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Study of Palaeo-Lobate Features from South Gujarat Alluvial Plains, Western India and Their Significance.

Tiwari K. C., Joshi A. V., Biswas S. K.
Department of Geology, M. S. University of Baroda,Vadodara – 390 002, India.
E-mail <kaicy56@gmail.com>< joshi_geol@yahoo.com>

ABSTRACT

The south Gujarat alluvial plains lie between two major peri-continental rift basins, Cambay (NNW – SSE) and Narmada – Tapi (ENE – WSW) and are characterized by thick accumulation of the Quaternary sediments. The study of the IRS-P6 (AWIFS Sensor) satellite data and subsequent field checks have revealed the presence of four distinct palaeo-lobate structures identified for the first time from the South Gujarat area. The study of palaeo-lobate features has revealed about the past dynamics of the south Gujarat fluvial systems and the palaeo land - sea boundary conditions. The geometry of these lobes has clearly indicated them to be the river dominated fan-deltas and their development is attributed to voluminous input of sediments by the then prevailing active drainage conditions.

Keywords: Remote Sensing, South Gujarat, Alluvial Plains, Western India, Palaeo-lobe Features, Fan-Deltas.

Introduction

The south Gujarat alluvial plains lie between 20^0 15’ N, 21^0 30’ N and 72^0 30’ E, 74^0 00’ E (Fig. 1) marked by proficient fluvial systems and varied geomorphic attributes. These plains lie south of the Narmada river and is marked by the presence of westerly flowing rivers such as Kim, Mindhola, Purna, Ambica, Auranga, Par and Damanganga and consists of thick accumulation of Quaternary sediments contributed by these rivers.

The study of digital satellite data (IRS P6, AWIFS Sensor, 2004) of this region has revealed the presence of various palaeo-lobate features distributed within the inland regions of Tapi, Kim, Mindhola and Ambica rivers as well as adjoining the shoreline. Survey of India

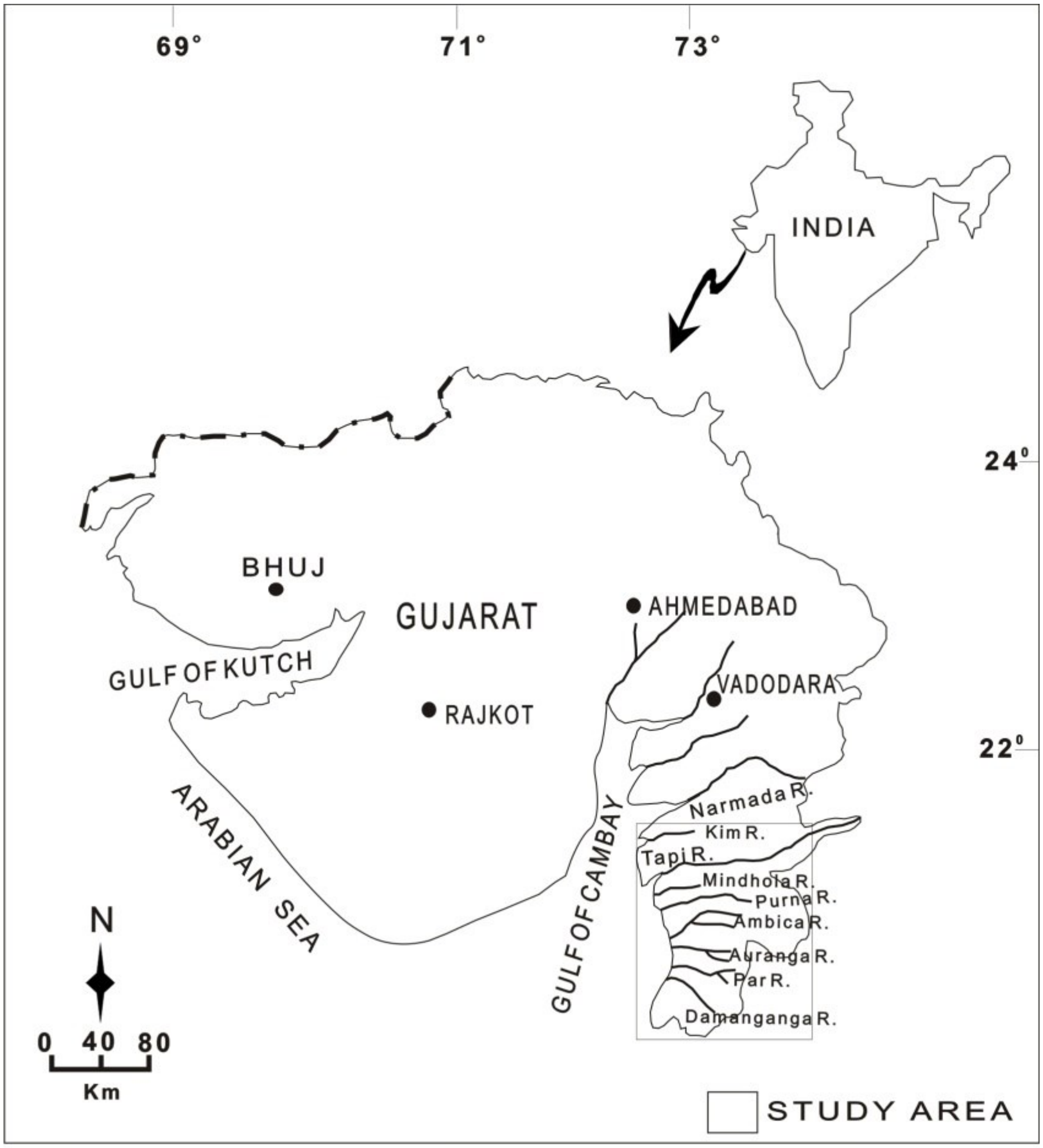

Fig.1

Fig. 1 Location Map of the Study Area

topographic maps (1:50,000) and borehole litho-logs were used for delineation of their geometry followed by field validation. The remote sensing study of westerly flowing south Gujarat fluvial systems has further helped the authors to establish the chronology of the evolution of the palaeo-lobate features with respect to the past and present dynamics of fluvial systems.

Litho-tectonic Setup

The south Gujarat alluvial plains fall within the realm of two major conjugate, peri-continental rift systems, viz. Cambay (NNW – SSE) and Narmada – Tapi (ENE – WSW); therefore the tectonic configuration of the study area is controlled by these two conjugate rift systems (Kaila et. al. 1981; Biswas 1982, 1987; Kaila and Krishna, 1992) (Fig.2). Tectonically, the study area is bounded by important tectonic elements, which include ENE – WSW trending Narmada Rift System faults in the north and south, Eastern Cambay Basin Marginal Fault in the east and the West Coast Fault (Krishnan, 1953; Auden, 1975) and the Panvel Flexure (Blanford 1867, Auden 1949, Powar 1981, Dessai and Bertrand 1995) in the west.

The deep seismic sounding profiles (Kaila et. al. 1981) have revealed a number of deep-seated transverse faults within the south Gujarat area, which extend down to the Moho, suggesting a deep active tectonism in this region.

The related system of normal faults have dissected the study area into several crustal blocks and subsequent episodic reactivation has resulted in the present horst and graben configuration (Biswas.1988; Powar, 1981; Alavi and Merh, 1991)

The south Gujarat area comprises sediments belonging to Quaternary and Tertiary (Paleocene to upper Miocene) periods, which rests unconformably over the Deccan Trap basement (Agrawal, 1986; Merh, 1995). The Deccan Traps (upper Cretaceous to Eocene) represent horizontally bedded lava flows; however, at places they show 10^0 to 15^0 westerly dip (Auden, 1949) these lava flows are predominantly cropping out in the eastern and southern portions of the study area. The overlying Tertiary sediments occur as patchy surface outcrops in the northeastern portion; however, the sub-surface data has revealed considerable thickness, particularly in the area lies between Surat and Ankleshwar (Chandra and Chowdhary

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1969, Kaila et. al. 1981). The Quaternary deposits are extensively distributed along the major river valleys and their tributary streams. The sub-surface records obtained from the oil companies have revealed more than 800m thickness of Quaternary sediments in the inter-stream areas of the Narmada – Tapi river mouths (Ganapathi and Pandey 1991).

Geomorphology

Based upon the altimetric variations and geomorphic attributes, the south Gujarat alluvial plains have been divided into four physiographic divisions namely:
(i) Lower Coastal Zone (0-10m); (ii) Middle Alluvial Zone (10-50m); (iii) Upper Pediment Zone (50-100m); and (iv) Inner Highland Zone (>100m)

The Middle Alluvial and Lower Coastal Zones show conspicuous presence of palaeo-geomorphic landform features. These landform features include palaeo-mouth bars, raised mudflats and lobate shaped features, occurring along the Tapi, Mindhola and Ambica river systems. The palaeo-mouth bar features are observed at Sena and Tena creeks (Kim and Tapi rivers), Dumas and Bhimpur (Tapi and Mindhola rivers) and Gandevi and Karneta (Ambica river). The raised mudflats located in the estuarine areas of the Kim – Tena, Mindhola, Purna, Ambica and Auranga rivers, are seen occurring at 6 – 8m above mean sea level and are highly dissected by the tidal inlets.

Drainage Configuration

The south Gujarat terrain is characterized by presence of structurally controlled westerly flowing drainage systems. These drainage systems have developed over two contrasting lithological domains i.e., the Deccan Traps and the alluvium. The nature of the drainage systems and their pattern of development convincingly reflect the control of both lithology and structure. Almost all the trunk streams of major drainage systems like the Tapi, Purna, Ambica and Auranga rivers, are aligned along ENE – WSW lineaments, which are sympathetic to the Narmada geo-fracture. The middle order streams show abrupt swings and are aligned along the conjugate sets (NW – SE & NE – SW) of fractures, whereas the lower order streams are oriented along the N- S fractures. The rivers, particularly the Kim, Tapi, Mindhola, Purna and Ambica show reticulate to braided channel patterns in downstream reaches, which may be ascribed to gradual subsidence causing local deceleration in channel energy conditions (Ouchi, 1985).

The Palaeo Lobate Features

In coastal geomorphological study the palaeo lobate features have always intrigued the workers from the point of view of understanding the coastal region dynamics and evolution of the terrain in geological past. There has been a considerable research on the mechanism, evolution and governing climato-eustatic factors in the formation of modern and Holocene - Quaternary river dominated deltas that form lobate or bird's foot shaped depocenters (Miall, 1985 & 1996; Posamentier and Vail, 1988; Postma, 1990; Leeder, 1999; and Calvache et al., 2003). Further, in-depth study on the influence of various allogenic factors on the alluvial fan morphology and the relationship of various morphometric attributes with their source areas is available in the scientific works (Harvey, 1984, 1987; Muto, 1987; Ferrill et al., 1996; Calvache et al., 1997; Sorriso-Valvo et al., 1998; and Harvey et al., 1999a).

The lobate shaped palaeo-features as deciphered through satellite imagery are observed much inland ward as well as towards the present day shoreline along the Mainland Gujarat coast (Fig. 3). The Tapi River environs show three palaeo-lobate features whereas the Ambica and Purna Rivers further south together show one such feature.

The geometry of these alluvial fan lobes indicate the proximal portions as narrow and concave in shape, whereas the distal portions are broad, fanning out with gentle convexity and characterized by the presence of marked incised drainage channels. In order to ascertain the geometry of these palaeo - lobate features and sedimentation pattern, various sub-surface profiles (transverse and longitudinal) have been prepared. The different physical as well as dimensional parameters for the individual palaeo-lobate features are described in Table 1.

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Tapi Lobe – I (72^{0}52' E, 73^0 13' E & 21^0 03' N, 21^0 19' N): This lobe is located at a mean elevation ranging between 12m and 41m above mean sea level (AMSL), in the middle alluvial plains. On the satellite imagery, this lobe is characterized by dense brownish tone, medium to coarse texture and it is marked with number of palaeo-distributory channels (Fig.4) including the upper Mindhola river drainage system. This lobe is the largest of all the lobes, having dimension of around 21 X 29 km2 and is located in the southern proximity of

the present-day Tapi river channel. The central long axis of this lobe shows an orientation of N 2470 azimuth.

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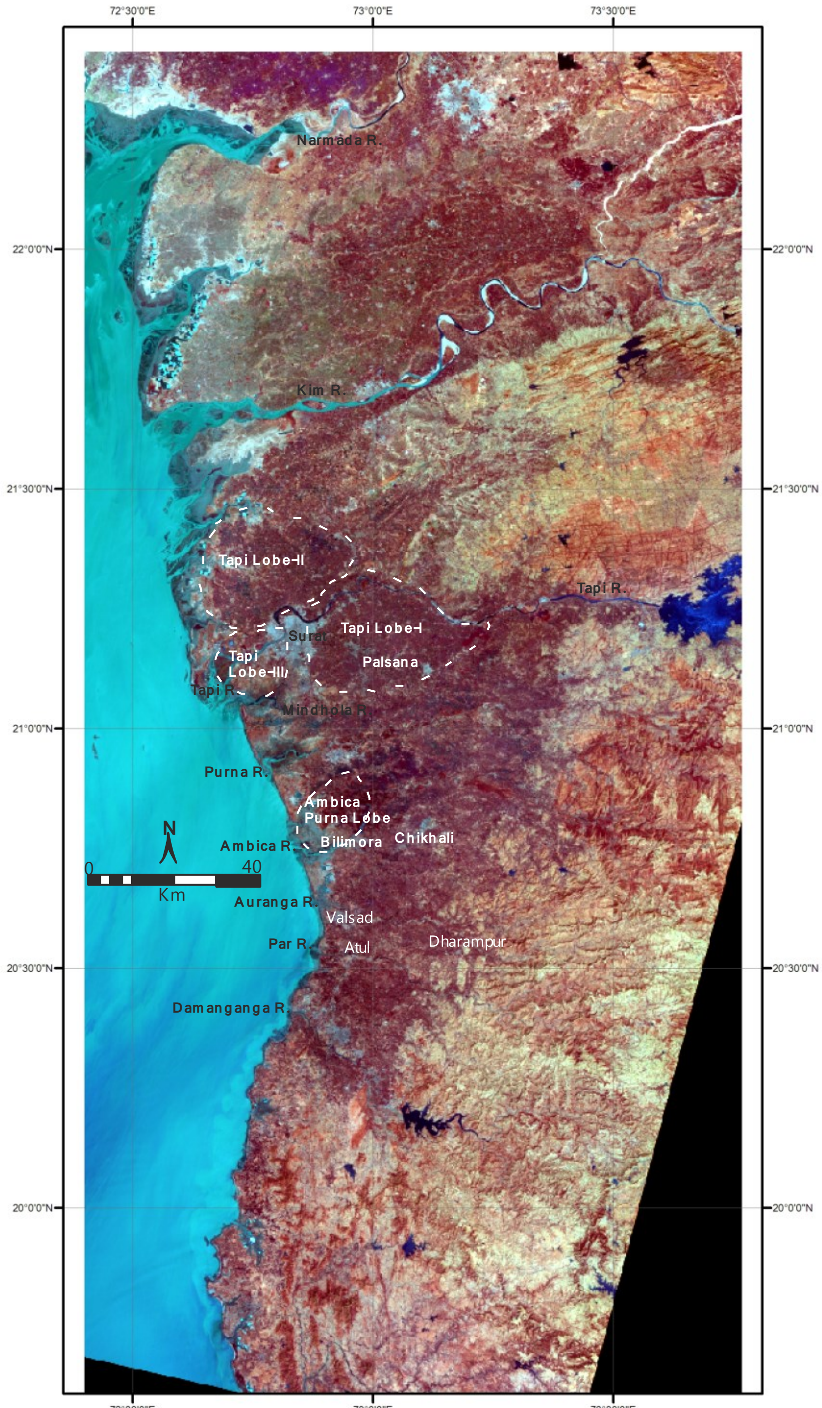

Fig.3 Satellite Scene (IRS P6,Awifs Sensor, 2004) Of South Gujarat Plains Showing The Paleolobatic Features

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River Systems	Palaeo-lobe	Geographical Position	Elevation Range (m)	Length and Width (km)	Gradient & (tan Θ)	Total Area (in km^2)	Axis Azimuth	Sweep Angle (As)
Tapi, Mindhola And Kim R.	Tapi Lobe – I	72^0 52’-73^0 13’ E ; 21^0 03’-$21^0$19’N	12 – 41	21X 29	1:724 (0.079)	609	N 247^0	66^0
	Tapi Lobe – II	72^0 30’ – 73^0 00’ E ; $21^0$14’ – 21^0 27’ N	07-35	17 X 22	1:607 (0.094)	374	N 263^0	67^0
	Tapi Lobe – III	72^0 40’ – 72^0 55’ E ; $21^0$01’ – 21^0 16’ N	6.5 – 20	12.5 X 17	1:925 (0.061)	212	N 217^0	68^0
Ambica And Purna Rivers	Ambica – Purna Lobe	72^0 50’ - 73^0 05’ E ; $20^0$45’ - 20^0 55’ N	02 - 21	28 X 33	1:1473 (0.038)	924	N 245^0	79^0

Table – 1 Physical Attributes of Palaeolobes

The sub-surface sediment distribution pattern of this lobe as deciphered through the bore hole records (Fig. 5) depict the presence of alternating clay and sand units. The longitudinal profiles A-A’, B-B’ and C-C’ display a linear nature of the clays, with a gentle inclination towards the distal end of the lobe. The surface exposures of this lobe also represent alternating sand and clay units.

The sands are poor - moderately sorted, gravelly in nature, comprising angular clasts of trappean composition, embedded in a sandy matrix. At places, such as Wareth-Petia along the Tapi River and Amalsadi and Palsana along the Mindhola River, these sands show large scale planar as well as trough cross-stratifications; with the length of individual trough varying from 1m to 6m.

Tapi Lobe – II ($72^0$30' E, $73^0$00' E & $21^0$14' N, $21^0$27' N): This lobe is associated with the lower coastal and middle alluvial plains and is slightly smaller in dimension as compared to Tapi lobe – I. Unlike Tapi Lobe – I, it is located in the northern proximity of the present-day

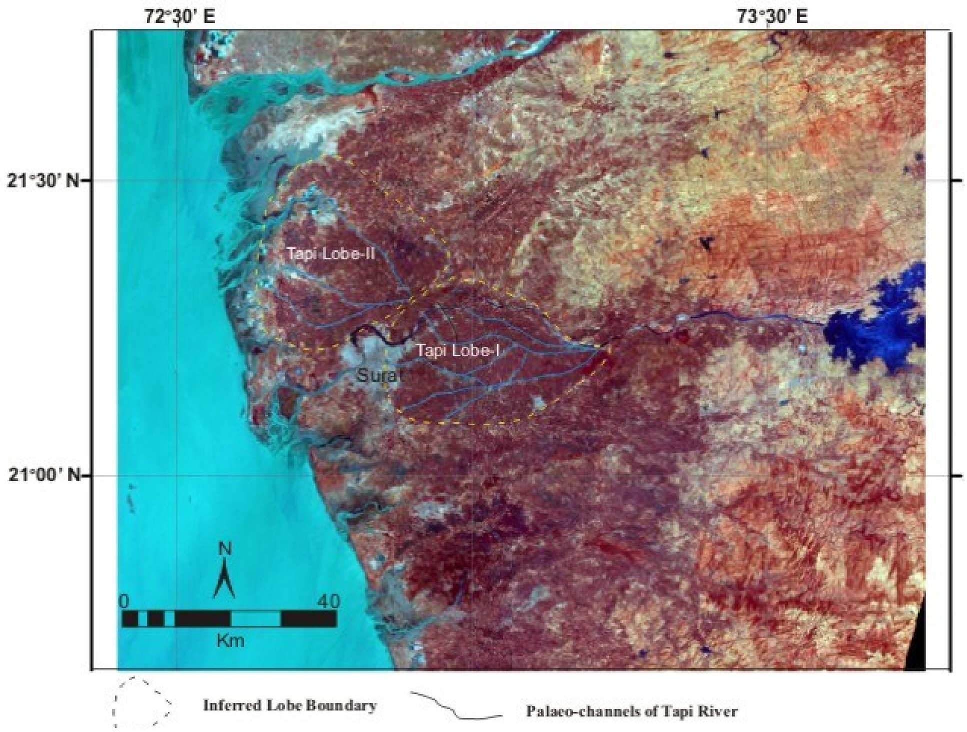

Fig. 4 Satellite Scene (IRS.P-6, Awifs Sensor, 2004) Showing Palaeo-distributory Channels in Tapi Lobe I & II.

Tapi river channel and range in elevation between 7m and 35m AMSL. On satellite imagery, this lobe is characterized by a light brownish tone with medium to rough texture and numerous traces of palaeo-distributory channels (Fig.4) including the lower Kim river drainage system. The longest axis of this lobe points to its E – W orientation (N 263^0) with an aerial extent of 17 X 22 km^2.

The longitudinal profiles A-A', B-B' and C-C' indicate that the clay members occur as long, continuous layers within the sands and show a gentle inclination towards the distal part of the lobe and gradually decrease in thickness from proximal to the distal end of the lobe.

Tapi Lobe – III ($72^0$40' E, $72^0$55' E & $21^0$01' N, 21^0 16' N):

This lobe is comparatively smaller in dimensions (12.5km X 17km) with respect to the earlier two lobes and is located in the lower coastal and middle alluvial zones with altitudinal range between 6.5 and 20m AMSL. A major portion of this lobe is occupied by the present-day settlements; therefore, on satellite imagery its proximal part is not clearly discernible. However, its distal portions are characterized by yellowish to light brownish tone with a medium to rough texture. Geometrically, this lobe is oriented in NE – SW direction with its longest axis showing an azimuth of N 217^0. This lobe is associated in the close proximity of the present day Tapi and Mindhola river mouths, and is marked with numerous palaeo-distributory channels. Like other lobate features large scale trough cross stratifications have been observed along the Mindhola river course and inner flood plain sequences.

The longitudinal profiles A-A' and B-B' show intercalating layers of clay and sand members (Fig. 7). The clay layers are long and continuous and show a gradual increase in their inclination from proximal to the distal portion of the lobe, towards SW direction.

Ambica – Purna Lobe (72^{0}50' E, 73^{0}05' E & 20^0 45' N, 20^0 55' N): This lobe is located between the present-day Ambica and Purna rivers, with an overall dimension of 28 X 33 km^2. The central long axis of this lobe shows an orientation of N 245^0 with a mean elevation range from 2m to 21m AMSL.

This lobe is characterized by brownish tone and rough texture and marked with numerous palaeo-channels and oriented sand bodies. The longitudinal profiles A-A', B-B' and C-C' depicts the occurrence of clay units as long and continuous layers within the sand units (Fig. 8) and show gentle inclination towards the distal part of this lobe.

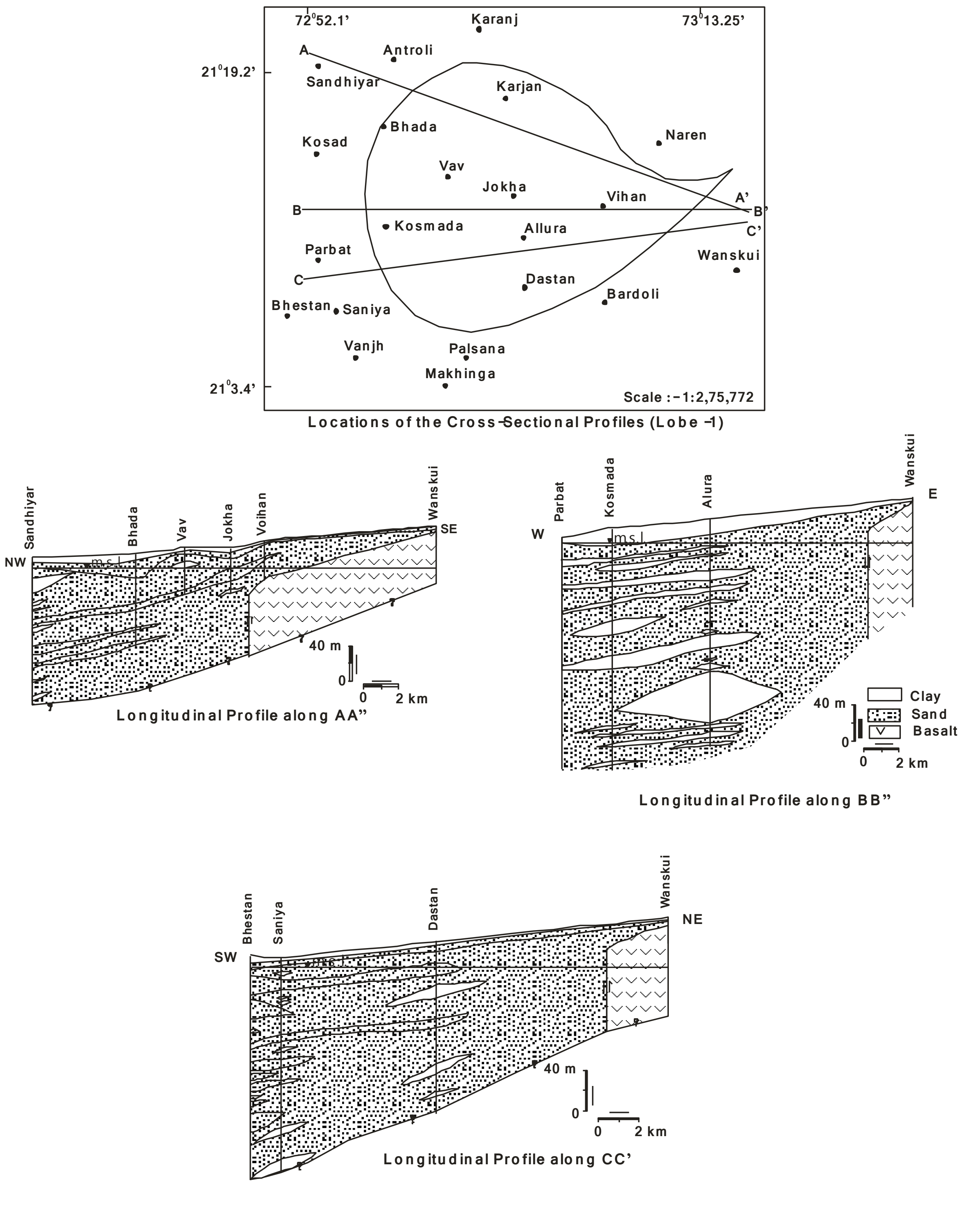

Fig. 5 Diagram Showing The Subsurface Longitudinal (A-A'.B-B',C-C') Profiles Along Tapi Lobe I

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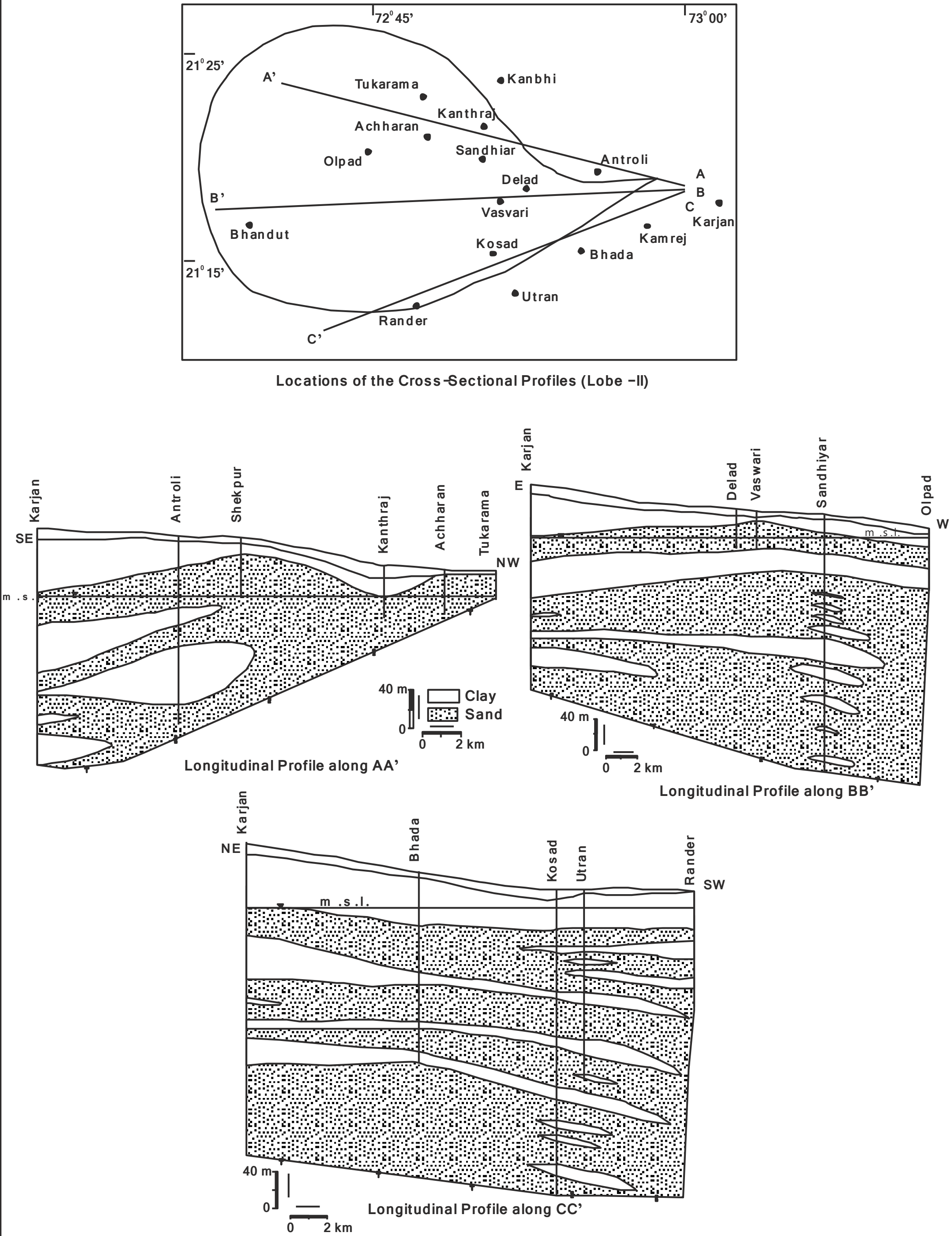

Fig. 6 Diagram Showing the Sub-surface Longitudinal Profiles (A-A’, B-B’, C-C’) along Tapi Lobe II.

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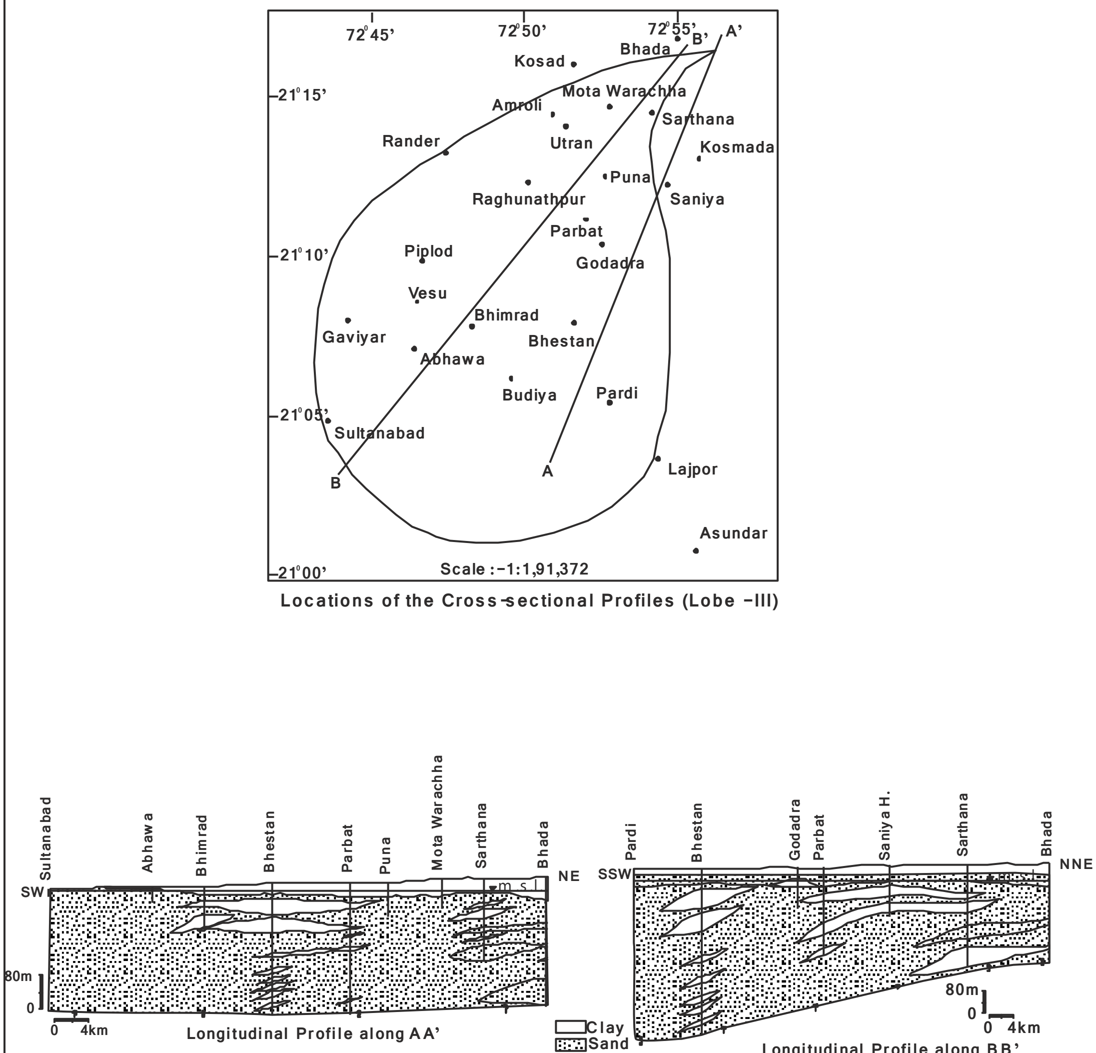

Fig.7 Diagram Showing the Sub-surface Longitudinal Profiles (A-A' and B-B') along Tapi lobe III.

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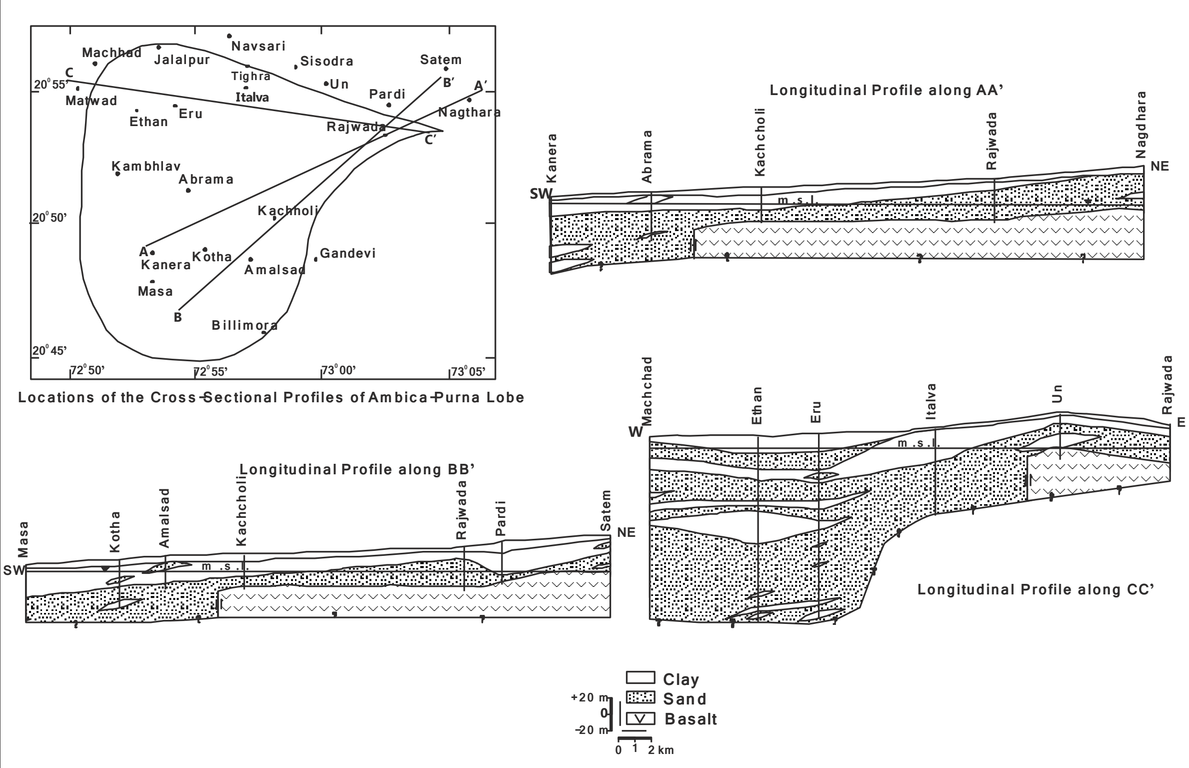

Fig.8 Diagram Showing the Sub-surface Longitudinal Profiles (A-A', B-B' and C-C') along Tapi –Ambica – Purna Lobe Lobe III.

Discussion

A development of an alluvial fan is a depositional response to the expansion of a confined channel flow as it leaves the rock head valley to emerge on to the fan surface (Leeder, 1999). The extremely well preserved palaeo-lobate features within the South Gujarat alluvial plains are remarkably significant from the point of view that they reflect the varying palaeo- strandline positions and focuses on the dynamics of the fluvial systems. The morphologic attributes of these river fans show characteristic less steep slopes in relation to the drainage area; constant or even concave in longitudinal profile. They inhibit short, deep incised channels, culminating down fan in a depositional lobe.

The study carried out on the palaeo-lobes of Tapi and Ambica river systems, very well exhibits the land-sea boundary conditions during the Quaternary times. In the absence of any geo-chronological data on Quaternary sedimentation record of south Gujarat, it may not be possible to assign a precise time framework for their development. Pandey (1986) has opined a regressive phase during the lower Pleistocene time along the west coast of India. Ramanathan and Pandey (1988), based on their studies on the Neogene-Quaternary boundary in the western Indian shelf have envisaged a regressive phase during the early Pleistocene times and have documented the presence of early Pleistocene sediments in the sub-surface stratigraphy of Hazira – 1 well. Taking into account the absence of surface exposures of Lower Pleistocene sedimentation record it is very much likely that the Quaternary sedimentation history of south Gujarat alluvial plains commences from middle Pleistocene time.

Evolution of these palaeo-lobatic features, Pleistocene onwards reflects a marked chronology of their formations through middle Pleistocene to Holocene times. The Quaternary sedimentation studies vis-à-vis sea level changes in the adjoining Lower Narmada basin by various workers viz. Bedi and Vaidyanathan (1982); Merh (1992); Chamyal and Merh (1995); and Khadkikar et al (1996) have also ascribed the age of the sediments from middle Pleistocene to Recent.

The surface exposures as well as the sub-surface longitudinal profiles of the palaeo - lobatic features clearly show alternating sand and clay layers. It is very much likely that the continuous sands encountered in the sub-surface data represent the delta-front sands with linearly oriented alternating clay units. The disposition pattern of sediments as revealed from borehole litho-logs profiles suggest that these lobatic features are the result of deposition of fluvial sediments in stream channels, natural levees, point bars and abandoned stream courses and interestingly they are preserved even though at times the distributory channels abandon their earlier courses (Sengupta, 1994). The development of such fluvial dominated deltas results because of high sediment input and low counter-action by coastal processes, indicating low energy conditions (Einsele, 1992).

The Tapi Lobe – I with its apex at 41m elevation and traces of large number of palaeo-distributory channels, represent the high strand at about +40m during middle Pleistocene (Tricart 1974, Ganapathi et al. 1981; Merh, 1992). The presence of a regional planation surface at 40±5m, representing palaeo-high marsh (Patel et al. 1982), further corroborates the observation on the genesis of this inner most lobe as well as position of the land-sea boundary.

The nature of occurrence of Tapi Lobe – II points to a perceptible northwesterly shift of the Tapi River perhaps during upper Pleistocene times. This abrupt shift in the course of Tapi river further northward may be attributed to the reactivation of Tapi fault (Kaila et al, 1981) followed by local regression in sea level during the upper Pleistocene times could have been the main cause for the formation of this lobe. The continual regression of sea during early Holocene times along with the change in the course of Tapi River as well as development of Kim River as an independent river system resulted in the formation of lobe – III.

The development of the palaeo-lobe feature in the adjacent Ambica-Purna river system with its apex at 21m elevation seems to be coeval with the formation of Tapi lobe – III. Interestingly, the satellite data has revealed that the formation of this lobe is the result of the combined contributions of Ambica and Purna rivers during the early Holocene times.

Possibly both these rivers had a common mouth, however the subsequent N-S faulting at 73^0 longitude east of Bilimora town was responsible in the abrupt shift in the course of Ambica River due south, thereby carving its present day mouth.

The nature of occurrence of these lobes strongly indicates their sequential development. The development of these lobes also suggests that in spite of different cycles of eustatic changes right from middle Pleistocene to early Holocene times, the consistency of their formation reflects the enormous supply of sediments by the then prevailing drainage conditions. Taking into account the geometry of the palaeo-lobatic features, they have been identified as the river dominated fan-shaped deltas, which are normally produced when heavy load of sediments is discharged by stream on a plain of low-gradient (Sengupta, 1994).

The overall observations made in the present study very well depicts that the palaeo-lobate features reveal the past as well as the present dynamics of the south Gujarat fluvial systems in response to the changing sea levels and demarcate the palaeo land - sea boundary conditions. The geometry of these lobes has clearly indicated them to be the river dominated fan-deltas.

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