

# Rocks for Coastal Protection

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### E-1 Introduction

Protection to shoreline may be required for beach stabilization, for backshore protection from waves and storm surges, for inlet stabilization and for protection of the harbour. Depending upon a particular requirement, a suitable structure is constructed from locally available material wherever possible. It is not always possible to meet all the specifications required for the construction material while designing a coastal structure. The building material locally available plays a significant role in bringing down the total cost of a structure. The qualitative requirements of rocks for coastal protection are only a few but they are required in large quantities. Therefore, it is essential that they are naturally occurring/outcropping in the vicinity of the structure proposed to be constructed.

### E-2 Essential properties of rocks for coastal protection

The strength properties of rocks vary significantly within the same rock-type and even within the same formation and therefore, it is only in a general way that the properties can be discussed. Durability, hardness, compactness, porosity are critical in determining the suitability of a rock for construction at sea (ref. 13).

The requirements for coastal protection demand that the rock must have sufficient strength to withstand hostile forces of the sea. The rock should also have a high resistance against chemical corrosion as the sea water corrodes almost everything with which it is in constant interaction. Some important properties of rocks with examples of common rock types along the Indian coasts are discussed below.

**E.2.1 Durability :** Rocks are aggregates of minerals and therefore, the nature of constituents and manner in which they are held together determine the capacity of particular rock to withstand disintegration and decomposition due to heat, pressure, etc. Of special importance is the chemical action of sea water and that too on sedimentary rocks.

Granites and basalts are generally preferred because of their fine grains and absence of joints. Sedimentary rocks, *i.e.*, sandstone, shale or limestone are products of secondary dynamic conditions, and therefore, they yield easily to powerful forces. Phyllites and schists may be durable, however, their cleavages may sometimes make them unfavourable.

**E.2.2 Hardness :** Hardness of rock is dependent on many factors such as constituent minerals, mode of origin and nature of cementing material in sedimentary rocks. Igneous rocks are comparatively harder than the sedimentary rocks while granites, dolerites and basalts are harder among the igneous rocks and quartzite is harder due to dominance of quartz. In the case of metamorphic rocks, hardness depends on the plane. A plane parallel to the cleavage naturally will have less hardness than the one perpendicular to the cleavage. Phyllites and slates are good examples of this.

**E.2.3 Strength :** The strength of rock is defined as its ability to resist crushing under direct pressure or sometimes its resistance to fracture when it is subjected to transverse forces. Strength of material is more important as some rocks have less strength in a wet condition than when they are dry.

**E.2.4 Size :** Since rocks are to be used in specific sizes according to particular design for the coastal protection, the availability of rocks in a particular size becomes very important.

**E.2.5 Weight :** Heavier stones have greater density, lower porosity and greater compactness. Thus fine grained, heavy dense rocks are highly desirable in coastal protection works.

**E.2.6 Porosity and absorption :** Porosity of the rock plays a significant role in the selection of the material which would be under constant attack of waves. Highly porous rocks are generally not favoured. Sea water will have negligible effects on granites and basalts whereas limestone is bound to react and will get dissolved in sea water. Laterite, though highly porous has been reported to have a high resistance to chemical decomposition and can be used for coastal protection as an alternative to other rock types of better quality. Due to abundance of laterite along the coasts of India, its use may be explored.

Table E.1 gives the range of values of important properties for some common rock types for comparison.

*Table E.1 Important engineering properties of common rock types (ref. 15).*

Rock	Young's Modulus at zero load 105 kg/cm <sup>2</sup>	Bulk density g/cm <sup>3</sup>	Porosity per cent	Compressive strength kg/cm <sup>2</sup>	Tensile strength kg/cm <sup>2</sup>
Granite	2-6	2.6-2.7	0.5-1.5	1000-2500	70-250
Dolerite	7-10	3.0-3.05	0.1-0.5	2000-3500	150-300
Basalt	6-11	2.8-2.9	0.1-1.0	1500-3000	100-300
Sandstone	0.5-8	2.0-2.6	5-25	200-1700	40-250
Shale	1-3.5	2.0-2.4	10-30	100-1000	20-100
Limestone	1-8	2.2-2.6	5-20	300-3500	50-250
Quartz	-	2.65	0.1-0.5	1500-3000	100-300
Gneiss	-	2.9-3	0.5-1.5	500-2000	50-200
Slate	-	2.6-2.7	0.1-0.5	1000-2000	70-200
Laterite*	-	1.8-2.2	-	7-25	-

\* Anonymous

Another factor which needs consideration in the use of locally available rocks apart from the cost of quarrying and transportation, labour, altitude, and is the design life of the structure and the cost involved in the replacement of material within that period versus the cost of transporting better material from sources at greater distances.

### E.3 General geology of peninsular India

The Indian peninsula is divided into three well defined regions, *i. e.*, the peninsular, the Indo-gangetic alluvial plains and the extra peninsula. The southern Indian shield known as the peninsula is a triangular tract extending about 1500 km from north to south. It has a width of about 800 km. The larger part of the shield is underlain by a vast complex of ancient gneissic and granitic rocks for which the name 'peninsular gneiss' has been given. These are typically migmatitic gneiss with alternate bands of amphibolite and tonalite with inclusions of older rocks (ref. 12). Islands and lenses of various sizes with a granitic and granodioritic composition are common within the gneissic complex. Over these ancient rocks lie Pre-Cambrian and later sediments and extensive sheets of horizontal Deccan Traps. Some Mesozoic and Tertiary sediments are found mainly along the coastal regions. The Western and the Eastern Ghats are the main mountains along the Indian coasts.

The western ghats is a long unbroken escarpment extending for about 1280 km parallel to the west coast and mark an important physiographic feature of the Indian peninsula. The ghats

commence south of the Tapti estuary in Gujarat and extend south up to Cape Comorin as a wall with only one major break at Palghat. The ghats comprise many geological formations of differing physical and structural characteristics. The northern half of the ghats from the Tapti valley down to Goa is formed of horizontal beds of massive Deccan Traps. South of Goa, the horizontal bedded traps give place to steeply dipping gneisses and schists and further south in Kerala, the ghats recede inland leaving a fertile coastal plain (ref. 11).

The Eastern Ghats include a series of rather detached hill ranges of heterogenous composition. These do not belong to a single geological formation, but vary with the country-side through which the hills pass. The ghats stretch intermittently from the northern border of Orissa, through the coastal regions of Andhra Pradesh to join the Nilgiris in the western part of Madras. They are uniform in their character in Orissa and in the northern part of Andhra down to the valley of the Krishna river. They are composed of garnetiferous sillimanite gneisses and large masses of charnockite (ref. 8).

The close of the Mesozoic era was marked by the outpouring of enormous lava flows which spread over vast areas of western, central and southern India. The lavas spread out far and wide as nearly horizontal sheets. The area now occupied by the Deccan Traps is about 500,000 sq km covering Gujarat, Maharashtra, Madhya Pradesh and extending up to parts of Andhra Pradesh and Karnataka. The Deccan Traps are thus the most extensive geological formation of peninsula at present, with the exception of the metamorphic and igneous complex of Archaean age. Dykes are numerous in the traps but they are not evenly distributed, some areas being devoid of them and others closely crowded with them. In many localities they form excellent building stones, provided that proper varieties are carefully chosen.

#### E.4 Geology of the coastal zone

Eastern and western coasts of India show some significant differences. The eastern coast is markedly low-lying with a number of large river deltas. The western coast is largely devoid of deltas and a large stretch especially in the central part is marked by cliffs and promontories (Maharashtra-Konkan coast) and lakes, lagoons or backwaters in the south (Malabar coast). At some places, especially along the tidal estuaries, deltaic fronts or salt marshes, mangrove swamps line the coasts. The coastline in front of the deltas, for example, the Ganges is liable to significant changes owing to the constant struggle between the seaward growth of the delta, the erosion by the waves and the formation of sand bars.

**E.4.1 Kutch coast :** A 5 to 16 km wide strip along the coast of Kutch is largely covered by alluvium consisting of wind blown loam and sand underlain by clay (Fig. E-1). Between the alluvial belt and the traps there are two belts of Tertiaries roughly parallel to the shore. The older beds consist of clays and limestones of Eocene Age. The younger beds are sandstones and clays ranging in age from lower Miocene to Pliocene (ref. 1). Occurrence of miliolite rocks is also reported from Kutch but no outcrops are seen along the coast (ref. 2).

**E.4.2 Kathiawar coast :** Deccan traps occur very close to the shore in northern part while in other areas the traps recede to the interior. Along the south-west coast from Porbandar to Veraval miliolites are extensively exposed along the coast and extend 30 to 40 km inland. The formation over the Pliocene and Miocene rocks directly overlies the Deccan traps towards the north and east. On the coast, its thickness increase appreciably and these form a thick wedge against the older traps (Fig. E-1). Along the southern part of the coast, the thickness of the miliolite formation has been estimated to be 60 m or more (ref. 2). The formation is marked by thin banding oblique lamination and a gentle seaward dip of  $5^{\circ}$ - $15^{\circ}$ . The miliolite is coarser near the shore but becomes progressively finer grained with increasing distance from the shores (ref. 9). Though the basalt occurs more than 25 km from the shore, because of its durability it will be advantageous to use the basalt instead of miliolite limestone for coastal protection works.

**E.4.3 South Gujarat coast:** The rivers Mahi, Tapti and Narmada form broad and fertile alluvial plain at their confluence with the sea (Fig. E-1). The plain resembles to a considerable extent the alluvial plains of the east coast. The plain covers a greater part of the Surat, Broach and Ahmedabad districts. It

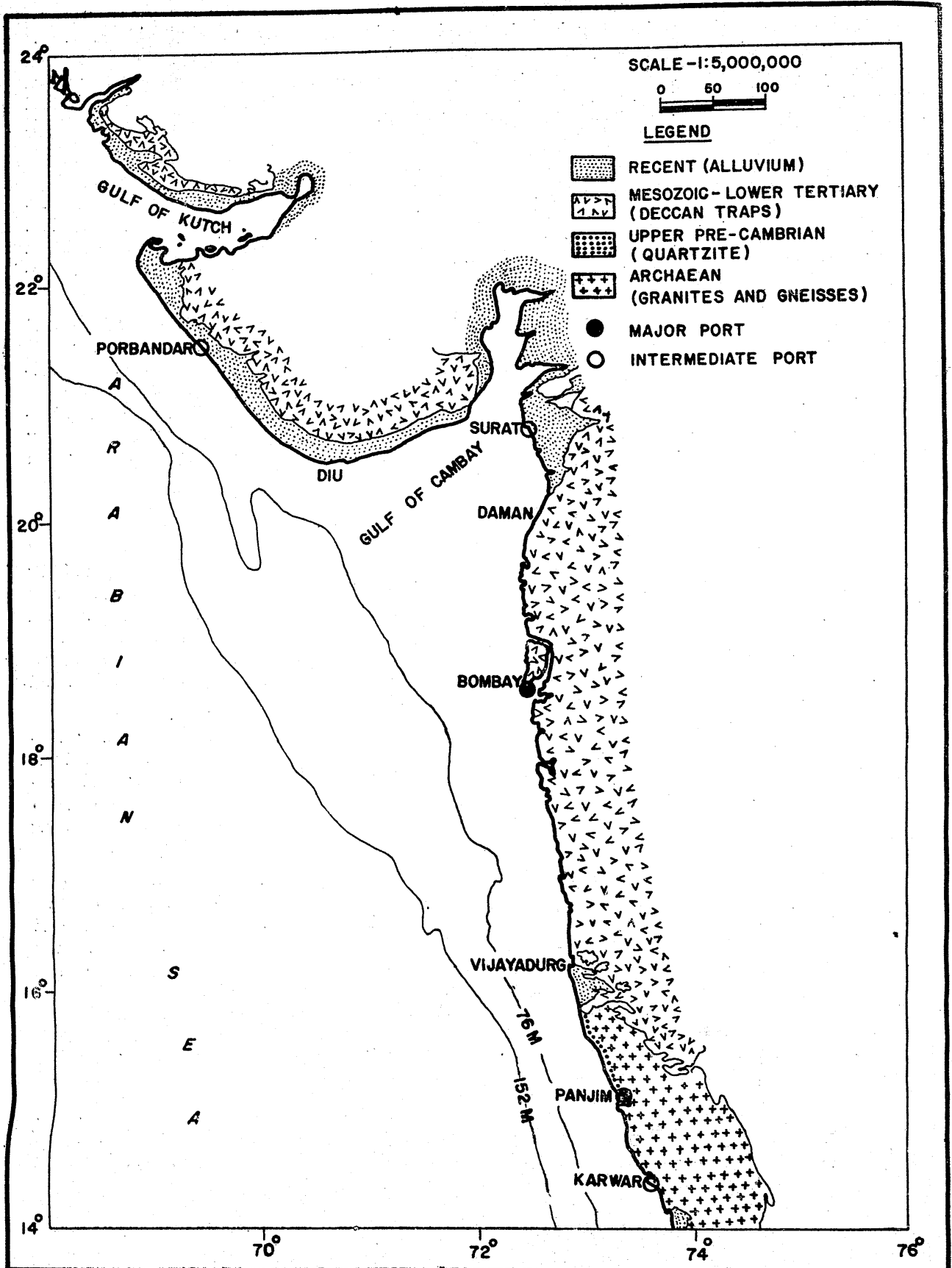


Fig. E.1 Geological map of north-west coast of India,

extends from the Rann of Kutch to just south of Daman. In the north, it joins the recent deposits of the Indus Valley (ref. 10).

Cambay trough runs nearly north-south and it is bounded by faults on its eastern and western sides. The Deccan traps which are exposed at the surface on both the sides of the trough, in Kathiawar and Baroda areas, have been faulted down to a depth of over 1800 m in the trough. The traps are covered by a full succession of Tertiaries. The Tertiaries between Broach and Surat are capped with laterite. A number of small detached outcrops of Bagh beds (Cretaceous) occur along the east-west trending Narmada Valley from Bagh to beyond Baroda. The formations are cherts, impure shelly limestones, quartzitic sandstones and shales. The sandstones underlying the Bagh beds, particularly near Baroda provide large quantities of excellent building stones of very handsome appearance and durability (ref. 14).

**E.4.4 Konkan coast :** From Daman to Vijaydurg in Ratnagiri District, the Deccan trap is the dominant geological formation and extends upto the coast and possibly continue to the shelf also (Fig. E-1). The lava flows at some places are separated by thin beds of lacustrine or fluvial sediments (ref. 14). The traps usually consist of basalt or dolerite. The most common being a dark green or nearly black normal augite basalt without olivine and often with significant assembly of basic glass. The rocks do not vary in its composition over wide areas. The average specific gravity is 2.9 but there is a wide difference in texture. Most of the varieties are homogenous, hard and compact (ref. 10) but some are vesicular and scoriaceous. The amygdaloidal cavities are filled up by numerous secondary minerals like calcite, quartz and zeolites. The quartzites are megascopically uniform micaceous (usually biotite) which gives rise to a feeble schistosity. The quartzites are dark grey to whitish grey and buffish white fine to coarse grained and massive to well stratified. Massive milky white quartz veins are seen cutting across the quartzites at many places. The quartzites have been intruded by quartz veins and basic dykes.

A laterite of variable thickness caps the geological formations along the coast. The laterite covers almost the entire coastal track except very steep slopes, rivers, valleys and the alluvial areas.

Granite and gneisses with intercalations of metabasalt form the dominant rocks of the coastal area from Betul to Karwar. The gneisses composed of fine grained quartz and feldspar are well bounded. The banding is generally parallel to the foliation but some streaks of quartz and feldspars cut across the foliation. The gneisses gradually merge with the massive coarse grained and unfoliated granite. The metabasalts represent very low grade metamorphosed Dharwarian basalt with feeble schistosity.

**E.4.5 Malabar coast :** The narrow coastal belt from Karwar to north of Quilon (except Calicut to Cannanore) is covered by alluvium which adjoins the gneisses and granites to the east (Fig. E-2). The gneisses are typically migmatitic with alternate bands of amphibolite and tonalite. Inclusions, lenses and islands of older rocks of granites, granodiorites and charnokites are common in the gneisses. From Calicut to Quilon laterite capped tertiary beds cover the gneisses in the coastal area. From Calicut to Cannanore, the alluvial belt is very narrow and the gneisses almost abut the coasts.

Along the south-west coast of India, various types of rocks constituting the ancient formations, *i.e.*, gneisses, garnetiferous sillimanite bearing granulitic, gneisses of high grade metamorphism, leptynites charnockites, crystalline limestones and graphitic schists are exposed at some distance from the coast (ref. 7).

Near Cape Comorin crystalline gneisses of Cardamon hills abut the shore. The coastal alluvium occupy the forms of an extremely narrow zone and landward is underlain by coastal tertiaries followed by gneisses and granites. The coastal area from Cape Comorin to Rameshwaram is largely covered by Tertiary and Recent sediments.

**E.4.6 Coromandal coast :** Between Manamadurai and Pondicherry, extending from the coast to about 80 km inland the area is covered by tertiary to cretaceous sedimentary rocks (Fig. E-2). These sedimentary rocks overlie the gneisses and charnockites of the basement (ref. 3, 4 and 5).

Between Cauveri delta to Visakhapatnam, there are isolated outcrops of the upper Gondwanas along a narrow strip of the country between the coast and gneisses to the east. The upper Gondwanas for the most part are composed of littoral sandstones, gravel and conglomerate rock with occasional shale intercalations (ref. 14).

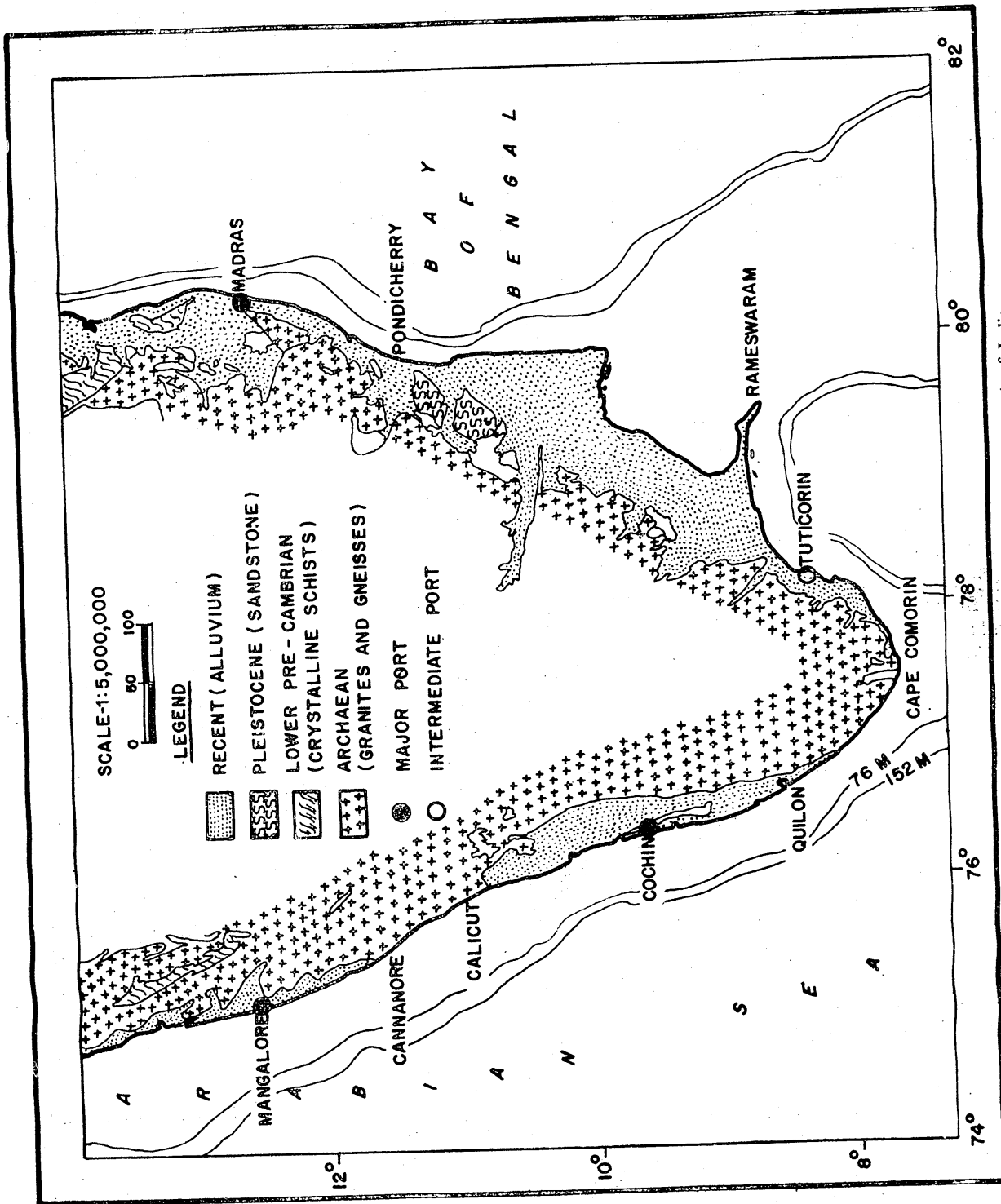


Fig. E.2 Geological map of south-west and south-east coasts of India.

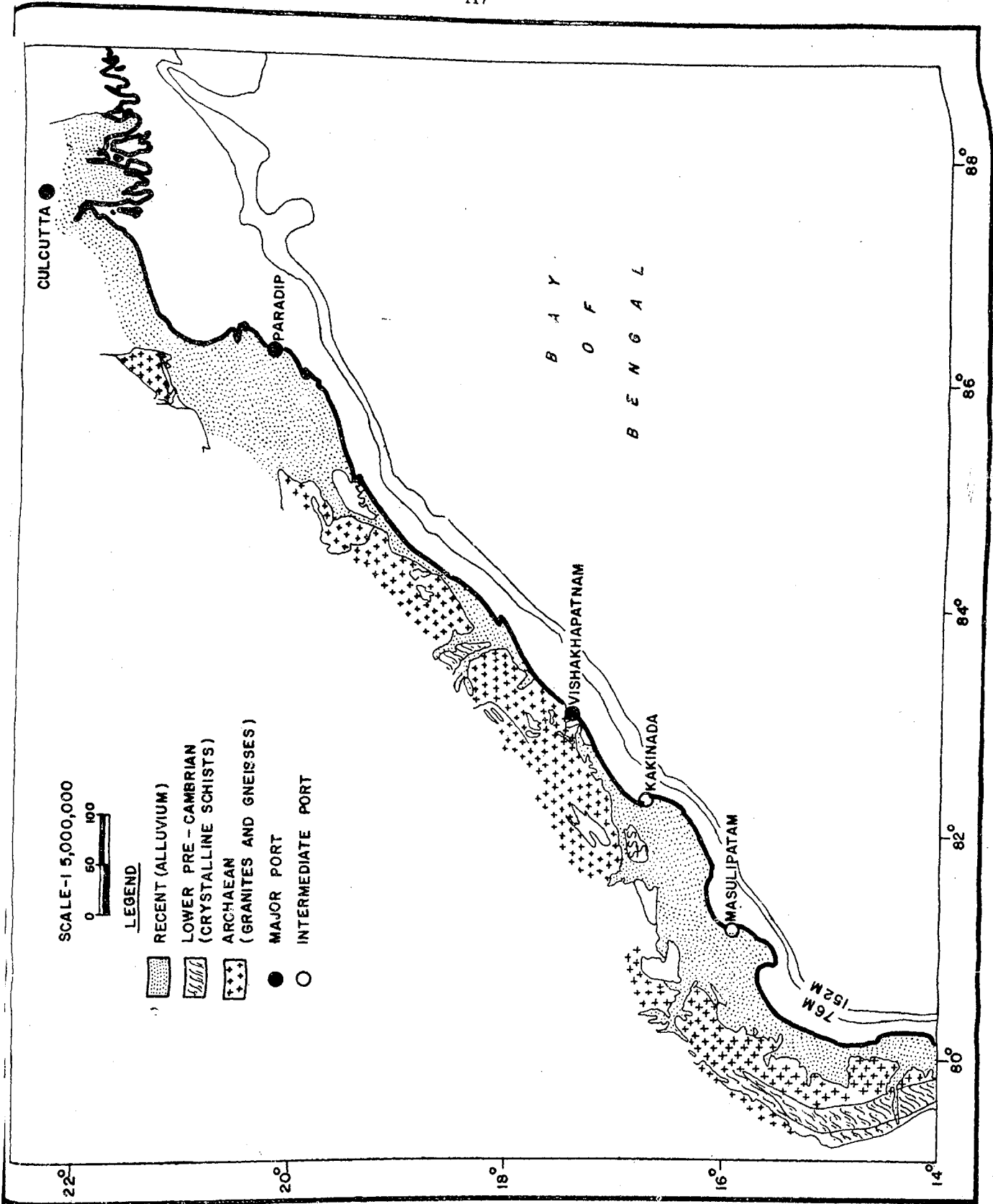


Fig. E.3 Geological map of north-east coast of India.

The Krishna and Godavari deltas and the adjoining coastal tracks are largely covered with pleistocene and recent deposits of the rivers. The thickness of the recent alluvium gradually decreases from the shore to the delta heads where the ancient granite, gneisses and basic rocks are exposed. A narrow triangular patch of the Upper Gondwanas occurs in the Godavari valley south near the town of Rajahmundry. The Upper Gondwanas consist of limestones, clays and sandstones with boulder conglomerates (ref. 14).

The northern Circars coast from Kakinada to Puri is mainly covered by alluvium except off Visakhapatnam where the rock cliffs abut the shore (Fig. E.3). In the interior the ancient gneisses and granites with khondalites and charnockites are exposed. The khondalites are particularly dominant in the north-eastern and south-western extremities of the region. A small outcrop of charnockites occurs between the Vasamdhara river and the Chilka lake.

The coastal region between the Mahanadi and the Ganges deltas is largely covered by recent and sub-recent deltaic deposits of these rivers. Shoreward the coastal zone of Ganga delta region adjoins the mangrove tidal forests of Sunderbans. Towards the west the monotony of the plain in Balasore and Midnapore is broken by sand dunes. In the Mahanadi delta the topography of the coastal region is marked by mangrove swamps towards the shore but further inland it represents an alluvial deltaic plain traversed by wide distributaries of river Mahanadi. The north-western margin of the deltaic plains is marked by lateritic hills near Cuttack. The ancient crystallines, gneisses and granites are exposed to the west at some distance from the shore, the nearest they reach the shore is Balasore (about 30 km). In the Mahanadi delta and the north patches of older fossiliferous sedimentaries (Baripada banks and Upper Gondwanas) occur near Baripada and Puri.

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