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Beach response to natural headlands on South Konkan and Goa coast

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Abstract

Coastline of Konkan and Goa is characterized by innumerable pocket sandy beaches. Many of these beaches are log spiral and parabolic in shape and are headland controlled embayed beaches. The shapes produced as natural equilibrium shapes suggest their response to headlands and bays and the pattern of refraction and diffraction of waves approaching the shore.

An attempt is made in this paper to investigate beaches from south Konkan and Goa to understand their response to natural headlands in terms of their shape and stability as a function of distance between headlands bounding the embayment, wave obliquity, and site specific shoreline configuration.

The equilibrium shoreline form of crenulated or headland-bay beaches is widely accepted by coastal geomorphologists and engineers. In this paper an account of 26 beaches from South Konkan sector of Maharashtra and 8 beaches from adjoining coast of Goa is given to understand their response to bounding headlands resulting in log spiral and parabolic shapes.

Keywords: *Beach response, headlands, spiral, parabolic, wave obliquity, embayment*

Introduction

All the beaches have a terminal boundary in the form of a sandy foreland or an inlet or the rocky headlands (Short and Masselink, 2000). Rocky headland is totally independent of the formative beach processes and in fact has a major influence on beach planform.

Headland embayed beaches are usually characteristic of rocky shorelines like the one along South Konkan and Goa coast. The length and spacing of such beaches is entirely controlled by bounding headlands. Such embayed beaches have a typically curved planform and are classified as crenulated, spiral or headland bay beaches (Pethic 1981, Davies 1977, Woodroffe 2002). The orientation and planform of these beaches are controlled by refraction pattern associated with approaching waves, Generally the planform is characterized by a strongly curved shadow zone, a mildly curved center of the embayment and a relatively straight stretch which is often parallel to the dominant wave crests (Short and Masselink, 2000).

This planform is approximated by logarithmic spiral or a parabolic shape and is supposed to be a response to bounding headlands. Headland control, leading to a crenulated equilibrium beach planform is considered to be a naturally functioning and preferable means of shore protection (Silvester1960, Silvester and Hsu (1993) and is also studied in detail by Moreno et al (1999). Logarithmic spiral and parabolic shapes suggested in the available literature are by and large observational and are described qualitatively by many.

The study of wave dynamics shows that the headland-bay equilibrium shoreline shapes are produced by wave sheltering by diffraction at the headland, combined with refraction, which increases with distance along the beach away from the headland. The condition of a strongly predominant wave direction plays a very important role in deciding the shape and morphology of such embayed beaches. It has also been shown that the crenulate beach shape remains constant with time, but with the entire form expanding at a rate according to a time function (Wind, 1994)

A log-spiral shape eventually turns around the headland and, at some ambiguously determined point whose location depends on the site it loses meaning for describing shoreline position. Site-specific constraints such as presence of other headlands or sediment-impounding features, trend of bathymetric and topographic contours exert controls that cause deviations of the shoreline from a simple and smooth form. The log-spiral shape might best be viewed as applicable to the beach located between two headlands for a coast with predominant wave direction (Moreno et al, 1999).

Objective: One objective of the present study is to ascertain the existence of such equilibrium shapes using a large data set of beach response to headlands of various types (single or double), distance between the headlands and wave obliquity. The second objective is to test the effectiveness of shapes by fitting parabolic and log spiral curves.

Methodology: A database was created using parameters like headland number, distance between the headlands, wave obliquity angle, bay indentation, beach length and length of curved and straight sector of beaches. The data were collected from 25 beaches from South Konkan sector of coastal Maharashtra and 9 beaches from adjoining coast of Goa. The observed headland-bay beaches were classified as having one, two, or "1.5" headlands (partial headland located down drift of the main headland as used by Moreno et al, 1999. The database was mainly developed from Google earth images.

Assuming that the observed equilibrium shape of beaches in the study area is similar to a log spiral, distance between the headlands and the maximum bay indentation distance were used to derive the log spiral equation, $\ln(R) = a \ln(Ro)^b$ where ln is natural log, R is maximum bay indentation distance and Ro is distance between the headlands. The log spiral equation was computed considering representative I, 1.5 and 2 types of headlands. Maximum bay indentation distances were estimated and residuals determined to identify those beaches which are embayed log spiral in shape. In this application the pole of the spiral is considered as a headland point which induces the diffraction of waves.

The development of parabolic shape as a response to natural headlands appears to be very common in the study area. Polynomial quadratic curves were fitted to the curved section and straight section of the beaches

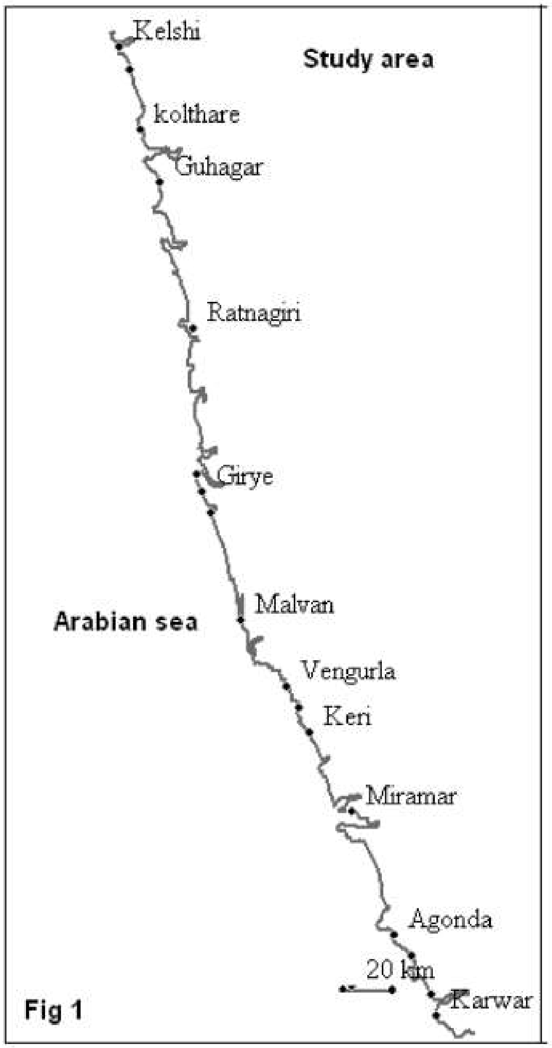

Fig 1: Study area

separately as suggested by Silvester and Hsu (1993). The quadratic equation of the type, Y= a+bX + cX^2 was used where y= R/Ro and x= A/a (R is maximum bay indentation distance, Ro is headland distance, A is wave obliquity angle and a is angle made by bay indentation vector with control line joining two headlands).For the parabolic shape also the focus of the parabola is the headland point. The coefficients defining the shape are basically the functions of predominant wave angle.

The parabolic shape of beaches is tied to two control points (Silvester and Hsu (1993). The upcoast control point is the diffraction point around which propagating waves diffract. This is usually the tip of the headland. The second control point is the second headland in downcoast direction. The line connecting these two points is the control line and has a length Ro. The angle between control line and the incident wave crests represents wave obliquity.

Study Area

South Maharashtra and Goa coast is a rocky shoreline characterized by innumerable pocket beaches (Fig 1). Many of these beaches are bounded by headlands. The rocky headlands are totally independent of the formative beach processes and have a major influence on beach planform, sediment transport and the morphodynamics. They are transformed to narrow beaches with steep to very steep beach faces in monsoon with varying degree of steepness and beach cutting.

There is a considerable amount of variability in sandy beaches, which is a result of wave environment. The entire beach zone consists of depositional facies formed by waves; wave induced currents and associated flows.

The length and spacing of these beaches is entirely dependent on pre existing topography.Along the hilly coast the average length of beaches is only 3 km with a standard deviation of 2 m. Most of the beaches are bounded by headlands at both the ends. Some beaches have a partial headland located down drift of the main headland. Moreover they are embayed beaches which represent relatively stable sections of the coastline and typically have a curved planform.

A striking characteristic of these beaches is the close correspondence between the beach planform and the refraction pattern associated with the prevailing waves. If the embayment is in equilibrium with the hydrodynamic conditions, the refraction pattern is such that no net longshore transport occurs due to obliquely incident waves. This is because all breaking waves arrive normal to the beach along the entire embayment. Weak longshore currents are however recorded in some of the embayments. Rip currents can also be observed at the extremities of the embayment.

The study of these embayed headland beaches shows that they have an asymmetric planform characterized by a strongly curved shadow zone, mildly curved center of the embayment and a relatively straight downcoast end. The shoreline at the straight section of the embayment is usually parallel to the dominant wave crests.

Discussion

The data collected from 25 beaches from South Konkan sector of coastal Maharashtra and 9 beaches from adjoining coast of Goa is shown in table 1.

The average distance between the headlands controlling the embayed beaches in the area is found to be 2.4 km in a two headland situation. The maximum bay indentation distance is 0.7 km and the average wave obliquity angle along south Konkan and Goa coast is 22 degrees and 23 degrees respectively. Maximum indentation point is however located at an angle of 54 and 58 degrees from the headland refraction point respectively. The beaches in both the sectors are small pocket beaches with an average length of 2 km.

Table 1: Beaches and measured parameters

Sr. No*	S. Konkan beaches	Location Lat/Long	HL distn. Ro,km	Indnt Distn R,km	Obliquity B,Deg	Angle of indent Q, Deg	Beach length km	Headland Number	Type p/s
01	Anjarle	17 52,73 01	2.32	0.39	20	30	2.3	1	p
02	Kolthare	17 39,73 08	2	0.78	5	30	1.64	1.5	s
03	Bhiv Bndr	17 36,73 09	0.42	0.28	40	80	0.35	2	p
04	Guhagar	17 29,73 11	8.7	1.43	10	30	6.7	2	p
05	Palshet	17 26,73 11	1.33	1.1	2	70	0.92	2	p
06	Vel'shwar	17 22,73 12	1.7	0.5	20	70	1.4	2	p
07	Muslondi	17 21,73 13	1.02	0.5	30	60	0.65	1.5	p
08	Sandkhol	17 16,73 13	1.11	0.33	15	40	0.94	2	p
09	Undi	17 14,73 04	1.76	0.56	25	70	1.3	1.5	p

10	Mirya	17 00,73 17	2.9	1.9	12	52	2.96	2	s
11	Ganeshgle	16 51,73 17	1.44	0.67	29	65	1.6	1.5	p
12	Vetye	16 40,73 19	5.5	0.95	10	68	5.24	1.5	s
13	Vijaydurg	16 34,73 20	0.72	0.4	65	80	0.46	2	p
14	Rameshvar	16 32,73 19	0.97	0.3	10	30	0.74	2	p
15	Girye	16 30,73 18	1.92	0.8	50	85	2.03	1.5	s
16	Hurshi	16 28,73 20	1.2	0.3	15	40	0.86	2	p
17	Padavane	16 25,73 22	1.31	0.27	12	30	1.17	2	p
18	Devgad	16 22,73 22	1.35	0.44	12	42	0.5	2	p
19	Kunkehwar	16 20,73 24	2.31	1.89	20	60	1.77	1.5	s
20	Tambaldeg	16 17,73 24	3.12	0.33	10	32	2.9	1	s
21	Munage	16 13,73 25	3.12	0.38	15	25	2.9	2	p
22	Malvan	16 04,73 28	0.99	0.36	35	70	1.5	2	p
23	Shriramadi	15 56,73 33	2	0.56	60	87	1.8	2	p
24	Vengurla	15 50,73 38	4.9	0.88	20	70	5.4	1.5	s
25	Shiroda	15 46,73 39	6.54	1.17	5	40	5.7	1.5	p
	Average		2.43	0.7	21.9	54.2	2.15		
	Goa beaches								
26	Keri	15 43,73 41	1.88	0.22	10	50	1.7	1	s
27	Kalangut	15 30,73 46	7.84	0.6	0	25	7.49	1	p
28	Mira mar	15 28,73 48	2.47	2.4	0	60	3.16	2	p
29	Agonda	15 02,73 59	2.98	0.8	20	70	2.99	2	p
30	Palolem	15 01,74 01	1.49	0.75	60	80	1.71	1.5	p
31	Canacona	14 59,74 02	1.9	0.43	20	55	1.9	1	p
32	Kolsar	14 58,74 03	1.37	0.34	30	60	1.1	1.5	s
33	Kalmath	14 56,74 03	0.48	0.07	10	40	0.42	2	s
34	Polem	14 55,74 05	1.42	0.53	62	85	0.68	1.5	p
	Average		2.42	0.7	23.6	58.3	2.35		

*Serial Numbers given in the table correspond with those given in figures 2 and 4

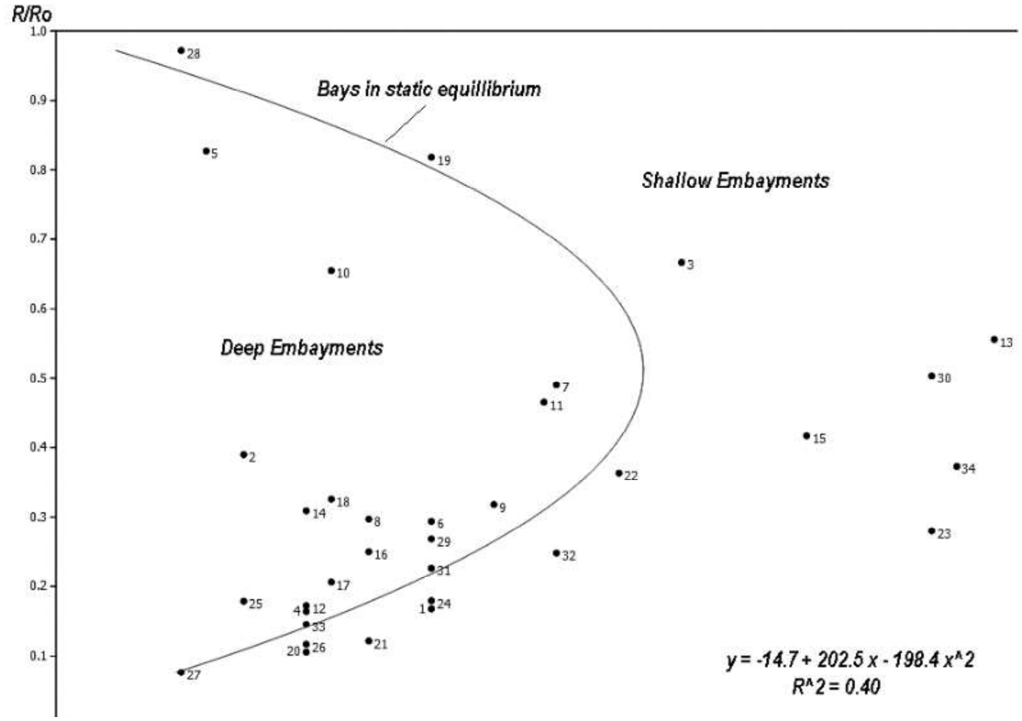

Fig 2: Classification of embayments in terms of wave obliquity and ratio of maximum bay indentation distance and headland distance.

The planform of these beaches from both the sectors which is more or less similar was approximated by log spiral and parabolic shapes as described in methodology given above. The parabolic equation Y= a+bX + cX^2 was used to plot the curve and to obtain the classification of embayments as shallow, deep and those in static equilibrium in terms of wave obliquity and ratio of maximum bay indentation distance Ro and headland distance Ro (Fig 2). It was found that the bays controlling beaches such as Kalangut, ,Kalmath and Canacona on Goa coast are in static equilibrium except Palolem and Polem which are bounded by shallow embayments. Beaches along northern part of south Konkan coast are mostly controlled by headlands forming deep embayments except a few like a beach at Shriramwadi wth a proximity to Goa coast.

The embayments that plot below the predicted parabolic curve are found to be deep,less indented and littoral drift in such embayments is not insignificant (Short and Masselink, 2000).Embayments that plot above the curve are shallow, more indented and comparatively less in number. The parabolic shape applies well to beaches in static equilibrium on Goa coast.

The log spiral shape of the beaches was ascertained by applying equation again computed on the basis of maximum bay indentation distance Ro and headland distance Ro (Fig 3). The log spiral equation developed was used to know the spiral characteristic angle required to maintain the curved spiral sector so that the alignment of straight section of the beach is parallel to approaching wave crests.

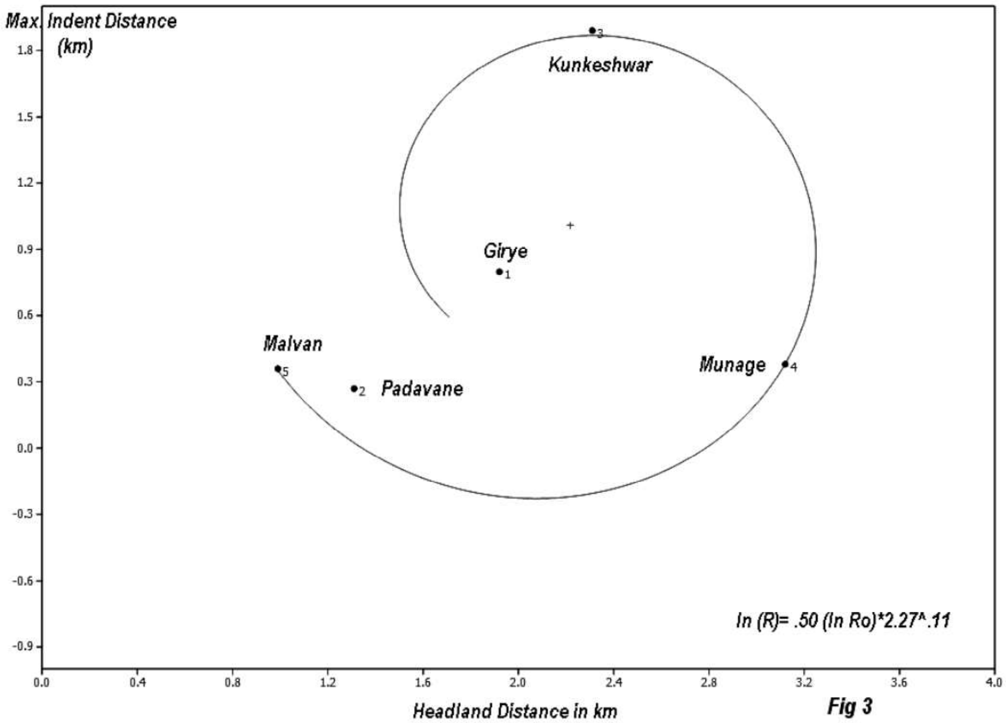

Fig 3: Determination of log spiral shape of the beaches.

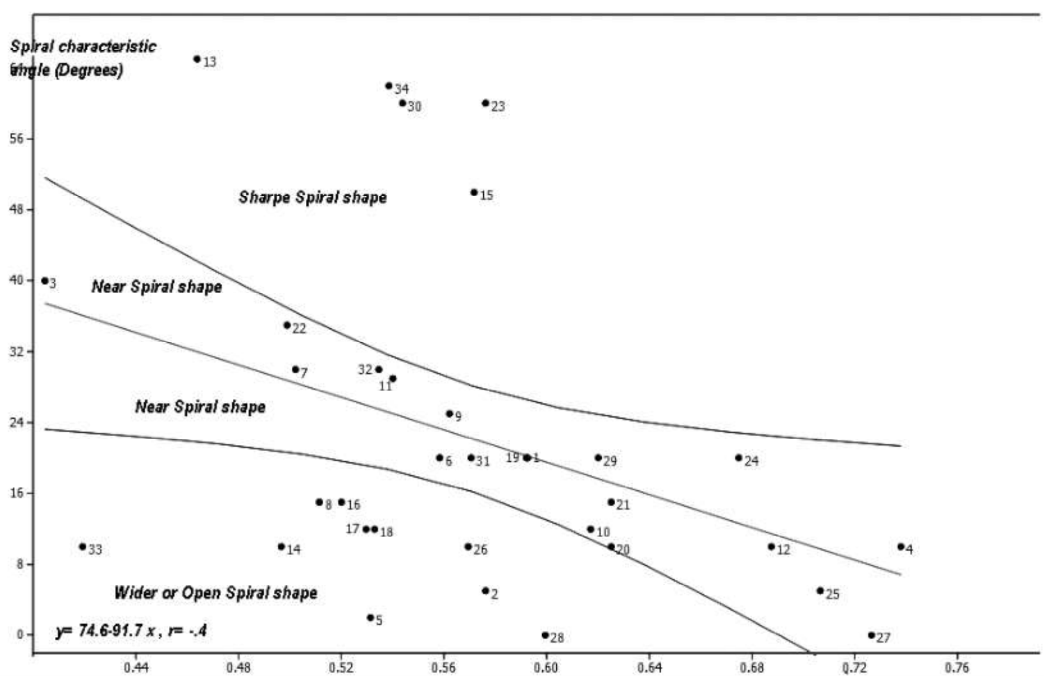

Fig 4: Plot showing required amount of characteristic spiral angle to maintain beach equilibrium.

The application of log spiral model also helped to ascertain the required amount of characteristic spiral angle so that the beach shape maintains its equilibrium in terms of seasonally changing refraction pattern associated with approaching waves (Fig 4).It is necessary to consider these spiral characteristic angles if the construction of offshore breakwater walls for various purposes are constructed.

Conclusion

The headland bay beaches on South Konkan coast were found to display a log spiral equilibrium shape and those along Goa coast display a nearly parabolic shape. The log spiral shape turns around the headland and is applicable to beaches located between two headlands with predominant wave direction. The angle made by approaching waves with diffraction point which coincides more or less with one of the headlands keeps on changing seasonally in monsoon and fair weather season on this coast. This angle varies from 10 to 50 degrees. As this angle becomes smaller the log spiral becomes wider and more open. The spiral becomes sharp with increasing obliquity of waves. Thus the spiral shape is sensitive to angular defining it especially on South Konkan coast .The straight section of these beaches is parallel to approaching waves.

The beaches on Goa coast show a distinct parabolic shape (Plate 1. See page 211) and maintain a static equilibrium stage. Many of the beaches in the study area (plate 2. See page 211) are deep embayments with a significant littoral drift. Some log (plate 3 see page 211) spiral beaches such as the one at Girye are shallow embayments where characteristic spiral angle is very sensitive to approaching waves (plate 4, See page 211).

It is not always easy to determine the exact diffraction point near headland leading to spiral or parabolic shape. The stability of these beaches is a function of angle made by approaching waves with the headland to headland joining control line and the maximum distance at which the spiral shape takes a turn. The stability keeps on changing seasonally. The estimation of characteristic angle is always necessary to understand the stability of spiral beaches and in any breakwater wall construction with reference to headlands. The alignment of such structures determined on the basis of this knowledge is useful in prior estimation of the stretch along the beach which will suffer erosion and siltation in future.

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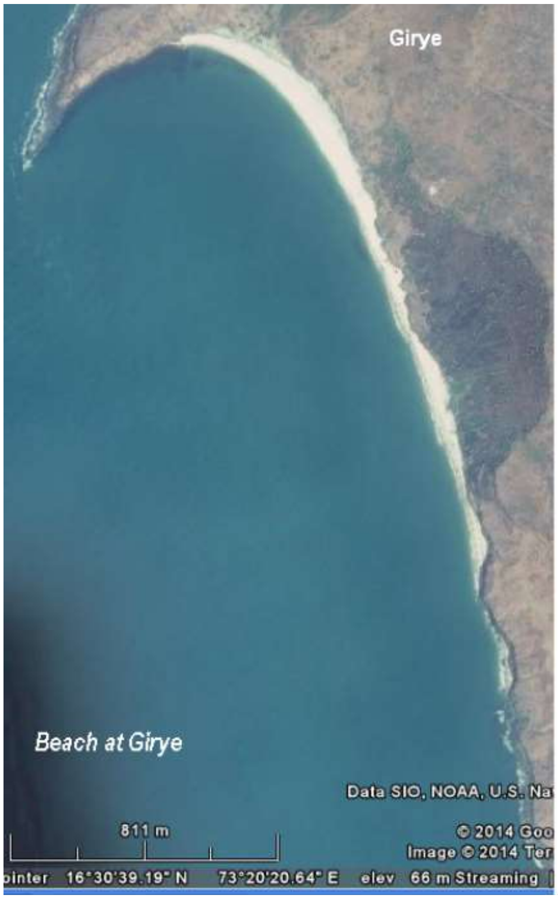

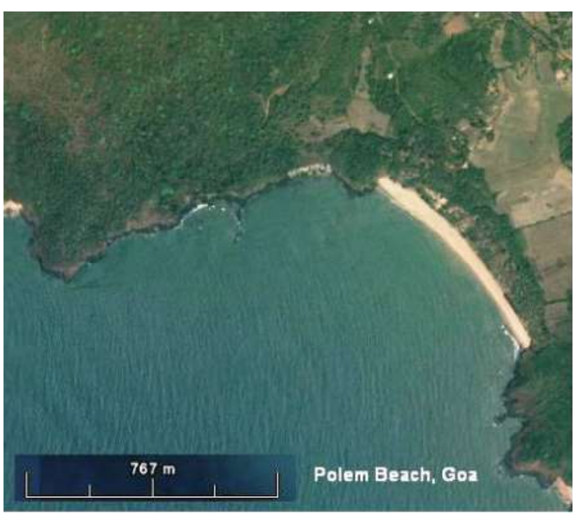

see page 208 for the text for all plates.