Relative fall in sea level in parts of southern Karnataka coast

K. R. Subrahmanya*

Geodynamics Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Jakkur, Bangalore 560 064, India
*On leave from Mangalore University, Mangalagangothri 574 199, India

Southern Karnataka coast has a variety of evidences which point to emergence of land. It has not been possible to provide a time frame for many of these. However, there are two features which offer information on an ongoing process of uplift and also the rate of uplift. Wave cut terraces and elevated beach deposits in the St. Mary islands and the dead oyster colony in the Suratkal beach support the tide gauge data which indicates a relative fall in sea-level of ~1 mm/year.

The St. Mary group of islands off Udupi near lat. 13°28' are oriented nearly parallel to the coastline (Figure 1)1. The volcanic rock of the islands was first described by Naganna2 who identified them as rhyolacitic. The age of the volcanics was determined as 93 Ma by Valsangkar et al.3. The Coconut island, which is in the northern end, has received the attention of both the geologists and the tourists. The rocks have very well developed columnar joints (Figure 2) and hence the island has been gifted by the Karnataka State Government to the Geological Survey of India which has declared the rocks as a National Geologica! Monument. The other reason is, its age. The Reunion hotspot which gave rise to Deccan Traps (67 Ma) has moved south relative to India and the ages of the volcanics become younger as the trace of the hotspot is followed southwards. Therefore, the occurrence of the St. Mary volcanics of 93 Ma age to the south of Deccan Traps has been a matter of debate. According to Subrahmanya4, the St. Mary volcanics are unrelated to Reunion hotspot and they are the products of partial melting of the crust during doming and rifting of India and Madagascar.

The volcanic activity which gave rise to the St. Mary islands, was subaerial in nature, as at that time Madagascar was still attached to India. Rifting of Madagascar from India took place around 88 Ma (ref. 5). That they were subaerial is confirmed by the presence of well-developed columnar joints and absence of pillow lavas. There have been several oscillations of the sea subsequent to the volcanic activity. Consequently, the St. Mary islands must have submerged, surrounded or surfaced from the sea, several times in its history. A situation similar to the present day condition occurred 125 Ka ago, when the sea-level was more or less at the present level7. This was followed by a fall in sea-level which reached ~95 m around 11 Ka BP. From 11 Ka to 6 Ka, there was a rapid rise in sea-level (~2 cm/year) when the sea nearly attained the present day level. Since then, the global sea-level has almost stabilized. This, in general, is applicable to the west coast of India, which shows very little evidence of significant sea-level fluctuation subsequent to 6 Ka. The southern Karnataka coast has a 'microwet environment', with a mean tidal range of 1.22 m. Hence, the tidal influence on the present day wave action is restricted to areas lying within ±0.61 m of the msl.

The Coconut island, which has the maximum elevation compared to other islands, attains a height of ~10 m above msl. Partly surrounding this peak, are surfaces which approximate +6 m, +3 m, +1.5 m and 0 m. These surfaces have the characteristics of wave-cut platforms, indicating that there have been episodic sea-level lowering or rise of land. The lower surfaces have negligible imprint of weathering, pointing to the fact

---

Figure 1. Location map of the study area. The map also shows coastal features (Ganapadkatil Bhut and Subrahmanya1)
that they are relatively recent. This situation allows two possibilities: (a) the surfaces might have been carved subsequent to 220 Ka when the sea-level which was +60 m started lowering and reached −95 m around 11 Ka or (b) the surfaces have developed subsequent to 6 Ka due to rise of land (as there has been no lowering of the sea globally subsequent to 6 Ka). Both the arguments are valid for the highest surface (~10 m) and the next lower surface (~6 m).

The island has a patchy layer of wave-worn rhyolitic pebbles and cobbles covering the +3 m surface. To the west of the pebble bed, is a shell deposit, whose top is nearly at +2.5 m. A trench dug through this deposit shows horizontal to gently sloping layers of fragmented shells, with variation in colours and intercalation of clay. The base of the trench at +0.25 m ends in boulders of rhyolitic. The shell samples from the bottom layer (+0.25 m) and the layer just below the surface (+2.25 m) have been dated by 14C method. The age of the lower layer is 3150 ± 800 years and that of the upper layer is 2800 ± 200 years. These deposits represent a normal sedimentary sequence formed under shallow marine conditions. When these layers were getting deposited, the waves would have cut a surface on the volcanics. On this logic, the age of such surface would be synchronous with the surface of the shell deposit, i.e. ~2800 ± 200 years. For this shell bed to get exposed at the present level, it is necessary to invoke lowering of sea-level or rise of land by ~2.5 m. The eustatic curve for this period shows no tendency of lowering.

The Suratkal beach is situated at a distance of 15 km north of Mangalore adjacent to a cliff. There are many small granitic gneiss outcrops on the beach. Because of their compact nature, the outcrops which have been exposed to wave action have developed smooth and rounded surfaces. On one of these outcrops, is attached a dead oyster colony (Figure 3). The oysters thrive in the intertidal zone. The colony is presently slightly above the tidal range, which leads to the conclusion that the organisms could not survive due to lack of contact with sea water. The shells have been dated by 14C method at the University of Arizona and their age is 1950 AD5. This means that in about 50 years, there has been uplift of land/lowing of sea, leaving the shells literally high and dry.

Tide gauge data for Mangalore have been recorded by the Tidal party of Survey of India. These data which are available through the Permanent Service for Mean Sea Level, Bidston Observatory, UK have been analysed by many. According to Emery and Aubrey10, the relative fall in sea-level/ride of land for Mangalore is 1.3 mm/year with a student confidence of 0.99. Bendick et al.11 have attempted to obtain accurate estimate of vertical movement of Mangalore with reference to Mumbai and Cochin based on the tide gauge data of the three stations. Relative to Mumbai and Cochin, Mangalore is rising by 1.95 ± 0.14 mm and 3.22 ± 1.1 mm per year respectively. Subrahmanya9 estimates an average relative fall in sea-level of 1.0 mm/year for Mangalore. If we take the values for Mangalore alone, the range is 1 to 1.3 mm/year.

Palaemangroves of the region have been studied by Caratini et al.12 for understanding sea-level changes. Organic clays from several well sections have been investigated for their palynology and chronology. The clays which occur close to the present day sea-level have assemblage similar to Holocene mangrove deposits with some differences. The ages obtained for the dateable vegetal matter vary from 30,000 to more than 45,000 years BP. Considering that the reliability of 14C datings become low for values older than 30,000 years BP and the sea-level comparable to present day level existed.

Figure 2. Rhyodacites showing well developed columnar joints, and wave cut surfaces. Loc: Coconut island, one of the St. Mary group of islands.

Figure 3. A close-up view of the dead oyster colony attached to a gneissic outcrop. Loc: Suratkal beach.
around 125,000 years BP, Caratini et al.\textsuperscript{12} infer that these organic clays were deposited 125,000 years ago. On this basis, they conclude that there has been no neotectonic activity in coastal Karnataka. However this conclusion may not be valid, because in estuarine conditions, onshore transport of fine and suspended matter prevails. This is confirmed by the anomalous pattern of ages (younger ages in the lower horizon) obtained. It becomes evident that the organic clay represents reworked sediments. Hence they cannot be sea-level indicators. Further proof of unreliability of these data comes from the study by Caratini and Rajagopalan\textsuperscript{13}. Their work relates to a well section which is close to the well sites studied by Caratini et al.\textsuperscript{12}. This well is situated close to Baidur, which is about 200 km north of Mangalore. The top of the well is at a height of 1 to 2 m from the present sea-level and the organic layer occurs at a depth of 5.5 m. The \(^{14}\)C ages for the sediment and shell samples from this layer are close to 6,400 years. On this basis, they conclude that about 6,400 years BP, the sea-level was 3 ± 1 m below the present sea-level. As discussed already between 11 Kka and 6 Kka, the rate of rise in sea-level was ~2 cm/year. This means that about 6,400 years ago the sea-level should have been at ~8 m (approximately). If the sea-level 6,400 years ago were to be lower than the present day sea-level (either ~8 m or ~3 ± 1 m), the shelly layer could not have been deposited at the present location, as at that time, the shoreline would have been considerably west of the well site. This means that after the deposition of the shelly layer, the sea has regressed exposing the well site. But, the global sea-level data are contrary to this. Hence the inevitable conclusion is that in the Baidur region, the land has been uplifted by 4 to 6 m in about 6,400 years or at a rate of 0.63 to 0.94 mm/year.

Subrahmanya\textsuperscript{a}, based on a variety of observations, has identified a zone of buckling in the Indian peninsula. The crest of the buckling which is close to 13\textsuperscript{N}, has been named Mulki-Pulicat lake Axis (MPA). The evidences for the upward include a major water divide running nearly E-W, migration of rivers away from the axis of uplift, palaeobeach ridges and swales, convex shape of the coast and the tide gauge data. Mulki, which forms the Western extremity of the MPA, is at the crest of the upward, and the effect of the upward extends to the South and North as indicated by the bulge or convexity of the coastline. The tide gauge data for Mangalore (20 km south of Mulki) indicate a relative fall in the sea-level of 1 to 1.3 mm/year. Assuming that the rate of relative fall in the sea-level to the north of the crest will be of comparable magnitude, the value obtained, i.e. +2.25 m in 2800 ± 200 years or 0.8 ± 1 mm/year for the top of shell deposits of the St. Mary islands (which is about 35 km north of Mulki) is in good agreement with the tide gauge data. On this basis the age of the ~3.0 m wave cut surface can be put at ~3000 years; that of ~1.5 m surface at ~1500 years and the 0 m surface is the present day surface. It is possible that even the ~6 m surface developed 6 Kka ago, but there are no dateable deposits on this surface or at that level.

The evidences presented here lead to the conclusion that several individual locations in the southern Karnataka coast are moving vertically up at a rate ranging from 0.63 to 1.3 mm/year. If we take into consideration the fact that the present global sea-level rise is about 1.0 mm/year, the net uplift of these locations would be 1.63 to 2.3 mm/year. Although it may be a bit speculative to extend this conclusion to the entire southern Karnataka coast, evidences for the relative fall in sea-level from Mangalore (1 to 1.3 mm/year), Suratkal, the St. Mary islands (0.81 mm/year) and Baidur (0.63 to 0.94 mm/year); evidences for buckling/upward close to 13\textsuperscript{N} latitude; and presence of progradational features like beach ridges and swales; compels one to think that these may not be isolated features. Viewed in this light, the problem of coastal erosion in Southern Karnataka is not because of the eustatic rise in the sea-level, but more due to human interference. The construction of structures like breakwaters and sea-walls has prevented the littoral drift resulting in erosion and accretion in the downdrift and updrift side respectively\textsuperscript{14}. The annual sedimentary budget for these beaches, which indicates a net surplus\textsuperscript{15} adds credence to the conclusion.

\begin{flushright}
\end{flushright}
Radiocarbon dated sedimentation record up to 2 ka BP on the inner continental shelf off Mangalore, south-west coast of India

K. Pandarinath*, A. C. Narayana and M. G. Yadava*

*Oceanography and Climate Studies Group, Physical Research Laboratory, Navrangpura, Ahmedabad 380 009, India
1Department of Marine Geology and Geophysics, Cochin University of Science and Technology, Fine Arts Avenue, Cochin 682 016, India

Sediment samples at 0–10 cm, 50–60 cm and 90–100 cm depth of a core raised from the inner shelf off Mangalore were dated using 14C dating technique to obtain a long term sedimentation record in the region. The surface (0–10 cm) depth of the core showed bomb-induced 14C activity and, hence, were considered as modern sediments. The base of silty-clay (50–60 cm depth) and sandy-clay (90–100 cm depth) layers were dated to 1330 ± 80 and 2090 ± 80 years respectively. The sedimentation rate in the study area has not varied much during the past 2 ka BP, which reveals that the sediment supply and hence weathering conditions at the adjacent interland have remained nearly the same during this period.

Sedimentation rates on the inner continental shelf are essential for understanding the fluctuations in sediment influx, climate, dating events and tracing the influence of industrialization and pollutants. On the western inner continental shelf of India, modern sediment accumulation rates were determined in the surficial sediment (top ~ 5 cm; < 100 years age) off Gulf of Cambay1,2, Bombay3, Karwar4, Mulki4 and off Mangalore2 by 210Pb excess method. There are however, very few sedimentation records extending further back in time and they are mainly derived from 14C dating of: (i) core sub-samples (off Karwar4) and (ii) a single peat sample that occurred at 2–4 m depth (off Karwar3 and off Taingapatnam5). These sedimentation records reveal that the sediment accumulation rates in the southern parts of the western inner continental shelf of India are considerably lower (2.6–0.12 mm/year) than those of the northern areas (19–5 mm/year) and are highly variable within short distances in the inner shelf region. As there is no sedimentation record back to longer period on the inner shelf further south of Karwar, we have measured sedimentation rates for the last 2 ka BP by 14C dating of three sediment sub-samples in a core off Mangalore.

The continental shelf off Mangalore contain surficial sediments of clayey-silts/silty-clays at < 50 m and sands from 50 to 100 m water depths2. A gravity core, 1 m long was raised from the inner shelf off Mangalore in 41 m water depth at 12°46.6′N and 74°39.6′E (Figure 1) during the 207th cruise of R.V. Gaveshini. Rivers Nethravathi and Gurpur, which meet the sea at Mangalore, are the main sources of terrigenous material to the study area. These rivers discharge annually 12,015 and 2,822 × 106 m3 water and 14 and 1 × 107 tonnes of sediment respectively into the adjacent Arabian sea10.

Sand, silt and clay percentages in the sub-samples (10 cm interval) were determined by standard wet-sieving and pipette analysis method11 and sediment nomenclature was based on the procedure of Shepard12. Radiocarbon dating of organic matter in the samples was carried out using the procedure described by Gupta and Polach13. The carbon in the organic matter of the sediments was converted into benzene. Radiocarbon activity of the benzene was measured by Liquid Scintillation Counter ‘QUANTULUS’. Ages were determined based on half-life period (t1/2) of 5730 years for 14C. The errors mentioned with the obtained ages are at 1% (one standard deviation) level.

Based on variation in sediment texture, the core can be divided into two layers: (i) silty-clay, 0–60 cm depth with 7.3–16.2% of sand, 23–28.5% of silt and 57.8–66.7% of clay; (ii) sandy-clay, 60–100 cm depth with 21.4–25.2% of sand, 12.2–18.6% of silt and 58.0–65.2% of clay. Based on this observation, surface of the core (0–10 cm), base of the silty-clay layer (50–60 cm) and bottom portion (90–100 cm) of the core were selected for the age determination. Owing to insufficient quantity of the samples, 10 cm length of the core was taken as a sub-sample.

The surface of the core (0–10 cm) showed 117 ± 1% 14C activity which indicates the influence of bomb-induced 14C activity. Hence, the sediments of 0–10 cm depth were considered as modern. The base of silty-clay layer (50–60 cm depth) and sandy-clay layer (90–100 cm depth) revealed an age of 1330 ± 80 and 2090 ± 80 years respectively (Figure 2). The grain-size distribution within