Chapter I

INTRODUCTION

The Rationale of Study

Background

As per Davis (1899) "The process of landscape evolution is a progressive change over cyclic time during a much longer time interval (millions of years)". In other words a landscape evolves when, for a considerable geological time period it is exposed to the agents of weathering and erosion (Bloom,1998) leading to disintegration and re-deposition of the sediments in various depositional environments such as fluvial, lacustrine, marine and glacial. So, the present landscapes are very much an expression of the processes operating during the Quaternary in the geological time scale. The term Quaternary (means "fourth") was proposed by Giovanni Arduino in 1759 for alluvial deposits in northern Italy and by Jules Desnoyers in 1829 for sediments of France's Seine Basin that seemed clearly to be younger than Tertiary Period rocks. The Quaternary time period is the most recent and a very short time span in the geological history of the earth. The Quaternary Period spans from the last 2.588 Ma to present and is subdivided into the two epochs; 'Pleistocene' and 'Holocene' (Table1.1). The Pleistocene extends from 2.588 to 0.0117 Ma whereas the Holocene is about the only last 10,000 years (10 ka). The Pleistocene is again divided in lower, upper and middle; early, middle and late terms are also used at times.

Quaternary research is equally concerned with changes operating on shorter and longer (thousand-year) time scales. The thousand-year time scale represents sea level variation due to glacio-eustasy, rate of the Earth's rotation and geoid shape as determined by lithospheric mass, while the hundred-year time scale reflect changes in water-mass distribution related to changes in oceanic circulation caused by the variations in climate and Earth's rotation rate (Mathur, 2005).

Table 1.1 Quaternary time scale with the subdivisions and age (After International Stratigraphic Commission).

Subdivisions of the Quaternary System			
System	**Series**	**Stage**	**Age (Ma)**
Quaternary	Holocene		0.0117 to present
	Pleistocene	Tarantian	0.126 to 0.0117
		Ionian	0.781 to 0.126
		Calabrian	1.806 to 0.781
		Gelasian	2.588 to 1.806

The relation between the sea level and the climatic variations is well established by the Milankovitch theory of climatic change that predicts the global ice volume and hence, sea level changes controlled by the long term quasi-periodic variations in the earth's orbital parameters i.e., obliquity, precession and eccentricity. However, these climatic changes caused by periodic changes in earth's orbit are slow and are amplified by concentration in the atmosphere of certain atmospheric trace gases, known as green house gases. The studies suggest that their concentrations have varied during the glacial and interglacial periods of Quaternary and that the Early-Quaternary climatic changes were not that frequent as in the Late Quaternary. Therefore, the present study on the late Quaternary period requires attention on these climatic changes and the sea level conditions to narrate the story of landscape evolution in Saurashtra through major and minor events taken place during this time frame.

The Late Quaternary refers informally to the past 0.5-1.0 million years. This period experienced long lasting glacial stages divided by warm episodes of shorter durations (30-50 interglacial-glacial cycles) and therefore it is characterized by a series of large-scale environmental changes that have profoundly affected and shaped the landscapes. The Late Quaternary period of earth history is characterised by changes in climate at various magnitudes. A distinct signature of such change has been observed in terms of relative sea level changes. Obviously, resultant oscillations in the sea levels get directly reflected in to the shifts of coastal environment, either sea ward or land ward. A sedimentary archive of coastal marine and fluvial systems should be therefore investigated to unravel the events and its time to reconstruct the evolution history of the region.

The transport of sediments to the beach environment by both fluvial and aeolian processes constitutes the coastal sediment supply. Although the aeolian transport plays a role in overall sedimentary budget, the fluvial influx makes up 95% of sediment entering the ocean which ultimately results the fluvial systems to be the key element for operating the Earth surface change.

The change in the coastal supply regime leads to erosional outcomes in a river by river scenario and accretion of shoreline at the increase of coastal sediment flux.

Along with the normally observed events, the shores also experiences relatively short-lived events of an instant to thousands of years leaving their stratigraphic traces. Such events may be represented by depositional, erosional or geochemical features of local or extensive significance in a random or regular cycle comprises under the study called as the event stratigraphy. These events can be classified to be instantaneous events (e.g., rain prints, footprints), short-term events (e.g., tempestites, turbidites, tsunamiites, lava flows and flood deposits), medium-scale events (glacial varves and some flood deposits) or long-term events (e.g., omission surfaces, paleomagnetic polarity etc). In the Quaternary setting, stratigraphy recognized from short duration events has led to use these features as the basis for correlation. These require recognition of the fluvial successions often hampered due to complex responses of a fluvial system to allogenic and autogenic controls. The four main allogenic forces, namely, the sea level change, basin subsidence, climate and source area, are related to the three key parameters of fluvial morphology; sinuosity, degree of channel constraint and number of channels (Catuneanu, 2007) which are further grouped into two main fluvial styles; meandering or braided systems, with many forms and combinations in between the two.

Changes in temperature and precipitation change rates of weathering and erosion which also considerably result in fluctuations in the river regimes. The fluvial system reacts differently to the climate change depending on the size, topography and the position of the catchment area (Vandenberghe, 1995a). During the Younger Drayas, the drainage pattern of the large fluvial systems even changed along the course of the rivers (e.g. Buch, 1989; Schirmer, 1995; Starkel, 1995; Vandenberghe, 1995b). Therefore to understand the past environmental changes, the fluvial activity becomes an important aspect of study.

The cliffy coast of southern Saurashtra, based on the geomorphic position of notches, has reported to have two major palaeo-sea strands as the preserved record of the sea level changes during the Late Quaternary. The present study therefore focuses on the study of southwest coast of Saurashtra in order to understand the resultant fluvial and coastal sequences.

The sedimentary sequences exposed reveals the history of the climate variation during the Late Quaternary, especially in the later phase i.e. the MIS 3 stage (60-30 ka) (Bhatt and Bhonde, 2003). The sedimentary facies (both, fluvial and coastal) depicts the environment prevailed during that time and hence, as a whole can be used to infer the climatic conditions of Saurashtra region. The climatic variability is a function of monsoon and atmospheric circulation, which can be influenced by any kind of change in the above parameters

Recent studies revealed that the fluvial systems of western India responded dramatically to the fluctuating climate during the Late Quaternary time (Chamyal et al., 2003; Sridhar, 2013; Jain and Tandon, 1997). The rivers like Sabarmati, Mahi, Narmada draining the alluvial plains of mainland Gujarat receives the annual discharge primarily from the precipitation in the catchment areas and secondarily in the region of their course and hence can be called as perennial rivers. Unlike these perennial rivers, the shorter distance drainages or the coastal streams flow during monsoon season only.

So far the Late Quaternary time frame is concerned, lots of fluctuations in climate at various intervals and of different magnitudes has been observed. The fluvial and coastal sediments corresponding to this time bracket has been reported from various regions throughout the globe. In India Late Quaternary successions have been reported from the Himalayas (Srivastava et al, 1999), Thar Desert (Dhir et al, 1992) and; Gujarat alluvial plains (Chamyal et al., 2000, 2002). However, very scanty data are available for the Late Pleistocene coastal sedimentary records. The coastal deposits we see today are mostly of Holocene age. Exceptions are the coast fringing carbonate deposits of Saurashtra region (Bhatt, 2003) which comprises of marine as well as aeolian component. These deposits have remained in a prolonged dichotomy regarding their origin.

The purpose of establishing the sedimentary history or architecture is to strategically and systematically build a model for the landscape evolution and link the possible perturbations during the Late Quaternary time period. The sedimentary history of any region reveals the mode of deposition and accumulation or residence of the sediments reveled by major depositional and erosional events, at times also preservation of minor or catastrophic events. The present study has focused on recognition and documentation of such events from the Late Quaternary sequences of southwest Saurashtra.

Objectives

A major objective of this study is therefore,

- To study the coastal and fluvial archives for its sedimentology to reconstruct event stratigraphy and evaluate the Late Quaternary environmental changes.

To achieve the aforesaid objective following approach was adopted.

Methodology

- Use of remote sensing data and ground checks for large scale geomorphic mapping.
- Mapping of sedimentary architecture of coastal and fluvial sequences by vertical and lateral logging.
- Analyzing the samples for their textural and compositional characteristics to understand this depositional dynamics.
- Synthesis of these data to build the geological history.

Study Area

The study area lies on the western margin of India in the Saurashtra (Kathiawar) region of Gujarat state and lies spanning between North Latitude 21^{o} 00' and $21^{o}45$' and East Longitude $69^{o}30$' and 71^{o} (Fig.1.1). The coastal stretch of Saurashtra is almost straight with rocky shore platforms covered at times with sand, whereas the southern Saurashtra coastline is cliffy. Majority of the drainages in Saurashtra are bedrock rivers and have deposited thick sediments in the past and presently cutting its own valley fills. The Saurashtra region has been explored mainly for the limestone deposits i.e. the Miliolite

Formation. Bhadar, Ojat, Shetrunji, Hiran, Singwado, Machhundri are the major drainages of Saurashtra and earlier studies have shown that these rivers were active during various times in Late Quaternary period and so, host a sedimentary archive that must have preserved the imprints of aforesaid

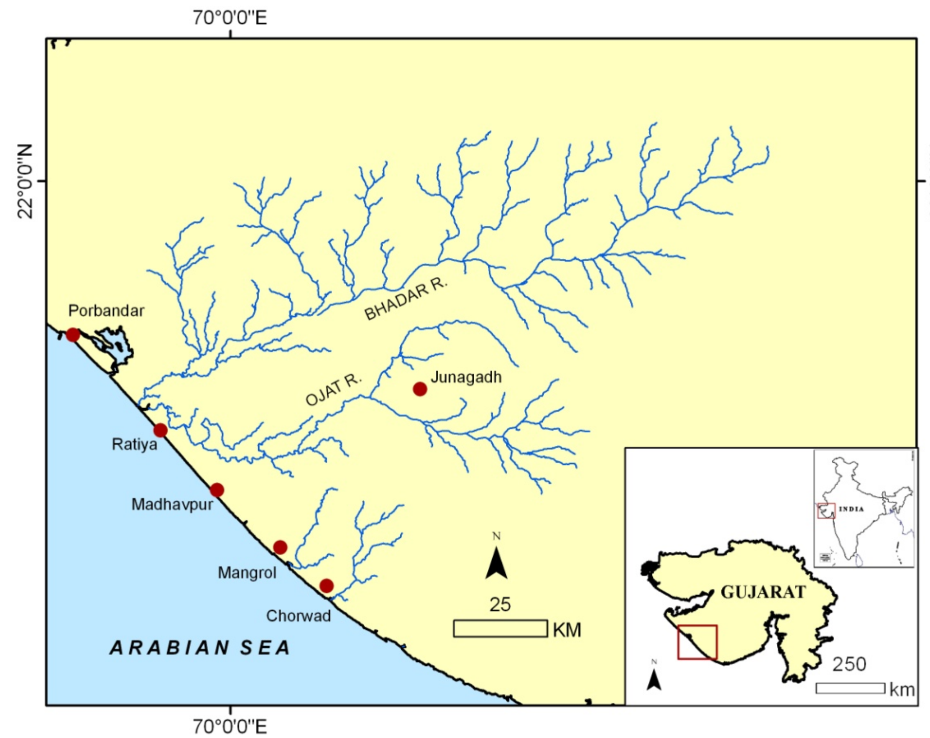

Fig. 1.1 Location map of the study area.

climatic changes in the region. The Bhadar river basin has been studied in detail for its morphology (Lele, 1989) and the fluvial sequences (Bhatt and Bhonde, 2003). However, no other river has been studied for its sedimentary packages that may give a clue for the Quaternary climate, and hence the present author has carried out detailed geomorphology and constituent sedimentary packages from Ojat and Bhadar rivers that drain through a major part of the study area The Bhadar is the longest of these which covers a distance of more than 180 km to meet the Arabian Sea at Navibandar. The

Ojat River is a major tributary of Bhadar river, and drains almost parallel to it for about 150 km to join it just before debouching into the Arabian Sea. The study area thus encompasses these two major drainage basins and adjacent coastline.

Previous Work

Saurashtra region has always remained in discussion for the Quaternary bioclastic deposits, much famous as the Miliolites. The huge spatial and temporal accumulation of these deposits has attracted many well known National and International workers/scientists to study the evolutionary parameters of this region. The Saurashtra peninsula is also a favourite of Archaeologists and many archaeological sites has been discovered in the Hiran and Bhadar river valleys. The shore parallel ridges all along the western coast point towards the sea level fluctuations during the Quaternary time period.

The Saurashtra region has been investigated by many researchers till date. Since the report of the bioclastic shore deposits by Fedden (1884), the Saurashtra coast has remained important for various aspects, viz. Sea level studies, geomorphic evolution, stratigraphic successions, cliffs and notch making processes (Bhatt and Bhonde, 2006).

Saurashtra has been a centre of attraction from the archaeology point of view as well. The discovery of Lower Palaeolothic tools by Sankalia (1965) in the Bhadar valley opened the way for archaeologist to hunt for the ancient culture. The archaeological evidence also helped to understand the landscape changes during the Holocene. However, since the report of miliolite by Fedden (1884) the major debate was on the origin of these huge carbonate depositional environments. There were two schools of thoughts, one saying it to be of totally marine origin and the other defending it to be marine and aeolian both (Bhatt, 2003).

The Miliolite Formation has also been studied by many to deduce the chronology using various techniques such as radiocarbon, ESR, Ca/Mg ratio and AMS as well (Table 1.2). Bruckener et al (1987) first attempted to date these carbonate deposits with some samples from scattered locations. Later on Baskaran et al (1989) made available many U-series radiometric ages from these deposits. These and other available ages are used in the present study to constrain various events from the Late Quaternary sequences of the study area. The significant inputs on overall geology and stratigraphy by other scientists have been summarised in the next chapter wherein the geological constituents of the study area are dealt with in more detail.

Table 1.2 Summary of available chronology of Quaternary deposits from the Saurashtra region. (After Bhatt, 2003)

Location	**Material**	**Age (ky)**	**Reference**
Chorwad	Shell	82.1	Bruckener et al. (1987)
Mangrol	Ostrea sp.	86	
Porbandar	Tellina sp.	37.3	
	shell	105+10%	
	Tellina sp.	94.9	
Chorwad	Shell	115	
Veraval-Madhavpur	Miliolites	52+3.2-3.1	Baskaran et al. (1987)
		168+22-18	
		65.4+5.5-5.2	
		235+36-27	
		177+19-17	
various parts of Saurashtra	Miliolites	56-70	Baskaran et al. (1989)
		75-115	
		140-200	
Kothara, Mukuda, Roha	Miliolites	54.8+5.1	Chakrabarti et al. (1993)
		36.9+1.5	
		138.6+13.9	
Chikasa	clam shells	129.3+110.7-9.7	Juyal et al. (1995)
Harshad	Oyster	126.5+8.5-8.0	
Porbandar	Clam Shell	132.7+11.0-10.0	
Rupen River	Oyster	2.5+0.2	
Chikhali	Oyster	3.3+0.2	
Diu	Oyster	87.2+9.7-9.0	
Jafrabad	Oyster	71.1+6.2-5.9	
	Oyster	6.4+0.7	
	Oyster	8.6+0.6	