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Geotechnical Studies of Inner Shelf off Mutyalammapalem-Pudimadaka, North Andhra Pradesh Coast, Central East Coast of India

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Abstract:- The survey implemented in two phases i) Survey by mechanized boat ii) survey by R.V.Samudra Kaustubh. Laboratory studies include textural and determination of geotechnical properties of sediment, geochemical analyses of seawater and sediment carried out in laboratories. The bathymetric contours are in parallelism with the shoreline, in NE-SW direction. The seafloor is smooth with moderately steep gradient. The shallow seismic survey indicates two prominent sub-surface reflectors, R1 and R2. The reflector R1 is almost sub-parallel to the seafloor. The thickness of unit – I (between seafloor and reflector R1) is 3 - 4 m. The deeper reflector R2 is a marker reflector with good reflectivity present through out the area. The reflector R2 is dipping towards the offshore and merging with reflector R1 in the NE part and further exposes onto the seafloor. The thickness of unit –II varies between 0 to 11m. The echo character of reflector R2 suggests that this reflector represents the top of a relatively hard substratum which crops to the surface in the north eastern part likely to be the hard formation and surface on to the seafloor in the northeastern part.

The sediment type is uniformly sand. The sand unit extends both vertically as observed from the core logs and laterally up to 30 m isobath. The moderately sorted and well sorted sediment which are negatively skewed are suggests relatively medium energy conditions. The surface current speed varies from 0.304 knots to 0.48 knots and direction varies from 59^o to 190^o. The bottom current speed varies from 0.29 knots to 0.41 knots and direction varies from 61^o to 210^o. The direction of the littoral drift is towards northeast and the magnitude varies from 0.104 knots (beyond the wave breaker) to 0.4047 knots (wave breaker to lowest low tide zone). Sediment geochemistry reflects the source rock from the adjacent eastern Ghat Group of rocks comprising both Khondalite and Charnockite.The base line geochemical data of sediment, sea water coupled with Pollution Load Index (PLI), Geoaccumulation Index (Igeo) and the concentration levels of toxic metals analyses are far below the world average marine sediment.

Keywords:- Mutyalammapalem, beach profiling, littoral drift, geotechnical appraisal , textural characteristics

I. INTRODUCTION

The work was carried out in six stages i).Reconnoitary survey, ii). R.L transfer, iii) Beach profiling, iv) Littoral drift measurement, v) Near shore shallow water survey by mechanized boat and vi) offshore survey on board R.V.Samudra Kaustubh.

A. Location

The study area falls in parts of NHO chart no. 308 and 354 covering part of Survey of India Toposheet No 65O/2 and O/3. The beach profile stations are located in a stretch of 7 km from the village Jogannapalem in the south to Mutyalammaplem in the north (Fig.1).

B. Objective

The objective of the geotechnical investigation was to carry out integrated marine geo-scientific surveys within the Territorial Waters off Mutyalammapalem together with the collection of basic data on bathymetry, sediment distribution, subsurface geology, geotechnical parameters of the sediments, current patterns and geochemical parameters of sea waters for development of project.

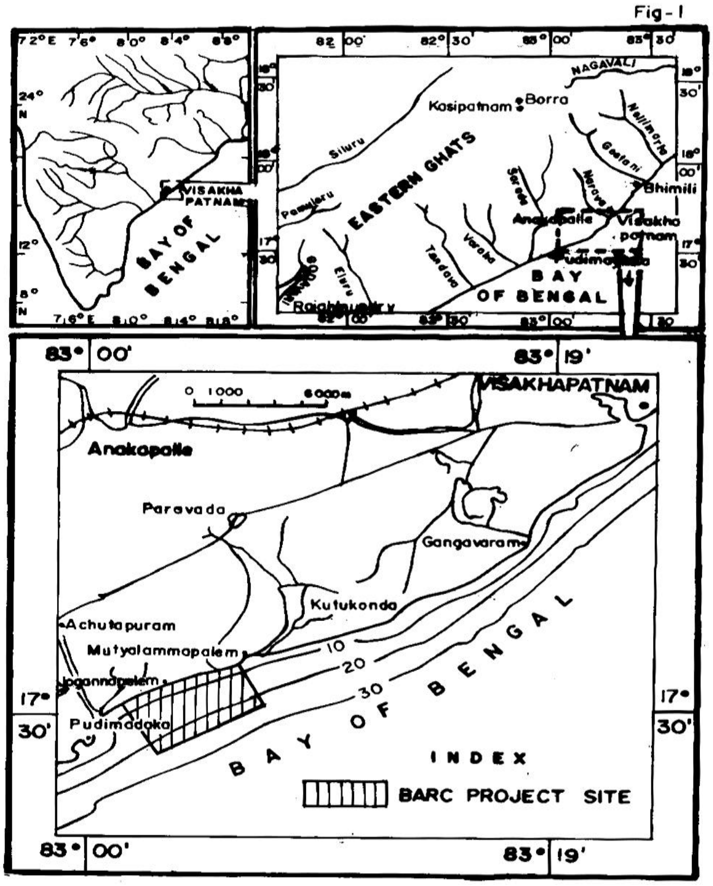

Fig.1: Location of the study area

II. GENERAL CLIMATE AND RELATED FEATURES OF THE SITE OF STUDY

A. Physiography

The coastal and the hinterland is characterized by hills and mounts of Eastern Ghat complex and at places the rock exposures continue towards the offshore as found at Mutyalammapalem and Pudimadaka south and north respectively of the area under study. These offshore rock exposures are associated with a bay feature immediate to the northern side of the exposures. Being a wave dominated coast, the coastal part near the shoreline is invariably characterized by sandy beaches the size, width and the characteristic shapes of which are variable from place to place.

Mutyalammapalem (latitude 17^{o} 32′ 08″ N; longitude 83^{o} 05′ 30″ E) located on the sand zones rising to an average height of about 3 m above MSL is a fishing village on the east coast of Andhra Pradesh, India between Visakhapatnam (latitude 17^{o} 43' N; longitude 86^{o} 16' E) on the north, and Pudimadaka (latitude 17^{o} 29'13" N; longitude 83^{o} 00'15" E) on the south. The distance between Visakhapatnam and Mutyalammapalem is about 30 km by sea and 50 km by road. Around Mutyalammapalem, the coast line is straight trending NE – SW and is crescent shaped at Pudimadaka due to hard rock promontories extending offshore. During the monsoon, the flood waters of the surrounding catchment area bordered by Pulla konda (106 m), Niti konda (167 m)and Devi konda (139 m) collect into a small ephemeral stream and discharges into the sea through creek at Mutyalammapalem. An isolated outcrop of Khondalite rising to a height of about 3 m above MSL lays ENE of the creek. A few Khondalite exposures are also seen along the coast line trending ENE-WSW with steep dips (80^{o}) towards south. The shoreline at BARC site trends almost NE-SW in a linear pattern but rocky exposures and promontories are conspicuous both at Mutyalammapalem in the north and Pudimadaka in the south. The open shore promontories are prominent morphological features at these locations.

B. Sediment Source

Eastern Ghats form the major source area for the drainage basin. The principal lithological units of the Eastern Ghats are the Khondalite and Charnockite series. The landmass adjoining the study area has a fairly good surface drainage system. A number of non-perennial mountain streams and perennial spring waters flowing in a general SE and ESE direction contribute to the total drainage system of the area. Sarada is major stream with large catchment area and there are minor streams with small catchment area. Littoral drift from Godavari river mouth is evident from the sediment characteristic on the coastal tract [1].

C. Climate

The climate of the region is sub-tropical to tropical. There are two monsoon periods namely the south-west monsoon from June to September and north – east monsoon from October to February. In the pre-monsoon period from March to May, the winds are from south west direction. Even though the maximum sustained wind during October and November does not exceed 110 km per hour from ENE, gusts of an intensity of 150 km per hour have been occasionally experienced during cyclonic storm. The wettest season coincides with the south west monsoon and post monsoon period. September and October are the wettest months of the year with an average rainfall of 420 mm. The average annual precipitation is 944 mm.

The landmass adjoining the inner shelf area under study is influenced by semiarid (D) type of climate. The moisture index (Im) of the area is 42.9 %. May is the hottest month (maximum 34^{o}C) and January the coldest month (maximum 17^{o}C). Relative humidity from April through September is very high on account of monsoonal rains and ranges from 80 to 84 %. Maximum rain fall of 426.6 mm occurs from September to October during the retreating monsoon period. October the wettest month with maximum rain fall of 259.3 mm and January the driest month with minimum rain fall of 7.2 mm. Soil has a field capacity to hold 200 to 300 mm of water at any time, and is never saturated or replenished because of high water need and low rainfall. Even the excess of rainfall during September – October (only 83 mm) is hardly sufficient enough to replenish the high field capacity.

D. Winds

The magnitude and direction of the wind in the area varies season wise, rather it is driven by the monsoon prevailing in this sub-tropical part. During the North East monsoon from November to February the average strength is force four. But this strength reaches force six in April and May. Land and sea breezes are also prominent during both pre-and post monsoon transition periods. The onset of southwest monsoon brings rough weather in June and this continues up to September with an average strength of force four to five with a constancy of about 80 %. Variable winds prevail in the post-monsoon period of October to November, with force two to four but occasionally during rain squalls or gusts the force increases to seven. Thermal and topographical effects produce considerable change of speed and direction of wind along the coast. The threat of cyclones affects coastal sectors at different times of the year.

III. SEA STATE CONDITIONS

A. Surface Currents

The northeast monsoon produces a westerly drift in the open waters of the Bay of Bengal resulting in a counter–clockwise circulation. The northeast monsoon produces a westerly drift in the open waters of the Bay and a current setting southwestward and southward along the east coast of India. But northeast winds, blowing over the lands of wintry cold cools more the waters at the head of Bay than those at Ceylon and consequently a density current flows up the coast. The seasonal variation in the direction of winds and the resulting seasonal currents in opposite directions cause an intricate circulation pattern in the Bay waters, which varies every month.

B. Littoral Currents

A north-east flowing long shore current is produced the entire coast by the high waves of the southwest monsoon season which break at an angle with the shore. A southerly long shore current is developed similarly in the northeast monsoon season when the swell changes its direction by about 45^{o} due to the monsoon effects. Because of the longer duration and greater severity of wave action of the southwest monsoon the northerly longshore current is stronger than the southerly one. These longshore currents are however effective only in the surf zone near the coast[2].

IV. COASTAL AND NEARSHORE ZONE SURVEYS

A. Beach Profiling

***1) Reference Level Transfer*:** The reference Level (Jogannapalem cyclone shelter fixed by Survey of India for BARC designated as BM: S-26) has been transferred to beach profiling station P2 where offshore Jetty of BARC is proposed. The same RL carried to the other beach profiling stations P1, P2 and P3. Transfer of RL further north to P4 at Mutyalammapalem could not be achieved terrain conditions and time constraint. The RL at P4 near Mutyalammapalem was assumed for beach profiling.

2) Fixation of reference pillars at 4 stations: Reference Concrete pillars were erected and RL was marked on the top of the Pillars.

3) Study of Beach profiles: The beach profiles are measured using measuring staff, measuring rope and WILD auto-level with the help of surveyors. Profiling was done during low tide, at each station from the reference point up to lowest low tide level from the available predicted Tide Tables published by Naval Hydrographic Office (NHO). The data collection time and duration was planned in advance with reference to tides at Visakhapatnam port.

4) Study of littoral drift using tracers: Tracer study was carried out off reference point P2 (Jogannapalem, Fig. 2 to 8) using Rhodamene–B as tracer released aligning the flags erected in 145^{o} and measured at a distance of 15 and 50 m where flags were erected both side of P2 for alignment and found the direction and speed of the littoral drift. At the same place current speed and direction also taken with the help of EMCON make current meter.

5) Survey by mechanized boat: The shallow segment of the seabed lying between the coastline and 8 m isobath was surveyed by a mechanized boat for collection of basic data on bathymetry, current observation and collection of sediment samples grab

V. OFFSHORE SURVEYS BY R.V. SAMUDRA KAUSTUBH

A. General

The area off Mutyalammapalem to Pudimadaka between 4 to 40 m depth located in NHO chart No: 308 was covered in detail by sediment sampling, bathymetric surveys, shallow seismic surveys and swath bathymetry.

B. Instruments Deployed On Board

Shallow seismic surveys were carried out by deploying a shallow seismic unit of EG&G make which consists of a power unit (model 232), a capacitor bank (model 231 A), 6 electrode sparker array and two sections of hydrophone streamers. The receiving system comprises preamplifier / filter (model 202) of INNER SPACE TECHNOLOGY INC. and the EPC-2000 graphic recorder to obtain record in analogue form. High cut frequency 800 Hz and Low cut frequency 150 Hz and 200 Joules energy was used during survey.

Bathymetric surveys were carried out with Bathy-1500 echo sounder along the cruise tracks. The navigational positioning of the vessel is aided by Differential Global Positioning System (Leica) and applying corrections from Beacon receiver for differential mode throughout the surveys. The survey was carried out using “Advanced Hydro Survey” software and the position location data is processed using Hydro Survey advanced version 3.0.

Bathymetric and shallow seismic surveys were carried out simultaneously by deploying Bathy-1500 Echo sounder and sparker seismic profiler of Ocean Data Equipment Corporation. Sea-bat 8111 Multi Beam Echo Sounder of RESON Make, DENMARK was used for swath bathymetry and data were processed by software PDS2000.

C. Samplers Deployed On Board

Sub-surface samples were collected with Vibro-Corer sampler at 13 stations. The length of the core recovery varies from 0.15 to 3.1 m. Water sampling was carried out at 6 stations (9 nos.) by Niskin water sampler. Current observations were carried out using current meter of EMCON, Kochi at six stations.

VI. BATHYMETRIC STUDIES

Bathymetric survey by RV Samudra Kaustubh was carried out along 3 coast perpendicular lines of 3.5 km at 500 m apart; and 23 coast parallel lines of 8 km each at 100 m spacing, between 5 m and 22 m of water depth. In addition, near shore zone, i.e., up to 10 m isobaths was carried out by using a mechanized boat along 45 zig - zag lines of average 750 m length with a variable spacing of 500 m to 1000 m. It may be noted that the line spacing for bathymetry data acquisition is maintained at 100 m interval in view with the maneuvering of the ship.

A. Acquisition of Data

1) Survey by R.V.Samudra Kaustubh: The echo sounder BATHY 1500 Model was used with analog recorder, correspondingly the positions along the tracts were obtained from DGPS through beacon receiver interfaced with a PC having hydro-survey programmer. The depth data with its location were logged at five minutes time interval mode. During the bathymetric survey the speed of the vessel was maintained around 6 knots.

2) Survey by Mechanized boat: The depth data with its location was acquired by Portable echo sounder of RESON (Navy sound 200 – single beam) make with analog recorder and Portable Global Positioning System of Micro logic ML – 150 models. The data was logged for every one/two minutes of time interval mode. The speed of the boat was maintained around 3 to 4 knots. Due to the frequent shoaling and high waves near the breaker zone the proposed cruise tracks could not be maintained aned the mechanized boat had to follow a zig-zag.

*3) Swath Bathymetric Survey:*Twenty lines of 3.358 km at 50 m interval were planned for swath bathymetric coverage, but fishing activity hampered the survey and only part of the planned area was covered. Total of 28 lkm of survey was carried out covering an area of 2.2 sq. km

VII. GEOPHYSICAL STUDIES

Shallow seismic and bathymetry surveys were carried out along three N-S coast perpendicular transects L-P2N, L-P2 and L-P2S, covering a distance of 500m on either side of the line L-P2 which is passing through the alignment of the reference Pillar P2 on shore. Four coast parallel transects were also covered in NE-SW direction along RL-400, RL-900, L-650 and L-900.. In addition a cross line L-cross is also taken for stacking of coast parallel transects. The length and direction of transects were chosen keeping in view the maneuverability of the vessel in shallow depths.

A. Seismic Survey

The shallow seismic reflection survey was carried out along eight transects in the bathy zone of 5 to 23 m and out put data was recorded in analogue form. The analogue record of the seismic data is processed and digitized to obtain the two-way travel times for seabed and sub-seabed reflecting layers. Seismic time sections were prepared for all transects taking the two-way travel times in millisecond in 1:50000 scale. The depth to the acoustic reflectors has been expressed in two-way time in millisecond (m.sec.) as the actual velocities of sub-bottom formations were not known. However an average velocity of 1800 m/s (1 milisecond (t.w.t.) = 0.9 meters appx.) is assumed to calculate the thickness of the different sedimentary units and depths to the sub-surface reflectors.

1) Transects L - P2N, LP2 and LP2S: The two - way time sections along the transect L-P2N, L-P2 and L-P2S are prepared and presented in the Fig. 18. In general the seafloor is very smooth and gently slopping towards the sea. The bathymetry variation along these transects was between 5 and 23 m. The reflector R1 is almost parallel to the seafloor. The thickness of sediments (between seafloor and Reflector R1) of unit-I varies from 3 -5 m along these transects. The reflector R2 occurs at a depth of 18 -34 m.sec. along transect P2N, 19 -39 m.sec. along transect P2 and 18 – 45 m.sec along transect P2S from the sea floor. The thickness of the unit-I between seafloor and R1 increases towards offshore. The thickness of sediment unit-II (between reflector R1 and R2) varies between 2 -12 m.sec, along these transects. The total thickness of the unconsolidated sediments along these lines increasing towards offshore and vary from 4 *to* 14 m.

2) Transects RL-400 and RL- 900: The seafloor is smooth the water depth varies from 4 to 15.6 m along these transects. Reflector R1 is occurring at a depth of 20 - 24 m.sec and 24 - 27.5 m.sec along the transect RL-400 and RL-900 respectively from the seafloor. The thickness of sediment unit – I varies from 3 to 10 m along these transects. The reflector R2 is present only in transect RL-900 and it is merging with reflector R1 at fix no. # 345 which was disposed at a water depth of 25 - 32 m.sec from the sea level. The thickness of unit-II along RL-900 varies from 2 to 5 m. The total thickness of sediments of unconsolidated sediments varies from 5 to 10 m.

3) Transects L- 650 and L- 900: The seafloor is smooth. The depth to the seafloor varies from 16-19.5 m. The reflector R1 is almost sub-parallel and mimics the seafloor. The reflector R1 occurs at a depth of 30-33.6 m.sec and 32-36 m.sec from the sea level respectively along the transect L-650 and L-900. The reflector R2 occurs at a depth of 30.5-43.5 m.sec and 31-44.8 m.sec from the sea level and merges with reflector R1 at fix no. # 314 and #342 respectively along the transect L-650 and L-900. The thickness of sediments of unit-I varies from 4 to 7.5m and that of unit-II varies from 0 to 10m. The total thickness of unconsolidated sediments vary from 4 to 15m along these transects.

4) Transect L-Cross: The seafloor is smooth and dipping towards sea. The depth to the seafloor varies from 11 – 21m. The reflector R1 is occurring at a depth of 33.2 to 40.2 m.sec from sea level and the thickness of sediments of unit-I vary from 4.5-7 m. The reflector R2 occurs at a depth of 20.2-48.5 m.sec. and merges with reflector R1at fix no. # 374 (Fig.23). The thickness of sediments of unit –II varies from 0 to 7.5m along this transect. The depths to the reflectors at the cross over points on different transects are matching well.

5) Stratum Contour Map: Stratum contour map to the top of reflector R2 is prepared to know the total thickness of unconsolidated sediments deposited over the reflector R2 (Fig.2). The stratum contour indicates a thickness of unconsolidated sediments between 2 to 15 m with its thickness increasing with depth both in SSE and SW direction. The thickness is, maximum in the south-western part of the area surveyed. The thickness of sediments decreases as the reflector R2 surfaces on to the seafloor in NE part of the area. No surface or sub-surface dislocations / faults were found in the area.

6) Conclusions: Two distinct reflectors are identified in the surveyed area within a probing depth of 18m.sec. The reflector R1 is almost sub-parallel and mimics the seafloor. The thickness of unit – I between the seafloor and reflector R1 varies between 3 - 4 m.

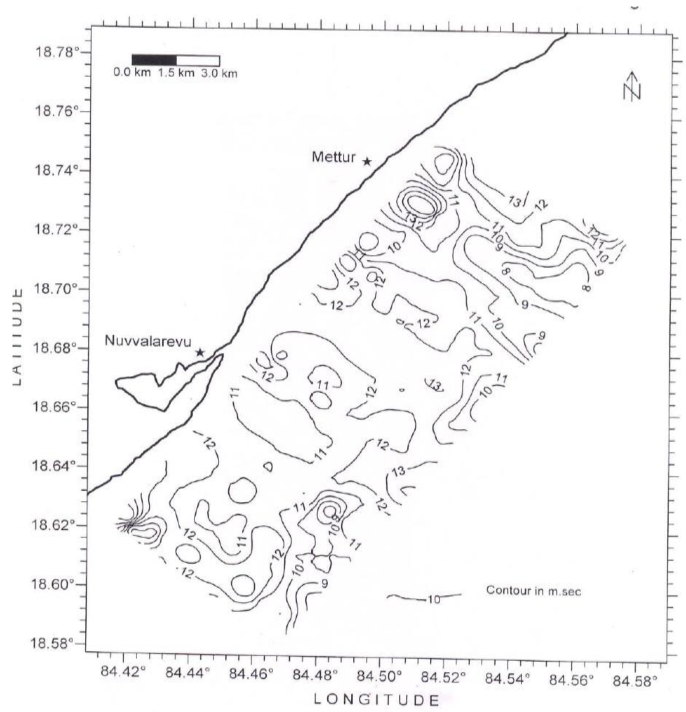

Fig.2: Isopach map of Unit-1

The deeper reflector R2 is a marker reflector with good reflectivity present through out the area surveyed. The reflector R2 is dipping towards offshore direction. The reflector R2 merges with reflector R1 in the NE part of the area and crops to the seafloor. The thickness of unit –I varies between 0 to 11m. The echo character of reflector R2 suggests that it is relatively a hard formation which surfaces on to the seafloor in the northeastern part. This reflector R2 seems to be the extension of hinterland rock formation exposed in the near shore area.

The stratum contour generated to the top of reflector R2 indicates a maximum thickness of unconsolidated sediments which vary from 2 to 15 m with its thickness increasing with depth both in SSE and SW direction in the surveyed area. No surface faults/lineaments are observed in the area surveyed. The extension of hinterland rock formations into the offshore area in the NE part of the area acts as a barrier to prevent long shore sediment transport.

VIII. SEDIMENTOLOGICAL STUDIES

Grain size distribution is an important component of the seafloor sediments and plays a vital role in determining the physical properties of the sediments like strength, compressibility, elasticity, plasticity etc. The grain size distribution is controlled by the relative abundance of dominantly three size classes, namely, sand (63µm - 2 mm), silt (2 µm – 63µm) and clay (<2 µm). Amongst these, cohesive sediments that come under the fine fraction of sediments (fine silt and clay) are determinant in the stability and strength of the seafloor.

A. Methodology

A total of 75 samples (sub-samples of 12 vibro-cores) collected on board R.V.Samudra Kaustubh and 17 grab samples collected on board a mechanized boat were subjected to size analysis following standard method of sieving [2], and / or pipetting [3] as described in [5]. The data thus obtained is processed by the Inclusive graphic measures of [6] and are used to calculate the conventional grain size parameters.

B. Characteristics of Surface Sediments

Sand, silt and clay percentages and their statistical parameters are determined for 29 surface samples derived from vibro-cores and grab samples collected off Mutyalammapalem to Pudimadaka in order to understand the sediment distribution, textural characteristics and the environment of deposition. The sediment nomenclature is after Shephard [7].

The sediment type in the mapped area is uniformly sand (Fig. 3). The sand unit extends both vertically as observed from the core logs and laterally up to 30 m isobath as reported by [8]. The nature and sub-classification of the sand unit will be dealt in the following sections.

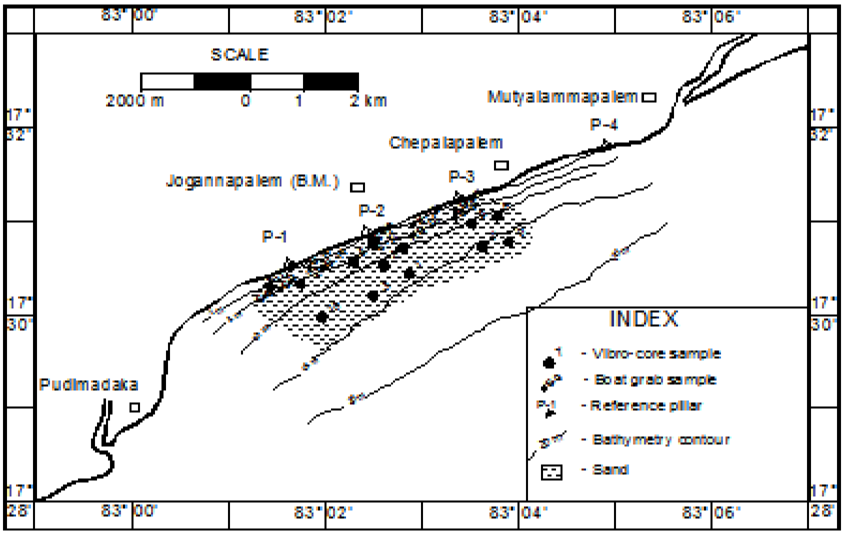

Fig.3: Surface sediment distribution

1) Mean Size (Mz): The sub-classification of sediment type is represented by the mean size which is the average grain size of the distribution taking the entire grain size distribution curve into account. In the surface sediments, the mean size varies from 2.74 Ø (fine sand) to 3.64 Ø (very fine sand) with an average of 3.21 Ø (very fine sand). Very fine sand is the dominant unit in the surface sediment. The fine sand unit occurs mainly as isolated patches in the nearshore regions below 10 m isobath.

2) Standard Deviation (√ I): Standard deviation is a measure of the degree of sorting of the sediments that reflects the energy of the depositional environment. The energy of the depositional environment controls the relative proportion of coarse and fine sediment fractions. Standard deviation values varying from 0.31 Ø (very well sorted) to 1.34 Ø (poorly sorted) is recorded from the area. Based on the sorting index the sediments in the area largely falls into four categories, viz. very well sorted, well sorted, moderately sorted and poorly sorted.

The nearshore area within 5 m isobath is characterized by moderately sorted sediments. The moderately sorted sediment grades into well sorted sediment off the region between P2 and P3, whereas in the region off P1 to P2, the sediments are very well sorted. In the 10 to 15 m isobath zone, poorly sorted sediments occur in the NE part and moderately sorted sediment occurs in the SW part. The variation in energy condition within the small area may be a cumulative effect of the shoreline configuration and the offshore anthropogenic construction structure present on the SW part of the area.

3) Skewness (Ski): Skewness (SKI) is a measure of the symmetry of the grain size distribution and it is about the relative proportion of fine and coarse sediment in the sample. A normal distribution, being symmetrical, has zero skewness. If the distribution possesses a coarse tail portion relative to the finer sizes, the skewness is negative whereas, if there is a tail portion in fine sizes relative to the coarse sizes, the skewness is positive**.**

Skewness is varying from -0.72 (very negative skewness) to 0.10 (near symmetrical skewness). Based on the skewness index, the sediments of the area can be grouped into three major categories, viz. very negatively skewed, negatively skewed and near symmetrically skewed. The near shore sediments up to 10 m isobath are dominantly negatively skewed with some patches of near symmetrically skewed sediments within. In the zone between 10 and 15 m isobath is covered by sediment of very negative skewness. Overall the skewness pattern indicates a deficit of fine fraction and relative abundance of coarser fraction in the sediment. The skewness pattern of the sediments suggests relatively high energy conditions.

4) Kurtosis (Kg): Kurtosis (KG) measures the ratio of the sorting in the extremes of the distribution compared with the sorting in the central part of the curve and as such is a sensitive and valuable test of the normality of the distribution. Kurtosis, a measure of degree of peakedness of the frequency distribution curve, indicates the ratio of the sorting in the extremes of the distribution to the central part. It is a sensitive and valuable measure in testing the normality of the distribution. If the central part of the distribution is better sorted than that of the tails, in other words a peaked shape in the frequency curve, the distribution is leptokurtic. When the sorting in the central part is nearly same as that of the tails, the distribution is mesokurtic. When the tails of the distribution is better sorted than that of the central part, in other words a saddle shaped or flat – topped grain – size frequency curve,l the distribution is platykurtic [6].

Kurtosis varies from 0.75 (platykurtic) to 2.05 (very leptokurtic) with an average of 1.18 (leptokurtic) in the area. Based on the kurtosis values, four categories of sediments are identified in the area. They are platy, meso, lepto and very leptokurtic. The sediment distribution has no definite pattern of kurtosis values. Sediment units with different kurtosis values occur in isolated patches. Very lepto kurtic sediments are confined to the zone beyond 10 m isobath and the other three types occur in all the zones irrespective of the depth domain.

C. Characteristics of the Sub-Surface Sediments

Sediment type in the sub-surface level is also similar to that of the surface level and is evenly carpeted by sand. Sand remains as the dominant constituent of the sediment column up to 3 m as evidenced by the longest core of 3.10 m recovered off P-1. The relative proportion of silt and clay is very less as compared with that of sand in the sub-surface levels.

1) Mean Size (Mz): Mean size in the 50 cm below seafloor level varies from 2.06 Ø (fine sand) to 3.48 Ø (very fine sand) and accordingly two mean size classes, namely fine sand and very fine sand are identified. At 50 cm below seafloor level, the very fine sand unit is confined to the central part of the area and spreads across the bathymetric contours perpendicular to the coast. Fine sand occurs on either side of the very fine sand unit. The down core variation of mean size shows a steady decrease towards lower levels.

2) Standard Deviation (√ I): At 50 cm below seafloor level, the standard deviation values vary from 0.67 Ø (moderately sorted) to 2.36 Ø (very poorly sorted) with an average of 1.43 Ø (poorly sorted). Based on the sorting index, the sediments at the sub-surface level fall under two categories- poor and very poorly sorted. At 50 cm below seafloor level, moderately sorted sediment occur as a narrow strip perpendicular to shoreline in the offshore region between P-1 and P-2. Rest of the area is covered by poorly sorted sediment except at sample location 7. In the core samples, standard deviation shows a trend reverse to that of mean size and thus shows a general increase towards bottom. Increase in standard deviation indicates decrease in sorting index and implies a decrease in energy condition during deposition. Down core variation of mean and median size also indicates a typical regressive upward coarsening sequence.

3) Skewness (Ski): In the 50 cm below seafloor level, skewness varies from -0.74 (very negative) to 0.01 (near symmetrical) and accordingly zones of three distinct classes, namely very negative, negative and near symmetrical skewness have been identified. Dominantly the sediment at 50 cm below seafloor level is very negatively skewed and thus indicate negligible fraction of finer sediments in them. Sediment with negative and symmetrical skewness occurs off P-2. Skewness decrease with depth in the majority of the core samples.

4) Kurtosis (KG): In the 50 cm below seafloor levels, Kurtosis value varies from 0.70 (platykurtic) to 5.3 (extremely leptokurtic) with an average of 2.39 (very leptokurtic) and are further classified into platykurtic, leptokurtic, very leptokurtic and extremely leptokurtic. Sediments on the SW corner of the area across the bathymetric contours exhibit leptokurtic nature indicating very narrow range of size class in the sediments. Leptokurtic, very leptokurtic and extremely leptokurtic sediments occur as isolated patches in the NE part of the area. Kurtosis in most of the cores increases with depth with exceptions of few where increase up to certain depth then decreases again.

IX. GEOCHEMICAL STUDIES

The geochemical data presented in the foregoing pages would be identifying the intrinsic relationship between several elements and for interpreting their genetic relationship. The methods can be utilized in the study of special and elemental variation of the data set. However, the spatial variation is not studied as most of the samples represent only a thin veneer of sediments of small area. The elemental variations are studied for identification of their chemical relationship in bulk sample set.

A. Methodology

The sediment samples have been analysed for Al, Mg, Ca, Total Fe, Na, K, Ti, Mn, Cu, Pb, Zn, Ni, Co, Cr, Cd, V and Mo by Atomic Absorption Spectrophotometer (AAS) (Varian 240FS).The organic matter (ROOM) was determined by the titration method of [9] as modified by [10].

In this study the interstitial water and dissolved solids are considered as an integral part of the sediment and therefore the chemical analysis were done on air-dried samples [11][12][13][14][15][16]. An attempt is made here to condense the information by statistical means of linear correlation and multivariate factor analysis (R-Mode), to study the elemental variations and to identify their chemical relationship in the sediment samples.

Seventy five samples related to 12 vibro - cores have been taken and seventeen variable representing $CaCO_3$, ROOM (Readily Oxidisable Organic Matter), major elements Al, Mg, Ca, Total Fe, Na, K, Ti, Mn, minor and trace elements Cu, Pb, Zn, Ni, Co, Cr and Cd have been studied.

The coefficient of variation for Pb is the highest followed by Cr, Ti, $CaCO_3$, Ca, Cd, ROOM, Total Fe, Mg, Ni, Cu, Co, Mn, Zn, Al and k. Most of the elements have variation less than 50 %. The minimum variation around 12 % is by Alkali's. The linear correlation coefficients higher than 0.40 are considered as significant. Most of the elements show very high correlation to the other elements except few minor/trace elements and organic matter.

B. Correlation Matrix

In order to study the relationship in depth, the correlation matrix is utilized for the determination of Eigen values. These Eigen values represent the total relationship split up into component relationships. The highest Eigen value represents 32 % relationship, the second one 14 % and last 11 % they total to 57 %. Rests of them are too minor for further computation. To identify the factors responsible for the inherent, the correlation matrix is rotated using Kaiser's varimax rotation principle. The loadings which are very high are underlined. All the major elements viz Na, K, Ca, Mg, Al, Total Fe, ROOM, $CaCO_3$ and trace elements Cu, Pb, Zn, Ni, Co, Cr and Cd gives high loadings and the Ti shows the lowest value in the system even though given as second factor. The Al, total Fe, Co and Zn show higher loadings in the third factor. More interesting than this, is the occurrence of base metals (Cu and Pb) along with Cr, Cd and Mn showing high loading in the second Factor.

***1) Factor 1*:** Most of the major elements viz Ca, Mg, Na, K, ROOM, $CaCO_3$ and trace element Ni are reflected as significant loading in this factor which explains 32 % variance. This factor is interpreted as combined silicates, carbonate and organics factor. This factor represents the 1) weathered products of Precambrian rocks 2) calcium carbonate in the sediments and 3) organic matter. The concentration of Ca, Mg, Na and K is mainly controlled by lithogenous concentrations appear to be indicating of derivation from acidic granite or granulites of the source area. Shells, shell fragments and skeletal matter contributed mainly to the Calcium carbonate in the sediments and are reflected in the factor. The organic matter varies from 0.22 to 1.85 % (av.1.08) and results from high biological productivity in surface waters due to reported upwelling and / or from he high degree of preservation in the sediments on the sea floor and is reflected in the first factor.

2) Factor 2: This factor explains the 14 % of the variance where the loading of Cu, Mn, Cd, Pb, Ti and Cr are reflected as a factor which is interpreted as base metals factor. There is reported occurrence of base metals and heavy minerals reflected as their genesis.

3) Factor 3: This factor explains the 11 % variance and the loadings of Al, Mg, Total Fe, Co and Zn are reflected. This factor is interpreted as Alumino silicate factor. The aluminosilicates itself is of lithogenous origin and the remaining elements associated with it and derived from the source rocks are reflected in the factor.

C. Inferences from Geochemistry

The basic factors that are identified in the detritus sediments can be related to the bulk chemistry of the metamorphic rock types present in the source region, i.e. Khondalites, which represent the aluminous metamorphosed rock types and Charnockites which have dominant amounts of Ca and Mg. Ti also is an important component of the bulk chemistry of rocks. From the chemical analyses and statistical parameters determined it is construed that the provenance of the sediment is from the adjacent hinterland comprising Khondalitic and Charnockitic suite of rock.

In brief, the following important parameters can be stated:

1) The sediments show a consistency in the bulk chemistry. The coefficient of variation is markedly medium.
2) The elements analysed show strong relationship with Na/Mg, Ca/Mg, Mg/Co, Mg/Zn, Fe/Zn, Fe/Mn, Fe/Cu, Cu/Zn, Cu/Zn, Cu/Cr, Co/Zn and Cd/Pb

X. ENVIRONMENTAL GEOCHEMICAL STUDIES

A. Coastal Pollution Studies

The coastal pollution studies can be grouped into two types in India i.e. 1. Pollution from natural sources and 2. Anthropogenic activities which impacts the coastal environment considerably.

1) Main Source of Coastal Pollution: The possible sources of pollution in the area could be i) Industrial and Municipal wastes ii) river run off including agricultural water and iii) miscellaneous sources (dredging, port based activities etc.).

2) Pollution Due to Anthropogenic Activities: include i) over loading coastal waters with enormous volumes of biodegradable substances in which the level of dissolved oxygen becomes a limiting factor i) sewage from cities, large town ii) anaerobic conditions created by organic chemicals which will have a high demand for oxygen makes the aquatic life difficult to survive iii) toxins which effect marine life directly which effects human health through food chain iv) heavy metals (Pb, Cd, Hg, As, Cr etc) have a long term effects on human health and creates serious problems through bioaccumulation and entry into food chain v) Non-degradable substances like oils, plastic and polymers that damage marine life and spawning grounds and vi) dumping of solid wastes without proper treatment.

The Visakhapatnam port every year handles about +30 million tones of cargo consisting of iron ore, Pb-Zn ore concentrates, rock phosphate, sulpur, crude oil, coke and coal etc. Most of the sewage enters into the harbour which partly treated and the arrangements are being made for total treatment of the sewage. The municipal sewage also enters the coastal waters from nalas. Majority of the industrial effluents from the near by industries, Pharma-city, Industries in Achutapuram SEZ and some more industries discharge their effluents into the coastal waters north and south of the present area of study.

An attempt is made here to assess the metal pollution levels. Pollution Load Index and Geo-accumulation Index are taken as a tool to asses the pollution levels if any of the coastal area off Mutyalammapalem to Pudimadaka.

B. Methodology

1) Pollution Load Index (PLI): The Pollution Load Index (PLI) is evaluated using the following equation: PLI= n / Product of n number of CF values Where CF = Contamination factor, and n= number of metals. The contamination factor (CF) = Metal concentration in polluted sediment/Back ground value of metal. Interpretation for PLI: > 1 by anthropogenic inputs such as industrial effluents and domestic sewage into coastal waters.

2) Geoaccumulation Index (Igeo): Igeo values falling in the class zero indicate predominant occurrence with lighogenic flux, while those falling in 1 - 2 or 2 - 4 indicate their excessive accumulation due to anthropogenic inputs. The Mutyalammapalem – Pudimadaka near shore area is very near to the major ports of Visakhapatnam and Gangavaram.

C. Inferences on Geo-environmental studies

Pollution Load Index (PLI) which less than one and Geo-accumulation Index (Igeo) zero indicate that level of pollution in the area is negligible.

Studies are taken up for geo-environmental appraisal for the present area. The concentration levels of toxic metals analyses are far below the world average marine sediment concentrations. The V & Mo are <1 ppm, Cd average concentration is 2.1 ppm and other major traces are far below the world average. The water samples analysed shows that the carbonates is in non-detectable limits, Cr, Mn, As, V and Mo also in non-detectable limits, Cu and Zn are in <5 ppm limits, bicarbonates are in ppm levels where as remaining major and trace metals are in low ppm levels indicating that there is least pollution in the area of study. Present base line data clearly shows that coastal waters are pollution free during survey period. The base line geochemical data of sediment and sea water clearly shows that the area of study is least pollution.

XI. GEOTECHNICAL STUDIES

A total of 12 vibro core were collected from the water depth ranges of 5.51 to 17.2 m. The length of vibro core sediment varies from 0.2 to 3.1 m. These vibro core samples were cut at every 25 cm interval and the sub-samples were preserved in a refrigerated storage container during the voyage. Later all the sub-samples were transferred to the laboratory and kept in the deep freezer till the geotechnical tests were carried out as described by [17] . Thus a total of 75 sub-samples were generated.

A. Laboratory studies

Water content, liquid limit, shear strength by hand torvane and sensitivity are measured on vibro-core sub-samples. The vibro cores were collected in a PVC liner after vibro-core penetration into seabed. As such the pore water remained within the sediment (sand). The cores were cut into sub-samples of 25 cm each immediately after collection and shear strength measurements were done by hand torvane. The sub-samples were then preserved on board in the refrigerator container and the same sub-samples were transported to shore laboratory and kept in freezing conditions till the remaining tests were conducted with minimum time lapse. As such the water content within the core was not allowed to drain and measurements of water content were done. As such all the above samples contain low natural moisture content and liquid limit when compared to samples containing more clay/silt fraction. The various geotechnical tests, which include, the un-drained shear strength of the undisturbed and re-molded sediment, the wet unit weight, the natural moisture content, the specific gravity were conducted on the samples with more than 12 % of fines (Silt + Clay). Wherever the fines content is less than 12 % and sand content is more than 88 %, properties such as, water content, wet unit weight, specific gravity only determined. The various geotechnical tests which include, the shear strength of the undisturbed and re-molded sediments, the wet unit weight, the natural moisture content, the specific gravity, and the Atterberg Limits (Plastic) were determined as per Lambe, 1951. Plastic limit and liquid limit could be measured on only one sample (VC-10/150) where sufficient clay content is present. Void ratio and porosity were computed by using the standard conventional formulae. The downcore variation of geotechnical parameters measured is given in Fig. 4

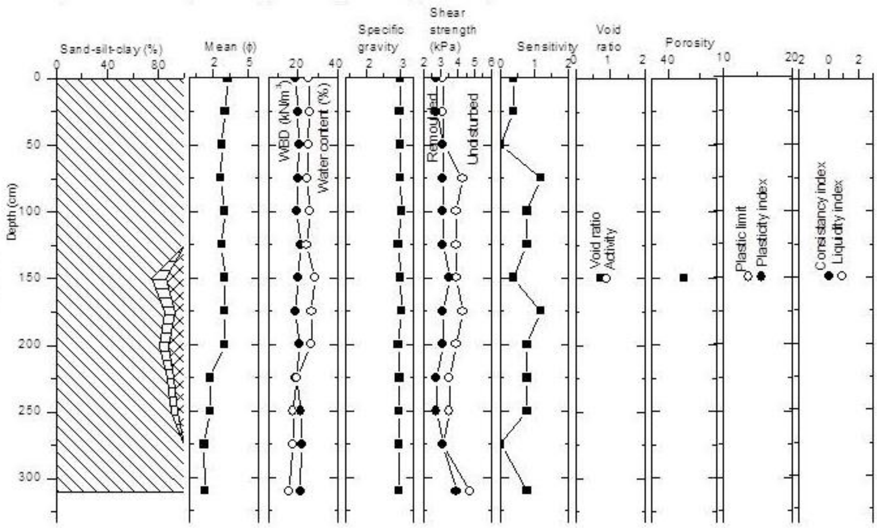

Fig.4: Down-core variation of Geotechnical property of VC-10

1) Specific gravity (Gs): The specific gravity varies from 2.6 to 2.8 (Average 2.66). There is no remarkable variation ether laterally or vertically.

2) Shear Strength: Although the sediment is predominantly sandy in saturated condition, shear strength has been determined as per the values observed in the samples.

3) Undrained Shear strength (Su) of undisturbed sediment: The un-drained shear strength in undisturbed state varies from 3.14 to 6.28 k Pa (Average 4.4 k Pa) and increases towards sub-bottom with exception in some cores.

4) Shear strength (Su) of re-molded sediment: The remolded shear strength varies from 2.35 to 4.71 k Pa (Average 3.28 k Pa) and increases towards bottom with few exceptions. The Shear strength values of un-disturbed as well as remolded sediment increases towards sub-bottom due to compactness and consolidation of sediment at that level. The Shear strength of remolded sediment are always less than the normal (undisturbed sediment) shear strength as the structural strength gets destroyed by remolding.

5) Sensitivity (St): The sensitivity varies from 1.1 to 2.0 with an average of 1.35. The sensitivity is a measure of loss of strength, when the structure strength of sediment is destroyed by re-molding. Higher the sensitivity, greater the loss of strength in re-molded condition. As far as sensitivity values are concerned all the sub-samples in the range of 1 to 2, which is suggestive of "slightly insensitive" nature of sediment with a strength loss of up to 50 % up to 3.1 m subsurface.

6) Wet Bulk Density (γ) or (Wet Unit Weight): The wet bulk density varies from $15.34 kN/m^3$ to $21.71 k N/m^3$ with an average of $18.98 k N/m^3$. The sediments have shown a general increase towards sub-bottom. The wet unit weight is directly related to the amount of sand material and decrease with increase in silt plus clay content. The increase towards bottom indicates the dominance of coarse sediment over the fines. The studies also suggest presence of medium dense coarse sand to very dense coarse medium sand.

7) Water content (Wn) or (Natural Moisture Content): The water content varies from 15.46 % to 29.57 % with an average of 24.24 % and decreases towards bottom. The water content is a quantitative measure of wetness of sediment mass. Generally, the water content in the finer sediments is more than the coarser sediments. Sometimes in fine clays, the water content is even more than 100 %, which means that more than 50 % of total mass is that of water (ratio between the weight of the water and weight of the mass). The water content is such an important property that soil changes to a marked degree with a variation of its water content. The water content increases with increase of silt and clay content. The variability in water content is due to the textural variations and normal burial effects due to loading. In general, the water content decreases towards sub-surface. As a whole, the nature of sediment is dense mixed grained sand; and loose mixed grain sand with average dense uniformity.

8) Void Ratio (e): Void ratio varies from 0.40 (dense uniform sand) (310 cm level at 14.6 m water depth, fine sand 100 % and water content 15.46 %) to 0.81 (loose uniform sand) (150 cm level at 14.97 m of water depth, sand with 82 % sand and 18 % fines and water content 29.57%) with an average of 0.67 (soft fine silt) showing general decrease towards sub-bottom.

9) Porosity (n): Porosity varies from 28.57 % (densest) (15.46 m bathy depth, 100% fine sand; void ratio 0.40 with water content 15.46%) to 44.75 % (loosest) (150 cm level at 14.97 m bathy depth, sand with 82 % sand and 18 % fines; void ratio 0.81 with water content 29.57%) with an average 39.39% . In general, porosity decreases towards sub-surface.

This type of finer sediment at this sub-surface level and at these water depths could be because of the active deposition followed by deposition of sediments in suspension etc. as discussed already. The engineering classification suggests nature of sediment types are of loose uniform.
10) Activity (A): The Activity for one sample is 1.23 (normal as per [17].

B. Atterberg Limits

1) *Liquid Limit (LL):* The liquid limit for one sample is 29.35 % dry weight.
2) Plastic Limit (PL): The plastic limit for one sample is 13.75 % dry weight.
3) Plasticity Index (PI): The plasticity index for one sample is 15.96 (medium plasticity and cohesive in nature as per [19].
4) Liquidity Index (LI): The liquidity index for one sample is 0.92 (very soft as per [18]).
5) Consistency (Ic or Ci): The consistency index for one sample is 0.08 (very soft or fluid plastic as per [18] and [20].

XII. PHYSICAL - CHEMICAL PARAMETERS OF SEA WATER

Sea water samples have been collected by deploying water sampler at 6 stations in water depths ranging from 8.92 m to 21.17 m. Analyses of sea water samples for salinity, temperature, dissolved oxygen (DO), hydrogen ion concentration (pH) and conductivity have been carried out on board by using the water analysis kit.

A. Materials and methods

Surface water sample collection with Niskin water sampler was carried out at 6 stations in the month of February, 2010. The sampling is spread over the surveyed area. The waters collected separately and preserved nitric acid media are analysed at shore laboratories with state of the art AAS. The total uranium, gross alpha and gross beta measurements are made at Bhabha Atomic Reseach Centre, Environmental Assessment Division, Radiation Protection Section (Nuclear Fuels), Radio analytical Laboratory, Mumbai.

B. Salinity, Temperature, Conductivity, DO and pH

The Salinity values varied from 31.6 to 31.9 ‰ at surface level to 31.7 to 31.8 ‰ at bottom level; the Temperature from 27.4°C to 28.8°C (average 28.11°C) at surface to 26.8°C to 28.6°C (average 27.86°C) at bottom; the Conductivity from 48.1 to 48.8 x mS/cm at surface to 48.3 to 48.6 x ms/cm at bottom; the DO from 4.79 to 5.5.4 (average 5.07) mg/l at surface to 4.82 to 4.92 mg/l (average 4.866 mg/l) at bottom; and the pH from 8.45 to 8.91 at surface to 8.15 to 8.78 (average 8.514) at bottom. The values show almost uniform for salinity, conductivity and the pH and marginal decrease of temperature and DO towards bottom.

The salinity off coastal waters off Visakhapatnam as reported earlier [2] varies in the range of 15 to 35 ‰. The observed values are well in agreement with the earlier reported values.

The relatively higher temperature in the surface waters may be due to shallow depth and nearer to the coast. The temperature values are gradually decreasing from surface to bottom. The relatively high surface temperatures in the shallow depths can be explained due to fact that the sea waters become warmer due to exposure to the suns heat near the coast than the deeper waters. The dissolved oxygen values are slightly lower than the oceanic average (6.0 ppm) as quoted in [21]. Hence the area under study may be considered as slightly low oxygen region. There is a slight decrease from top to bottom waters.

C. Carbonate, Bi-Carbonate, Major And Trace Metals

Carbonate (CO_3), bi-carbonate (HCO_3), major elements (Al, Mg, Fe, K, Na, Ca, Mn) and trace metals (Cu, Pb, Zn, Ni, Co, V, Bi, Cr, Cd, Mo, As, Sr) are analysed by AAS in the water sample preserved in acid media.

The carbonates is in non-detectable limits, Cr, Mn, As, V and Mo also in non-detectable limits, Cu and Zn are in <5 ppm limits, bicarbonates are in ppm levels where as remaining major and trace metals are in low ppm levels indicating that there is no pollution in the area of study. Present base line data clearly shows that coastal waters are pollution free.

XIII. CONCLUSIONS

Bathymetric contours are in alignment with the NE-SW shore-line. The sea floor is smooth with moderately steep gradient. Rock exposures are present on the seafloor in the southern part of the area around 8 m isobath. The profiles drawn across the beach to 22 m isobath in the offshore reveals a gradient varying from 1:4 to 1:800 on the beach sector and 1:22 to 1:247 in the offshore sector off P1; 1:4 to 1:38 in the beach sector and 1:23 to 1:290 in the offshore sector off P2; 1:6 to 1:117 on the beach sector and 1:17 to 1:298 in the offshore sector off P3 and 1:4.5 to 1:48 in the beach sector and 1:51 to 1:147 in the offshore region off P4

The reflector R1 is almost sub-parallel and mimics the seafloor. The thickness of unit – I between the seafloor and reflector R1 varies between 3-4 m. The deeper reflector R2 is a marker reflector with good reflectivity present through out the area surveyed. The reflector R2 is dipping towards the sea. The reflector R2 is merging with reflector R1 in the NE part and further exposes onto the seafloor. The thickness of unit –I varies between 0 to 11m. The echo character of reflector R2 suggests that it is the hard formation and surfaces on to the seafloor in the northeastern part. This reflector R2 seems to be the extension of hinterland rock formation exposed in the near shore area. The stratum contour generated to the top of reflector R2 indicates a maximum thickness of unconsolidated / semi consolidated sediments of 2 to 15 m which is increasing with depth both in SSE and SW. Surface faults/lineaments are not present which makes the area suitable for any offshore development. The extension of hinterland rock formations into the offshore area in the NE part of the area acts as a barrier, creating an environment of Bay which is more suitable for offshore developmental activity.

The sediment type in the mapped area is uniformly sand. The sand unit extends both vertically as observed from the core logs and laterally up to 30 m isobath. Very fine sand is the dominant unit in the surface sediment. Area off P2 to P3 around 15 m isobath as isolated patch, poorly sorted sediments is noticed as a result of low energy conditions. The poor sorting of the very fine sands as per [8] in this area may be due to the curved nature of the coast line which resulted in creation of low energy conditions, showing the suspended fine sediment population to settle after a short travel. The remaining area is composed of very well, well sorted and moderately sorted sand due to the high/medium energy conditions. The promontories at Pudimadaka into the sea have created an accretion pattern giving rise to very well to well sorted sediments in the area. Littoral currents and wave activity played a great role in the deposition of the sediments in the area.

The moderately sorted and well sorted sediment which are negatively skewed are suggests relatively medium energy conditions. From the kurtosis values, the overall nature of sediment can be interpreted as a unit with few size class ranges. The distribution pattern is showing decreasing competency of the sorting agent from near shore to inner shelf area. The mixing is seen due to the addition of fine sediments from the creeks.

. Sub-surface Sand remains as the dominant constituent of the sediment column up to 3 m as evidenced by the longest core of 3.10 m recovered off P-1. The down core variation of mean size shows a steady decrease towards lower levels. Kurtosis in most of the cores shows an increase with depth. Sediment with negative and symmetrical skewness occurs off P-2. Skewness values in majority of the cores shows a decrease with depth.

The surface current speed varies from 0.304 knots to 0.48 knots and direction varies from 59^o to 190^o. The bottom current speed varies from 0.29 knots to 0.41 knots and direction varies from 61^o to 210^o

The direction of the drift on 21-02-2010 at 0830 hrs is towards north east and magnitude variable beyond the wave breaker is low having drift 0.404 knots and wave breaker to lowest low tide zone having comparatively high with 0.4047 knots.

The specific gravity of sediments varies from 2.6 to 2.8 (Average 2.66) and there is no remarkable/noticeable variation ether laterally or vertically. The Shear strength values of both undisturbed as well as remolded sediment increases towards sub-bottom due to compactness and consolidation of sediment at that level. The Shear strength of re-molded sediment are always less than the normal (undisturbed sediment) shear strength as the structural strength gets destroyed by re-molding. Higher shear strength suggests that the sediment is fine grained with low water content and with high density. The sensitivity is a measure of loss of strength, when the structure strength of sediment is destroyed by re-molding. Higher the sensitivity, greater the loss of strength in re-molded condition. As far as sensitivity values are concerned all the sub-samples in the range of 1 to 2, which is suggestive of "slightly insensitive" nature of sediment with a strength loss of up to 50 % up to 3.1 m below seafloor. The wet unit weight is directly related to the amount of sand material and decrease with increase in silt plus clay content. The increase towards sub-bottom indicates the dominance of coarse sediment over the fines. The studies also suggest presence of medium dense coarse sand to very dense coarse medium sand. In general the water content decrease towards sub-surface which is infers the domination of coarser sediment over the finer sediment. Sediment is dense mixed grained sand; and loose mixed grain sand with average dense uniform sand.

This type of finer sediment at this sub-surface level and at these water depths could be because of the active deposition followed by deposition of sediments in suspension etc. as discussed already. The engineering classification suggests nature of sediment types are of loose uniform.

The plastic limit for one sample is 13.75 % dry weight and is inferred to be medium state of plasticity.

Statistical appraisal of the sediment geochemistry shows that the basic factors that are identified in the detritus sediments can be related to the bulk chemistry of the metamorphic rock types present in the source region, i.e. Khondalites, which represent the aluminous metamorphosed rock types and Charnockites have dominant amounts of elements reported is an important component of the bulk chemistry of source rocks. In general, it can be stated that the sampled data represents the erosional products of the terrain consisting Archaean group of rocks.

The base line geochemical data of sediment and sea water clearly shows that the area of study is free from pollution. Pollution Load Index (PLI) which is less than one and Geo-accumulation Index (Igeo) zero shows there is no pollution in the area of study. Studies are taken up for geo-environmental appraisal for the present area. The concentration levels of toxic metals analyses are far below the world average marine sediment concentrations. The V & Mo are <1 ppm, Cd average concentration is 2.1 ppm and other major traces are far below the world average. The values show almost uniform for salinity, conductivity and the pH and marginal decrease of temperature and DO towards bottom.

The carbonate is in non-detectable limits, Cr, Mn, As, V and Mo also in non-detectable limits, Cu and Zn are in <5 ppm limits, bicarbonates are in ppm levels where as remaining major and trace metals are in low ppm levels indicating that there is no pollution in the area of study. Present base line data clearly shows that coastal waters are pollution free.

The seafloor is very smooth and gently dipping towards offshore. The reflectorR1 is almost parallel to the seafloor. The thickness of the sediment (between seafloor and Reflector r1) unit – I varies from 3 - 5 m and the thickness of the sediment (between Reflector 1 and Reflector R2) unit –II is 1.8 m to 10.8 m.The area is floored by sandy sediment which has mean size of fine to very fine sand 2.74 to 3.64 Ø (average 3.21Ø). Surface sand has continuity towards subsurface up to a minimum of 3.1 m.The fine sand indicates a moderate energy conditions.The bathymetric contours are linearly parallel to sub parallel with the trend of the shore line.There is a conspicuous break in gradient from 500 to 700 m after 6 m in the south to 12 m depth in the north.There are submerged rocky out crops between 7 to 8 m isobath with a relief of 1 m shore side to 4.7 m offshore side. Shallow seismic study indicates a relatively hard stratum below the seafloor to the first reflector of 3 - 5 m thick sediment and the second reflector of 2 – 15 m thick. Water analysis indicates that the area is free from any pollution. Similarly geochemistry of sediment also shows that the area is free from pollution. The gentle slope of the beach during February could be due to removal of top sediment during Northeast monsoon.The current meter observation indicate that the average current of the surface current is towards NE with 4.48 knots speed and bottom current direction also shows towards NE with 0.29 knots speed during survey. The littoral drift is towards north east and magnitude variable beyond the wave breaker is low (0.104 knots) and wave breaker to lowest low tide zone (onshore side) is high (0.4047 knots). The current pattern within breaker zone is in variation with deeper waters.A deeper drill into the R2 reflector may indicate the extent and nature of sub- surface soil.

A. Suitability of Pipe Line and Jetty Construction

The configuration of the seafloor, the disposition of the reflector R1, the thickness of the sediment (between seafloor and Reflector R1) unit-I, the thickness of the sediment (between Reflector 1 and Reflector R2) unit – II and no surface or sub-surface dislocations / faults were found, thus the area selected is suitable for any offshore development. Moderate gradient of the seafloor up to 1:8 is present. There is a conspicuous break in gradient at 700 m distance from the shore after 12 m depth. The area is floored by sandy sediments with a mean of 2.15 to 3.64 Ø (average 3.2 Ø). Surface sand has continuity towards subsurface up to a minimum of 2.3 m. Sediment characteristics indicates a moderate energy conditions. Water analysis and sediment geochemistry indicates that the area is free from any pollution. The surface current speed varies from 0.304 to 0.48 knots with 59^o to 158^o direction and the bottom current speed varies from 0.29 to 0.41 knots with 61^o to 164^o direction.

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