

Significance of Peat on the Western Continental Shelf of India

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Abstract: Peat layers 2 to 30 cm in thickness, 22 to 46 m below present sea level, are found along the inner shelf of India, up to 27 km from the coast. They are rich in plant debris, organic carbon and sulfur. These organic-rich layers are not sedimentary deposits. Lack of favourable substrates, absence of sheltered habitats, high energy physical environments, and a very rapid sea level rise during early Holocene indicate an unfavourable paleogeography and adverse oceanographic conditions for mangrove development and *in situ* peat formation. On the contrary, significant siliciclastic minerals, lithogenous elements and type III kerogen suggest a continental origin of peat. Restricted thickness, limited lateral distribution, absence of matted structures and laminated deposition imply transport of organics. Anomalous ages of wood with respect to present sea level are evidences of sediment reworking. Hence, peats on the continental shelf are not transgressive deposits.

Keywords: Economic Geology, Peat, Western Continental Shelf, India.

INTRODUCTION

One of the marked features of coastal Holocene sequences in many parts of the world, the tropical coastlines in particular, is the occurrence of organic deposits termed as peat. Onshore investigations along the west coast of India have indicated abundant peat deposits with vegetal debris, found between 400 meters and 20 km in the hinterland at Kerala, Karnataka and Goa (Agarwal and Guzder, 1974; Murty, 1977; Kale and Rajaguru, 1983; Nair, 1987; Bruckner, 1989; Rajendran *et al.* 1989; Tissot, 1990; Caratini *et al.* 1990; Caratini and Rajagopalan, 1992; *unpublished data*). Peat forms a prominent feature within the Quaternary coastal sequences (Fig. 1).

Likewise, marine cores from the inner continental shelf revealed grey-black layers with plant debris at several locations between 21 and 45 m water depth (Nambiar *et al.* 1991; Shankar and Karbassi, 1992; Mascarenhas *et al.* 1993; Nambiar and Rajagopalan, 1995; *unpublished data*). Peat is therefore common on the inner continental shelf of India (Fig 1).

This study evaluates these plant-rich sedimentary deposits from a geological perspec-

tive. Based on our results and some published data, an attempt has been made to decipher the origin and environmental significance of peat in the light of paleogeographic and paleoceanographic conditions on the inner shelf of India.

MATERIALS AND METHODS

During the cruises of ORV Sagar Kanya and AA Sidorenko, five gravity cores, 1 to 6.7 m long, were collected from the inner continental shelf between Goa and Mangalore, from depths ranging between 24 and 31 meters. The cores were subsampled depending upon the lithology. A core off Karwar was chosen for geochemical analyses.

Calcium carbonate was determined using a 'Karbonat Bombe' (Muller and Gastner, 1971). Organic carbon and sulfur were estimated by the methods of E1 Wakeel and Riley (1957) and Vogel (1961) respectively. In addition, the whole core was analyzed for 14 elements on a Perkin-Elmer ICP-AES. Mineralogical analyses were carried out on powdered samples on a Philips X-ray diffractometer. Organic geo-

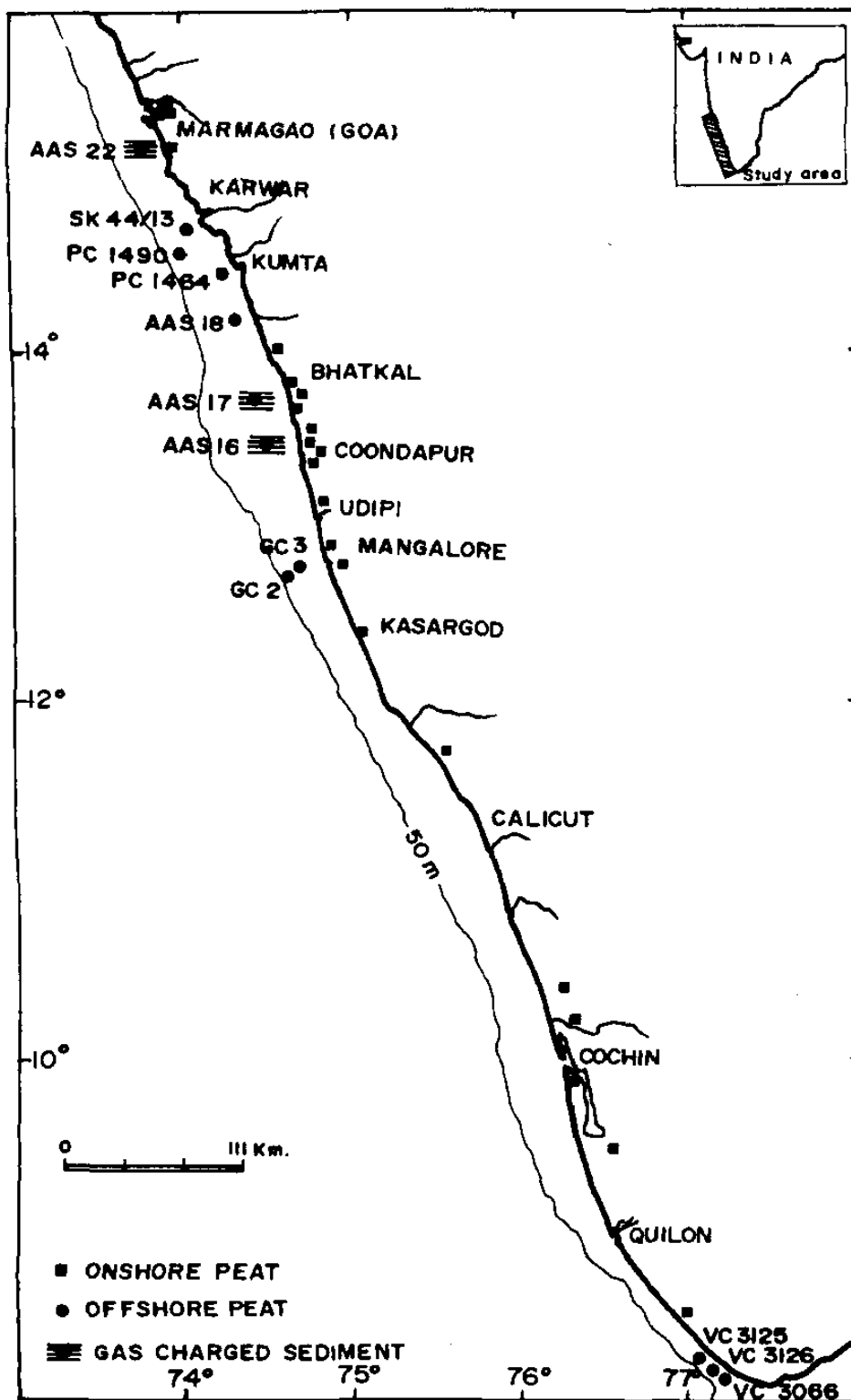


Fig.1. Locations of peat along the coast and on the inner shelf of western India (Data sources: Agarwal and Guzder, 1974; Murty, 1977; Kale and Rajaguru, 1983; Nair, 1987; Bruckner, 1989; Rajendran *et al.* 1989; Tissot, 1990; Caratini *et al.* 1990; Nambiar *et al.* 1991; Caratini and Rajagopalan, 1992; Shankar and Karbassi, 1992; Mascarenhas *et al.* 1993; Nambiar and Rajagopalan, 1995; unpublished data).

chemical analyses of peat were also carried out.

RESULTS

Occurrences of peat on the shelf and along the west coast are shown in Figure 1 and details of cores are given in Table I. Peat has been observed at variable depths from seabed, ranging from 22 to 46 m below the present sea level; it is found up to 27 km from the coast. The results suggest that peat on the shelf occurs as layers of restricted thickness (2 to 30 cm) with a limited lateral distribution and hence appear to be impersistent layers. A strong hydrogen sulfide odor was detected in three of our cores during subsampling.

Two layers of peat with intervening mixed sediment occupy the lowermost 20 cm in a 6.70 m core off Karwar. The lower layer is dark grey in color and silty in texture. A remarkable feature of this layer is a flaky component resembling broken twigs oriented parallel to the surface. Significant inorganic mineral constituents with few shells were also observed.

The elemental distribution in peat and overlying clastic sediments is presented in

Table II. Results show 3.85% organic carbon, 2.05% sulfur and 20% calcium carbonate; the twig like components exhibit as high as 5.44% organic carbon. Mineral matter comprises pyrite grains, garnet, sillimanite, andalusite, rounded rutile, hornblende, hypersthene, staurolite, quartz, microcline and mica. X-ray diffractometry confirmed quartz, potash feldspar, calcite and plagioclase as major minerals in decreasing order of abundance. Overlying this peat layer, a 'mixed organic-clastic' sediment occurs with negligible amount of organic carbon and sulfur but with substantial carbonate content (20%). Above this, peat is again identified; this contains 3.61% organic carbon, 2.35% sulfur and 17% calcium carbonate. Inorganic minerals are also present.

Contents of calcium carbonate, organic carbon, sulfur, Ca, Sr are high whereas Al, Fe, Mg, Mn, Cr, Pb are low in peat levels compared to the overlying siliciclastic sediments. Significant concentrations of Ti do not show any trend, as is the case with other trace elements (Table II). Organic geochemical analyses indicated hydrogen poor type III kerogen in organic matter; the hydrogen indices are very low.

Table I. Variable thickness of peat in various cores and its depth with respect to present sea level (SK and AAS cores: this study; PC: Nambiar *et al.* (1991); GC: Shankar and Karbassi (1992); VC: Nambiar and Rajagopalan (1995).

Core	Length (m)	Water depth (m)	Peat below seabed (m)	Peat thickness (cm)	Peat below m.s.l. (m)	Age (years BP)
SK 44/13	6.70	24.0	6.50	20	30.5	—
PC 1464	5.07	25.0	4.20	18	29.2	9630
PC 1490	5.90	33.7	5.78	2	39.5	8620
GC 2	1.60	45.0	0.85	16	45.8	—
GC 3	3.00	40.0	2.40	30	42.4	—
VC 3066	2.40	21.0	2.24	16	23.2	9390
VC 3125	1.17	21.0	1.07	10	22.1	8850
VC 3126	3.66	22.0	3.40	10	25.4	8750
AAS 16	2.39	27.0	2.18	21 (gas charged)	29.2	—
AAS 17	3.13	31.0	2.33	30 (gas charged)	33.3	—
AAS 18	3.65	30.0	0.83	16	30.8	—
AAS 22	2.75	30.0	0.70	? (gas charged)	30.7	—

Table II. Geochemical composition of peat and overlying clastic sediments in the bottom part of a core off Karwar.

Level (cm)	Sediment Type	CaCO ₃	OC	S	Al	Fe	Ti	Ca	Mg	Mn	Cu	Ni	Zn	Co	Sr	V	Cr	Pb
		%									ppm							
620-625	Clastic	10	1.43	-	7.30	6.52	0.64	2.72	1.90	1600	52	98	136	42	294	170	198	444
630-635	Clastic	14	1.19	-	6.64	6.06	0.72	4.52	1.64	1000	50	86	122	46	434	162	174	396
650-655	Peat	17	3.61	2.32	5.30	5.80	0.64	6.84	1.32	1200	74	82	120	46	708	176	160	380
660-665	Mixed	20	0.64	0.04	4.26	5.30	0.72	6.96	1.04	1000	52	52	76	38	700	146	126	306
665-670	Peat	20	3.85	2.05	4.58	5.26	0.70	7.68	1.18	1000	70	66	136	46	716	170	132	302

DISCUSSION

Thick mangrove (43 to 92%) peat, dated >40,000 years BP and 7230 - 4540 years BP, occurs 1.5 to 6.5 m below coastal plains. The west coast of India was occupied by extensive mangrove swamps during Late Pleistocene and mid-Holocene. (Agarwal and Guzder, 1974; Caratini *et al.* 1990; Kale and Rajaguru, 1983; Bruckner, 1989; Rajendran *et al.* 1989; Tissot, 1990; Caratini and Rajagopalan, 1992).

Mangroves promptly colonize suitable substrates under conducive physiographic and oceanographic conditions (Enos and Perkins, 1979; Woodroffe *et al.* 1985; Parkinson, 1989; Ellison and Stoddart, 1991). Over a period of time, mangrove remains produce peat. Considering that the Holocene sea level was once lower, that the present day shelf was subaerially exposed, and that the rivers debouched farther offshore, the possibility of mangrove forest growth has to be evaluated to explain the existence of peat within the Holocene sediments of the inner shelf.

Peat off Karwar contains high Ca and Sr contents. Calclitic mud is commonly associated with mangrove peats (Enos and Perkins, 1974) which also contain very high amount of carbonate material of all peat types (Davies and Cohen, 1989). Peat studied is also enriched in sulfur (>2%) which seems to indicate a marine influence. Cohen *et al.* (1989) reported 3 to 4% sulfur in peats from marine-to brackish water and less than 1% from fresh waters in the mangrove environments of Florida; highest contents were observed in mangrove peats (Casagrande *et al.* 1977). A reducing peat environment can constitute a major sink for

sulfur. This study shows that Mn and Fe are impoverished in peat as compared to overlying clastic sediments. These redox sensitive elements can easily be reduced in an organic-rich environment and are partly eliminated in soluble form. *In situ* conditions that prevail in peat environments also influence redox sensitive elements as Mn and S. Fe and S are negatively correlated indicating that a large part of iron is probably bound in the inorganic mineral fraction. Except Ca and Sr, elements Al, Fe, Mg, Mn, Ni, Cr, Pb show a moderate to strong negative correlation with organic carbon; this would suggest that these elements (including Ti) are detrital or partly detrital in origin. Carbonate and sulfur values tend to imply that peat off Karwar is mangrove derived. However, based on the geochemical variations alone, the delineation of the origin of peat has its own limitations.

The inner shelf where peat occurs presents a smooth and featureless topography. A series of coast parallel submerged ancient coral reefs and ridge-like features, now buried in clay, have been identified (Vora and Almeida, 1990). Although mangroves can thrive on carbonate substrates (Enos and Perkins, 1974; Woodroffe, 1983), there is no evidence of any peat deposits overlying these carbonate bodies suggesting a lack of mangrove growth on the shelf during that time.

Buried channels and submarine terraces beyond 30 m depth have been described from seismic profiles (Wagle *et al.* 1994). Although a possible existence of paleo-lagoons at selected places is invoked (which might have promoted growth of vegetation), they are made

of lithified products. Nevertheless, the erosional features suggest that high energy wave action prevailed on the shelf. An energy dominated physical environment works against the ecological requirements of mangrove populations as these trees cannot face an open ocean without an intervening barrier. The presence of a lagoon - barrier system can neither be visualized nor ascertained. From a paleogeographic point of view, there are no indications of any sheltered lagoons on the shelf where peat is presently identified.

Peat formation is restricted to sheltered basins of deposition, gently sloping intertidal areas, favorable substrates for plant growth, low energy conditions and a relatively stable sea level (Woodroffe, 1983). Moreover, mangroves can keep pace with a sea level rise of 8-9 cm/100 years, but they can neither grow nor peat can form at rates above 12 cm/100 years (Ellison and Stoddart, 1991). Since the sea transgressed at a very rapid rate of 200 cm/100 years between 10000-7000 years BP on the western margin of India (Hashimi *et al.* 1995), a seaward advance of mangroves under adverse oceanographic conditions appears doubtful. This is because the rate of sea level rise was 17 times higher, conditions under which mangroves cannot grow and peat cannot accumulate *in situ*.

Mangrove peat stratigraphy worldwide reveals that peat is not recorded during early Holocene since a rapid sea level rise precludes growth of mangroves, chokes them with high sediment input, redistributes organic sediment, mixes with allochthonous material, all due to higher wave activity and erosive tendency of the rising sea (Ellison and Stoddart, 1991). Mangroves established expansive colonies when sea level stabilized (Parkinson, 1989). Therefore, ideal conditions for peat formation prevailed during mid-Holocene times when the first extensive mangrove swamps appeared in sheltered areas particularly between 7000 to 5500 years BP and later (Woodroffe *et al.* 1985; Ellison and Stoddart, 1991).

It is difficult to trace the pace of sea level rise on the western margin of India based on published ages of peat. For example, a peat layer 29m below present sea level is dated at 9630 years BP, whereas another layer deeper offshore at 40m yielded 8620 years BP (Nambiar *et al.* 1991). This should have been exactly opposite if one is to trace the course of Holocene marine transgression. Incidentally, a similar situation is observed considering available dates (Nambiar and Rajagopalan, 1995) off south India. These cases can probably be attributed to sediment reworking. Further, if dates on submarine terraces are considered (Wagle *et al.* 1994), one again arrives at a contradictory scenario: around 9000 years BP, the sea level was much lower, on the outer shelf, at a time when peat is believed to have formed on the inner shelf. Such anomalies indicate that the simple presence of (mangrove) peat is not a reliable indicator of the position of sea level since these trees show adaptations to intertidal environments (Cohen *et al.* 1989), yield anomalous ages due to physical contamination by younger roots (Davies and Cohen, 1989), and as such these dates cannot be regarded as true ages (Woodroffe, 1983). Based on the preceding discussion, peats on the inner shelf cannot be regarded as transgressive deposits.

Therefore, there is no geological evidence that supports development of mangrove vegetation and associated peat formation on the continental shelf. An alternate explanation has to be sought as peats on the inner shelf of India do not appear to be *in situ* deposits:

—Peat occurs in the form of intercalated layers of restricted thickness of 2 cm off Karwar to 30 cm off Mangalore (Table I). In comparison, onshore deposits worldwide comprise mangrove dominated sequences several meters thick. Therefore, areas where mangroves laid *in situ* peats are marked by very thick plant-rich sediments which is not the case on the inner shelf (Fig.2).

— Arguments for autochthonous peat are

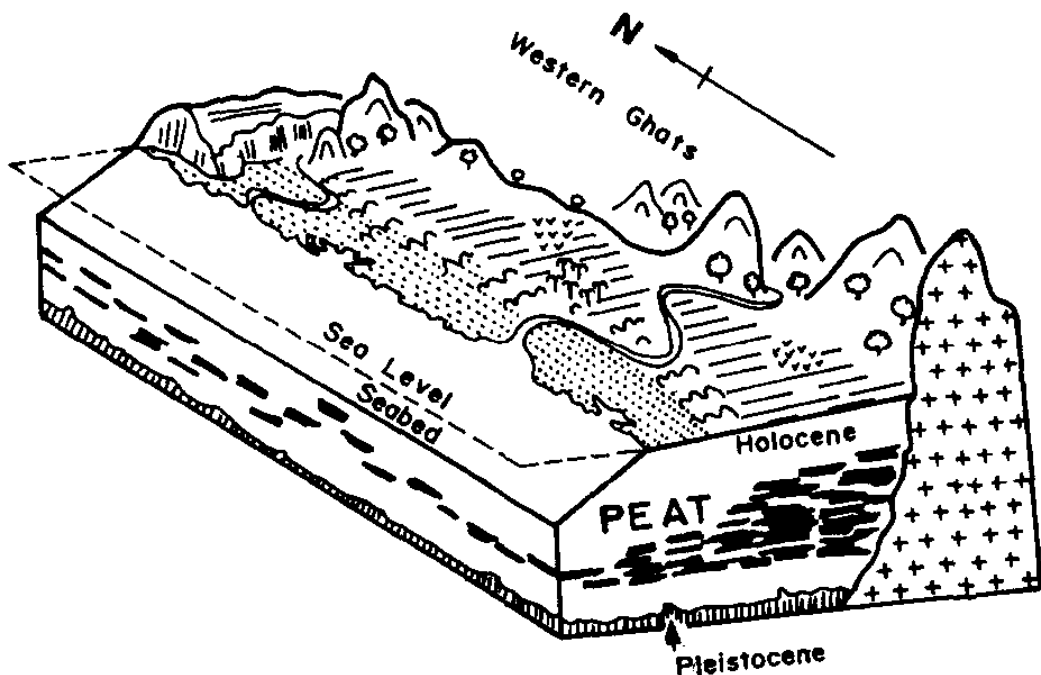


Fig.2. Diagrammatic sketch depicting thick peat deposits, below coastal plains, which pinch out as thin layers within Holocene inner shelf sediments.

the great lateral extent of seams and presence of matted structures (Cohen, 1970). Peat on the inner shelf has a limited lateral distribution and is conspicuously devoid of matted structures; hence its sedentary origin is doubtful. Randomly oriented wood fragments in several cores favor transport; twig-like components oriented parallel to the surface indicate redeposition in a laminated form. Mangrove litter flushed by tidal action to considerable distances offshore represents a major component of organic export as litter concentrates (Cohen, 1970; Boto and Bunt, 1981), a process which also operates on the inner shelf. These evidences support an allochthonous origin of peat (Fig.2).

— *In situ* peats are essentially pure organic deposits. Peat off Karwar, for example, contains minerals which point to an igneous and metamorphic rock provenance, found at higher altitudes. Since inorganic minerals are mixed with organic deposits from coastal anaerobic environments, now located 15 km offshore, transport of all these constituents is plausible.

— Continental supply is evident from the appreciable contents of aluminum and particu-

larly titanium, elements of lithogenous origin. On a C-S diagram, the points fall outside the field of normal oxygenated marine sediments (Stein, 1990). They correspond to anoxic sediments, conditions under which pyrite forms; this mineral has been identified. On a comprehensive plot (Rao *et al.* 1994), these points occupy the area designated for turbidites. This implies that these sediments were formed in an anoxic (coastal) environment and were subsequently subjected to mass transfer.

— Organic geochemical analyses of three samples revealed Type III kerogen with low hydrogen content (unpublished data), indicating that the organic matter is derived from higher plants of continental origin. High contents of terrestrial organic matter are also observed in a marine core which is incidentally rich in mangrove pollen (Caratini *et al.* 1994). A large influx of terrestrial organics to the shelf has also been reported (Siddiquie *et al.* 1981).

— The mixed organic-clastic layer in one of the cores off Karwar also indicates that

reworking and redeposition of older peat can occur. This is also supported by anomalous ages of peat with reference to present sea level off Karwar and southwest India. Similarly, geochronology of two other cores (Caratini *et al.* 1994) show younger ages below older sediment. These examples imply that the inner shelf has been the scene of intense hydrodynamic activity with associated sediment reworking.

— Excessive precipitation during the early Holocene must have led to higher continental drainage including erosion of onshore organic formations (Caratini *et al.* 1990). On the shelf off Cape Comorin, wood pieces have been identified in surficial sediments; these are undoubtedly transported (Chauhan, *pers. comm.*). In addition, pyritised wood pieces have been found below the seabed beyond the shelf break off Kerala (Ch.M. Rao, *pers. comm.*). Reddish brown terrestrial wood fragments within cores along the slope are also noted (unpublished data). These evidences support the argument that plant debris has been transported across the shelf even to deeper waters.

It may be pertinent to note that dark grey reduced sediments with a strong hydrogen sulfide odor have been detected in our cores off Goa, off Bhatkal and off Coondapur where peat is presently found. Microbial breakdown of plant material can produce gas which migrates upwards resulting in gas charged sediments. Type III kerogen with very low hydrogen indices (av. 26; unpublished data)

indicate gas prone peat. Methane is reported off Bombay (Siddiquie *et al.* 1981) and acoustic masking due to gases is observed on the inner shelf (Karisiddaiah *et al.* 1993). This suggests that peat is the main agent responsible for gases in sediments of the continental shelf of India.

CONCLUSION

Peats are not sedentary deposits since the paleogeographic setting and paleoceanographic conditions did not promote mangrove vegetation and in situ peat formation on the inner shelf. Our results show evidences of sediment reworking and support mass transfer of organic debris offshore. Therefore, peat layers cannot be categorized as transgressive deposits and hence cannot be used as markers to trace the Holocene sea level rise. Peat is the principal cause of gases within Holocene sediments of the continental shelf of India.

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