Nadu, and provides a glimpse of the Gulf of Mannar and the Indian Ocean. It has a narrow sandy beach, which is steeper (about 3-6 degree) than in areas further north (1-3 degrees), followed seaward by rocky shore platforms (Fig. 17). The shore platforms mostly occur in between the low tide and the high tide, and are formed of marine calcareous sandstone, rich in quartz and feldspar, with embedded Mollusc shells. At Tiruchendur, the older shore platforms/beach ridges could also be found several meters above the mean tide level.

Fig. 17. The sandy beach at Tiruchendur, followed sea-ward by rock platforms.

At least four strand levels could be identified, the highest and the oldest occurring at about 12 m above MSL. It suggests that the relative Holocene sea level along this coast probably dropped after the cementation of the sand, although some tectonic effects might also be involved (Chandrasekar, 2001). Abundance of fine to medium sand along this beach suggests a low wave energy environment. The original beach topography has become modified due to the construction of a number of edifices around an old temple on the beach (Fig. 18). Another old temple at the base of a sea cliff near by, occurs in a cave (Fig. 19). This cave has also been modified over the last few centuries, and it is difficult to establish if the cave was formed naturally by sea waves. The coastline south of Rameswaram was less affected by the Tsunami of 2004, especially because of the shelter effect of Sri Lanka landmass. At Tiruchendur

the overall change in beach volume due to the tsunami was estimated as net accretion of 0.48 cubic m, while at Manapad, about 18 km to the south, it was estimated as net erosion of 1.50 cubic m. A longer record of observations along the two coasts, from 1979 to 1988, showed a net accretion rate of 4 m per year at Tiruchendur and a net erosion rate of 8 m per year at Manapad (Natesan and Subramanian, 1994).

Fig. 18. The sandy beach at Tiruchendur with a temple of Lord Muruga.

As mentioned above, the narrow shore at Tiruchendur is famous for an ancient temple dedicated to Lord Muruga, which attracts huge crowd of devotees. The earliest inscription in the temple has been dated to 875 AD. Another temple nearby, known as Valli's Cave or Dattatreya's Cave, is located in a cave at the base of the sandstone cliff on the sea shore towards the north-eastern end of the Muruga temple. This cave temple is dedicated to Goddess Valli, consort of Lord Muruga, and has several carved stone pillars. Between 1646 and 1648 the Dutch East India Company occupied Tiruchendur during a fight with the Portuguese who had colonised the area earlier. The Dutch started living in the temple, and while vacating it, carried some of the idols and threw them in to the sea. The idols could be fished out after some years. The temple was re-built in 1868.

Fig. 19. A famous cave at Tiruchendur.

Stop 2: Manapad

The Manapad beach, located about 18 km south of Tiruchendur, occurs along a sharp bend of the coastline around a hard crystalline massif that has resisted the smoothening of the coastline. This projection of land and a strong longshore drift northward helped the formation of a long re-curved spit with lagoon, and facilitated the formation of an excellent natural harbour (Fig. 20). Locally, the sandy beach is

wider to the south of the headland that hosts the Lighthouse, and is narrow to its north. The old beach ridges inland, the likes of which occur at Tiruchendur, have also been found to occur at Manapad. The highest one forms a terrace at 25 m above MSL. Down the slope from this terrace towards the beach, three other terraces occur at 19 m, 8 m and 3 m, and appear to lose height progressively to the north and south of the headland (Fig. 21). This is perhaps due to a local upwarping at Manapad. A similar condition is reported from the coastlines of Wellington district, New Zealand and from the coastlines of Chile, where the coastal terraces have been displaced tectonically.

Fig. 20. Manapd Point, as seen on Google Earth image.

Fig. 21. The Holy Cross Church at Manappad.

Manapad is famous for its association with a Christian saint, St. Francis Xavier. It is believed that he came to Manapad first in October 1542 for one year, and again in 1544 for few months, before returning to Goa. An inscription at the entrance of a small cave here tells that St. Francis Xavier used to live and pray in the cave, which was dedicated to Goddess Valli, and used earlier for meditation by a Hindu saint. A rudimentary church on the beach, built in 1540 around a Cross made from the mast of a wrecked ship by its Portuguese sailors (named as Captain's Cross), was also used by St. Francis Xavier for his services and miracles. In 1581 the Church of the Holy Cross was built at the site of the old edifice (Fig. 22). An annual festival at the

church in September draws huge crowd of devotees. Another important tourist location is Manapad Point, which provides surfing activities.

Fig. 22. A coastal terrace at Manappad.

Stop 3: Vattakottai Fort and Beach Morphology

Located about 6 km NE of Kanyakumari beach, the Vattakottai Fort was built in the 18th Century as a coastal defence-fortification and barracks in the erstwhile Travancore kingdom. It was constructed under the supervision of Captain De Lannoy, an ex-Dutch naval officer of the Dutch East India Company, who became commander of the Travancore Army, after he earned the trust of the Travancore King Marthanda Varma (https://en.wikipedia). The fort is now under the protection of Archaeological Survey of India, and is guarded by a 8-9 m high wall (Fig. 23), which connected the Circular fort with the Padmanabhapuram but later this path was sealed due to various reasons. The fort provides a clear view of the Indian Ocean in the south and the Western Ghats in the north. A small river joins the sea on one side of the Vattakottai fort. The beach is rich in black sand.

Fig. 23. The high wall of the 18th Century Vattakottai Fort.

Day 5
Kanyakumari to Inayam and back to Kanyakumari
Stay at Kanyakumari.

Stop 1: Kanyakumari

Kanyakumari lies at the southern tip of peninsular India where the Bay of Bengal, the Indian Ocean and the Arabian Sea meet (Fig. 24). The confluence of these three places is also referred to as Thriveni Sangamam. Geographically, Kanyakumari also defines the southern end of the Coromandal Coast. The area around Kanyakumari provides numerous examples of interesting coastal geomorphological features (Fig. 25). Following is a description of the sites to be visited during the day.

Stop 2: Manakudy Estuary

Manakudy estuary is the second largest estuary in Kanyakumari district, in which the Palayar River from Mahendragiri drains. It is dominantly a sand-built estuary, connected to the sea during the rainy season (Fig. 26).

Fig. 24. Administrative map of Kanyakumari district.

During the period of total occlusion of the river mouth the estuarine water swells due to heavy inflow of water from the head of the estuary and also by the land drainage. There is also heavy surface runoff from the paddy fields and coconut plantations into the estuary. The clay-mixed alluvium gets deposited at the mouth of the estuary.

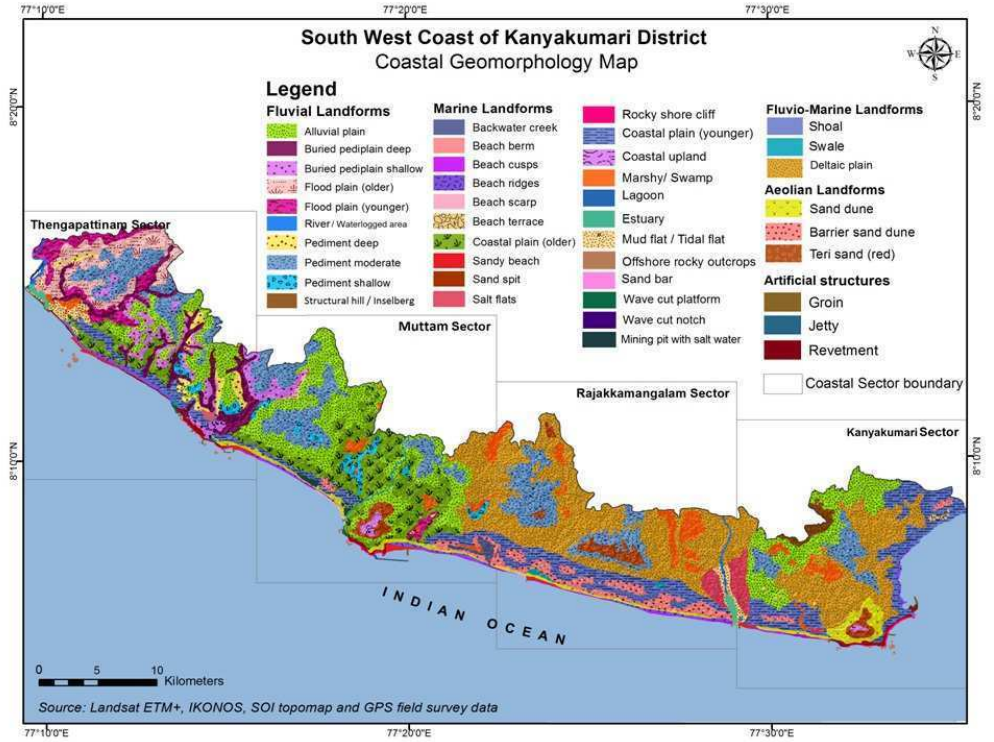

Fig. 25. Geomorphological map of Kanyakumari district.

During heavy inflow into the estuary the sand bar opens up under the force of gravity. Shallow fluvio-marine landforms like salt marshes and tidal mud flats are associated with the estuary. Other associated major landforms are the sandy beaches, rocky shores, oyster reefs, mangrove forests and small river deltas (Mujabar et al., 2011). The hills and uplands beyond are dominantly of Khondalite and Charnockite. The existing seawall, near the mouth of Palayar River is not stable, as there is considerable erosion at the tip of the seawall. This has damaged several dwelling units in the surroundings. To minimise further damage, it has been suggested to construct a groynes field for up to a distance of 1.5 km, and to raise the crest elevation of the existing seawall by 2 m.

Fig. 26. The Manakudy estuary and a sea wall.

Manakudy estuary abounds with fishery resources and has many fishing hamlets on the banks. Although there is no major industry near the estuary, three small-scale industries are well established on its banks. These are: coconut husk retting, lime shell dredging and salt works.

Stop 3: Beaches and Sand Dunes

Sandy beaches occur mostly in Sanguthurai, Pillaithoppu, Rajakkamangalam, and Colachel coastal areas due to swashing of larger sediments by constructional wave actions. Rocky shores are predominant in Kanyakumari, Muttam, and Colachel areas, where the immediate inland topography is also rocky/hilly. The inshore region at these places is also rocky, which act as a natural barrier to wave actions and storm surges. The rocky boulders and sea cliffs abound in the Muttam and Kanyakumari coasts (Fig. 27, 28). Typical wave-cut notches (0.38 km^2) and wave-cut platforms (0.62 km^2) are found along the Muttam (Fig. 29, 30) and Colachel coasts where the destructive waves undercut the weaker parts of the rocky shore to form the notches and platforms. Large sand bars (0.05 km^2) at river mouth can be noticed in the estuary near Thengaipattinam and Manakudi.

Fig. 27. Beach rocks along the south-western coast of Tamil Nadu.

Fig. 28. Beach rock along the Kanyakumari coast.

Repeated field measurements at Colachel beach between 2006 and 2008 revealed the range of wave height as between 0.5 and 2.5 m, and wave period between 8 sec and 15 sec, with strong seasonal fluctuations. This has its effect on beach profile, which undergoes erosion during the SW monsoon (June-September), but regains much of the lost volume and shape by January-February. A strong westward longshore drift takes place from June to August, carrying large volume of sediments along that direction, the transport rate apparently increasing after the construction of several man-made structures. The total volume of sand transported during the 2-year measurement period was estimated as 1810 m^3 (Hentry et al., 2013). The sediment drift, both along and across the beach due to littoral current and high wave energy, is leading to net coastal erosion (Kaliraj et al., 2013).

Fig. 29. Wave-cut platform at Muttam.

Fig. 30. Terrace formation at Muttam.

The Colachel beach and the Muttam beach are also the major hosts of radioactive minerals like monazite, mixed with ilmenite and zircon (Fig. 31). The total heavy mineral content in the beach sand at Colachel is 22% by weight, while at Muttom it is 21%.

The coastal sand dunes are dominantly the parabolic dune complexes with a height of 2-4 m, especially in the Kanyakumari-Kovalam (3.27 km^2), Manakudi-Periyakadu (2.38 km^2) and Manavalakurichi-Colachel (1.30 km^2) tracts (Fig. 32). The backshores and the foredunes at Kovalam, Pallam, Manavalakurichi, Mandaikadu and Inayam are affected by severe erosion due to strong backwash (Fig. 33).

Fig. 31. Monazite sand along a beach near Muttam.

Fig. 32. Coastal dunes along the coast between Kanyakumari and Kovalam.

Kanyakumari beach is a famous tourist location, especially for the beautiful views of sunrise and sunset over the open sea (Fig. 34). Kanyakumari is also visited for the Vivekananda Memorial Rock, which is an isolated rock outcrop in the open sea, about 500 m from the land, where the Indian Saint, Swami Vivekanada had meditated, as also the colossal 40 m high statue of Thiruvalluvar in granite on the same rock outcrop, and a Memorial to Mahatma Gandhi (Gandhi Mandapam; Fig. 35). Muttam, beach is also famous tourist destination (Fig. 36).

Fig. 33. Coastal erosion between Kanyakumari and Kovalam.

Fig. 34. Sunrise at Thriveni Sangamam, Kanyakumari.

Fig. 35. Gandhi Mandapam and Thiruvalluvar statue at Kanyakumari.

Fig. 36. Muttam beach and sea resort.

Fig. 37. Source rock for monazite sand along the beach between Muttam and Kolachel.

Beach Placer Deposits and their Mining: The coastal tract of Tamil Nadu is known for high concentration of heavy minerals (specific gravity >2.85), mostly derived from the crystalline basement rocks. The accumulation of beach placer minerals in the coast is chiefly due to the terrestrial sources, from where the minerals are carried by water to the sea through the estuaries (Fig. 37). The source rocks are abundant in the hinterlands of the coast, making the formation of placer very easy. The total average content of heavy minerals is around 39%. Of these, ilmenite forms the major constituent (24%; Fig. 38, 39), with rutile (1.8%), leucoxene (0.9%), zircon (20%), monazite (1%), sillimanite (3.5%) and garnet (5.5%). Ilmenite contains about 56% TiO_2. Muttam beach has high concentration of ilmenite and monazite (Fig. 40, 41).

The monazite has a total of 58% REE oxides and 8% ThO_2. The total reserves of heavy minerals in the Manavalakurichi-Colachel stretch are estimated to be about 1.6 MT. Ilmenite amounts to about 1 MT. The estimated reserves of other minerals are as follows: 0.075 MT of rutile, 0.035 MT of leucoxene, 0.082 MT of zircon, 0.043 MT of monazite, 0.23 MT of garnet, 0.14 MT of sillimanite and about 6850 tonnes of kyanite.

In fact, the coastal areas of India is known to contain large amounts of heavy mineral like ilmenite, rutile, zircon, monazite and sillimanite which are used in various fields of application like the paint industry, pharmaceuticals, nuclear sectors, communication, electronics, water purification, aviation, oil refineries etc. The exploration and exploitation of beach sand minerals started in the 20th Century, especially after the accidental discovery of monazite from the beach sands of Travancore state by a German scientist, Mr. Schombery. The oldest mining in this area was for monazite. The deposit extends to a length of about 6 km, from the north of Muttom promontory to Colachel, with an average width of 45 m. The area north of Colachel to Midalam has been found to contain workable deposits of heavy minerals estimated to about 0.5 MT. The reserves of ilmenite and rutile are worked out to be around 0.31 MT and 15,300 tonnes respectively. The beaches at

Kanyakumari, Sanguthurai, Rajakkamangalam, Colachal and Inayam come under the non-mining beaches.

Fig. 38. Ilmenite deposit along the Muttam beach.

Fig. 39. Layers of illmenite deposit at Muttam.

Fig. 40. Illmenite and monazite deposits on the backshore at Muttam.

Fig. 41. Layers of illmenite and monazite sand at Muttam backshore.

The beaches at Manakudi, Kadiapattinam, Manavalakurichi and Midalam are highly prone to erosion due to the above mining activities (Fig. 42). As the old beaches are dug for mining, the wave action on them increases, leading to strong swash and backwash that erode the beach to a few metres' depth and form a cliff. Ultimately, a new beach at a lower height is formed, as noticed at Midalam (Fig. 43) and Inayam.

Fig. 42. Beach erosion at the Midalam coast.

Fig. 43. A new beach at the base of the old wave-cut beach at Midalam.

Stop 4: Teri Sands

One of the typical landforms in the area is a degraded sand dune topography of reddish brown hue, known collectively as coastal "Teri Sands". Although the deposits occur in large patches roughly between Kanyakumari and Tuticorin, the topography is dominant along the coastal stretch between Kovalam and Manakudi, and in Muttam-Kadiyapattinam area (Fig. 44). The mean sand thickness increases from 1.5 m near the coastal headlands to 7.0 m inland, with weathered gravels and bedrock at depth. In Muttam area the dune topography is highly gullied. These reddish sands were deposited as a coastal dune system, mostly between 24 and 11 Ka, when the sea level was much lower (Jayangondaperumal, 2014). Subsequently it underwent rapid chemical weathering that led to kaolinite formation from the feldspar and concentration of hematite in the fine sediments that provided the reddish colour. Silica and carbonates precipitated within the sand profile, which favoured the localized formation of rhizoliths from the plant roots (Gardner, 1981; Hendry, 1987).

Fig. 44. Landscape on Teri sand dune deposits between Kovalam, Manakudi and Muttam.

Day 6:

Kanyakumari to Thiruvananthapuram

Depart from Thiruvananthapuram.

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