CHAPTER - 1

INTRODUCTION

1.1 SEQUENCE STRATIGRAPHY - CONCEPT

Sequence stratigraphy has become the pre-eminent method for describing cyclicity and architecture in sedimentary basins. Sequence stratigraphy emphasizes facies relationships and stratal architecture within a chronological framework (Catuneanu et al 2009). The sequences are composed of genetically related sediments bounded by unconformities or their correlative conformities and are related to cycles of eustatic change (base level/sea level). Outcrop-based sequence stratigraphic analysis is usually carried out to know potential sequence stratigraphic surfaces, unconformities and sequence boundaries based on certain criteria like, (1) clearly defined erosional truncation, (2) direct evidence of subaerial exposure, (3) abrupt basinward shifts of facies, (4) transgressive surfaces - maximum flooding surfaces, (5) regressive surfaces – maximum regressive surfaces (6) correlative conformities (7) omission surfaces, (8) condensed sections or (9) incised valley fill etc. Likewise, potential condensed sections need to be recognized on the basis of unusual burrowed surfaces, abundant digenetic materials and fossil concentrations, for identifying maximum flooding surface. The recognition of set of parasequences, potential sequence boundaries and condensed sections, systems tracts and major stratal surfaces (sequence boundary, transgressive surface, and maximum flooding surface) helps in understanding the detailed basinal history across a time slice. The most obvious implication of sequence stratigraphy is that depositional environments are constantly shifting and that an assumption of constant depositional environment in a section is probably erroneous to some degree.

Sequence Stratigraphy has developed into a powerful predictive facies analysis tool for both academic research and hydrocarbon exploration. Because of diverse interest, Jurassic sediments of the Jhura dome offer an investigation for sequence stratigraphic analysis which includes: parasequences; system tracts, correlative conformities, regressive surfaces, transgressive surfaces, maximum regressive surfaces, maximum flooding surface and drowning unconformity that forms in shallow marine environments and also leaves the characteristic features of the deposition of the sediments and their trace fossils content.

1.2 ICHNOLOGY IN SEQUENCE STRATIGRAPHY

Ichnology as a science helps in understanding the behavior of the organisms that alter and disturb the sediments during their life and produce biogenic sedimentary structures i.e. trace fossils. Trace fossils also provide an in-situ and undisturbed record of the animal activity. The detailed analysis of trace fossils leads to identification of various spacio-temporal ichno-assemblages, corresponding ichnoguilds and ichnofacies. The detailed study of such ichnological data can serve as useful indicators of paleoenvironmental parameters such as physical energy, sedimentation rate, oxygen condition, nutrient supply, salinity, temperature, substrate consistency, overall paleoecology and paleobathymetry. Integrating the data derived from substrate controlled ichnofacies with data from vertical ichnological successions provides a powerful tool for the recognition and interpretation of important sequence stratigraphic surfaces (Pemberton and MacEachern 1995). The integrated study of these ichno-assemblages and sedimentology will lead to formation of sequence stratigraphy and depositional model through time. Trace-fossils can also be employed effectively for recognition of various types of discontinuities / breaks and to assist in their genetic interpretation. Through the recognition of such surfaces which mark time gaps between the former deposition of a unit and later superimposition of a post-depositional trace-fossils assemblage.

It is well established, that trace fossils and cycles of sediment deposition are used together for defining sequence boundaries and sequence tracts. The most obvious use of ichnology is in demarcation of erosional discontinuities having a significant temporal break between the eroding event and the successive depositional event. The second use is more subtle and is concerned with the environmental implications of the trace-fossils suites, both soft-ground and substrate controlled. When these aspects are integrated with sedimentologic and stratigraphic analyses, the result is a powerful approach to the delineation and genetic interpretation of sequence stratigraphic surfaces, as well as their associated deposits (Pemberton and MacEachern1995). Thus, the prime focus of the research will be to develop sequence stratigraphy on the basis of sedimentary cycles and trace-fossil assemblages as both these two identities contain wealth of preserved information. Stratigraphic interpretations explain how a sedimentary rock acquires its layered character and paleoecological entity. This analysis can be in turn used to explain how and under what conditions do the sediments accumulate, when erosion occurs and how communities and habitats of different benthic organisms are developed in relation to space and time.

Trace fossils represent both sedimentologic and paleontologic (ichnologic) entities and, as such, represent a unique blending of potential environmental indicators in the rock record (Pemberton and MacEachern 1995). Trace fossils and trace-fossil suites can be employed effectively to aid in the recognition of various types of discontinuities and to assist in their genetic interpretation. The stratigraphic utility of trace fossils can take on many guises and their significance varies, depending on what stratigraphic paradigm one is employing. In the earlier times because of long time range and largely facies dependent character the biostratigraphic value of trace fossils was considered negligible. Traditionally, it was thought that there were only three ways in which trace fossils could be utilised: (1) tracing the evolution of behavior, (2) as morphologically defined entities and (3) as substitutes for the trace making organisms (Magwood and Pemberton, 1990). However, recently, integrated ichnological-sequence stratigraphic approach has been employed for recognition of key stratigraphic surfaces (e.g. Bromley and Goldring 1992; Taylor and Gawthorpe 1993; Ghibaudo et al. 1996; Pemberton and MacEachern 1995; MacEachern et al. 1999; Maplas 2000; Pemberton et al. 1992, 2001 and 2004; Van Wagoner et al. 1990) or for improved broad-scale facies interpretations based on a refined ichnofacies-based approach (e.g. Vossler and Pemberton 1988; Frey and Howard 1990; Savrda 1991a, b; Brett and Baird 1986; Siggerud and Steel 1999; MacEachern et al 1991a and 1991b; MacEachern at al 1992a and 1992b). High-resolution sequence stratigraphy also has been combined with work on meter scale rhythmic successions, particularly bedded platform carbonates and siliciclastic carbonate units. Quantitative and qualitative spatio-temporal record of biotic and abiotic field observable features and their mutual relationships relevant to 1st, 2nd and finer order sequence stratigraphy in the basin is being used for comprehension of high resolution intra-basinal dynamics.

1.3 APPROACH

The Middle Jurassic sediments of the Jhura Dome of the Mainland Kachchh preserve a great wealth of ichnological and sedimentological records concerning the lithological, biological, ichnological and stratigraphic data, but the sequence stratigraphic study from this region is woefully lacking. Therefore, the author proposes to undertake the ichnological studies in a sequence stratigraphic perspective, in order to understand the basinal evolution and depositional history within the context of cycles of relative sea level rise (transgression) and fall (regression) and geological events, in this region. The sequence analysis of the Middle Jurassic rocks of Jhura Dome will be carried out with an integrated approach by collection of the scientific data on vertical and lateral lithological relationship, sedimentary structures (physical and biological), depositional processes and associated fossil assemblages. The trace fossil assemblages will provide the key data base to understand the sedimentary basin evolution and geological events. The abundance of trace fossils will highlight the environmental conditions. The grouping of the trace fossils will provide information to determine the palaeobathymetry, wave and current energy, food supply, oxygen content, substrate consistency etc., which is used for identification of stratigraphic surfaces.

1.4 STUDY AREA

The Jhura (=Jhurio hill) dome (Fig. 1.1) has been named after Jhura village, a very famous junction between Loria and Nirona towns, just 37 kilometers NW of Bhuj city, the capital of Kachchh district, Gujarat State, India. It falls in between 23^0 30' to 23^0 40' N Latitudes and 69^0 30' to 69^0 40' E Longitudes of Survey of India Toposheet No. 41E/11 and 15 and cover approximately 65 sq. km. area. There are major six villages/towns (Jhura and Palanpur in the North; Loria in the NE; Nirona in the NW and Kamaguna - Bhakhri in the South and SSE respectively). All these villages are situated in the periphery of the dome and very well connected via fair-weather/mettle roads from Bhuj.

1.5 SCOPE OF WORK

The present study has helped in the understanding the Bajocian (?)/Bathonian to Oxfordian stratigraphy, their sedimentation pattern, behavioural patterns, paleoecology, depositional environment and basinal history of the Jhura Dome. The systematic approach to the sedimentology has given idea about facies relationships and related stratigraphic surfaces and boundaries. While trace-fossils (=Ichnology) have given the idea about their behavioural patterns and their abundance and diversity in the sedimentary sequences. Accordingly, the prime focus of the research would be to develop sequence stratigraphy on the basis of sedimentary cycles and trace-fossil assemblages as both these identities contain wealth of preserved information. The vertical distributions of the trace-fossils helped in dividing stratigraphy into facies, guild levels and date the sediments. This exercise is also useful in correlation with the other parts of the Mainland Kachchh.

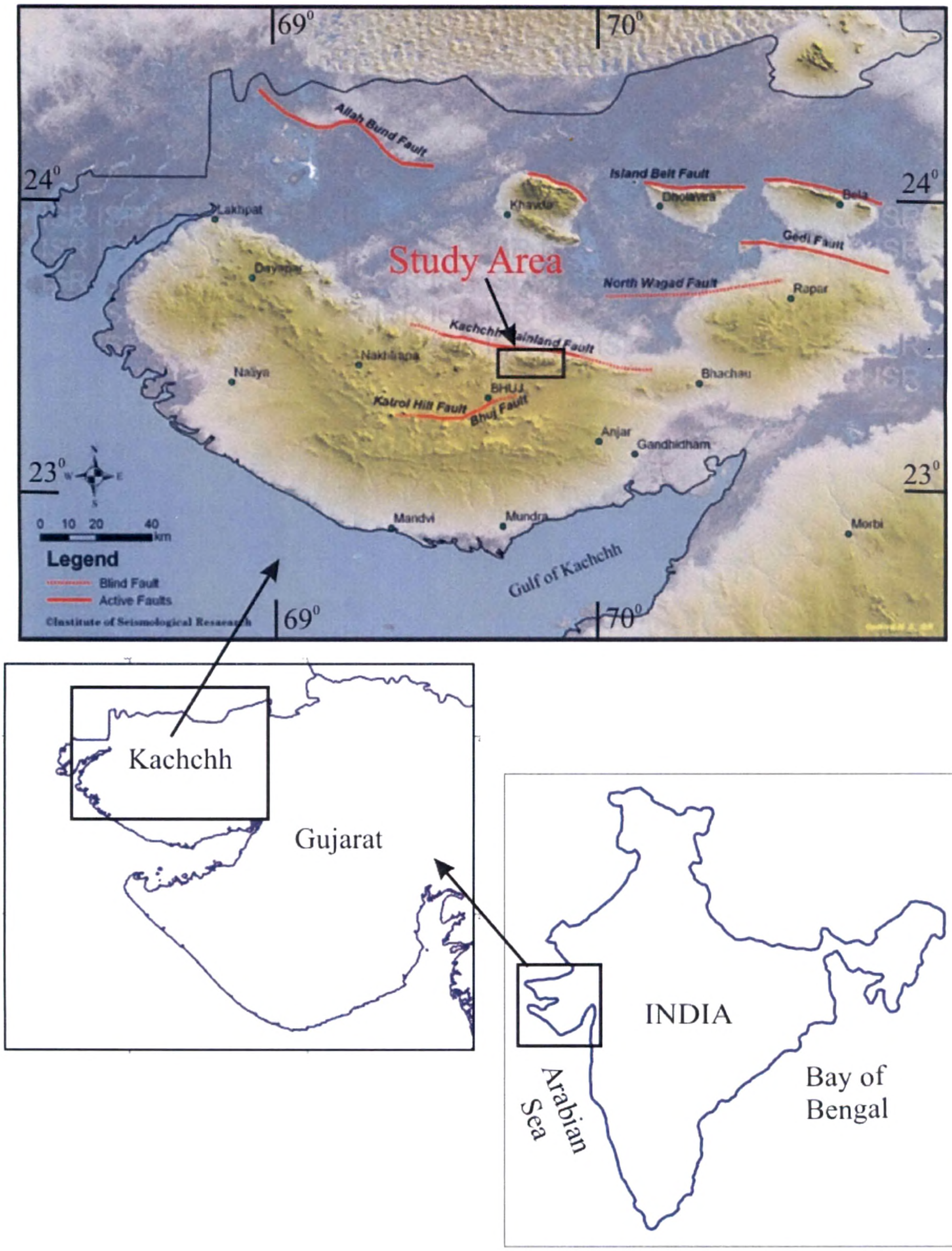

Fig. 1.1 Location Map of the Study Area

1.6 AIMS AND OBJECTIVES

The main aim of the present study is to generate and establish sequence stratigraphy of the sedimentary sequence of the Jhura dome using ichnological and sedimentological data.

- To mapped the area and reconstruct the lithologs and marking of various major contacts and collection of the representative samples (rocks and trace fossils).

- Analysis of the sedimentological and ichnological data.

- Recognition of the substrate controlled lithofacies and ichnofacies and further examination of vertical stratal patterns.

- Delineation and genetic interpretation of sequence stratigraphic surfaces/boundaries and their associated system tracks.

- Integration of sedimentological and ichnological data and reconstruction of the depositional model and determine basinal history of the Middle Jurassic rocks of Jhura Dome.

1.7 METHODOLOGY

To achieve the objectives following methodologies have been followed with standard procedures.

- Stratigraphic sequences have been measured at different places and mapped for their lateral and vertical continuity and lithologs have been prepared on the basis of correlatable conformities and rock types.

- Systematic stratigraphic sampling has been done; physical and biological sedimentary structures (trace fossils) have been observed, recorded and examined.

- Lithofacies have been analyzed based on field and laboratory studies.

- Rock samples have been analyzed petrographically for textural analysis and mineralogical study for each lithofacies.

- Qualitative and quantitative analysis of the trace fossils have been done (includes ichnotaxonomy, ethology, density and diversity, ichnoguilds, ichnoassemblages, ichnofacies, etc.).

- Various sequence stratigraphic surfaces; system tracts (genetic units); parasequences have been identified in context to sediment characteristics and substrate controlled ichnofacies.

- Ichnological, sedimentological and stratigraphical data have been integrated to reconstruct the depositional model for the Middle Jurassic rocks of Jhura Dome of Mainland Kachchh.

1.8 TECHNIQUES IN ICHNOLOGY

The study of trace fossil requires one to try and relate fragmentary two dimensional patterns to complex three dimensional records and behaviour left by a diverse range of organisms. A wide range of techniques have been developed. These include acid etching, base etching, sand blasting, staining, serial sectioning, X-Ray radiography, infra-red photography, peeling by polyester resin, lacquer, epoxy relief, casting using plaster of paris, silicon rubber, polyester resin etc. The Senckenberg box and the Can cover are the most satisfactory devices for sampling both intertidal environments and in modified form, off-shore regions. Relative merits of each of these techniques, however, depend on the likely problems one has to encounter.

In the present study most of the trace fossils were photographed in the field. Such samples that could be conveniently removed in the field were brought to the laboratory for their finer details. Burrows are generally accentuated by wetting the rock surface or by smearing ink over it and then washing it off. Ink smearing process is a stain controlled by differences in porosity. Alizarin red and Methylene blue are preferentially absorbed by clay minerals and thus are useful in dealing with trace fossils in fine grained sediments. In instances of traces having delicate claw scratches or other fine details, whitening by chalk dust and photography in strong side light advantageously produces good results. Many of the staining techniques normally performed indoor were also applied for the outdoor photography. Spraying carbonate cemented rocks with dilute hydro choleric acid (HCl) or siliceous rocks with KOH was advantageously used to increase relief on fresh faces or rock surfaces.

1.9 OBSERVATION AND RECORDING OF TRACE FOSSILS

In order to observe, measure and record the trace fossils effectively, Collinson and Thompson (1982) have prepared set of questionnaires. They have made an attempt to describe the trace fossils in relation to their morphology of preservation, mode of preservation and the position and process of preservation as discussed below.

1.9.1 Morphology of Preservation

What is the morphology of the trace fossil? Are these identifiable shapes of organisms or a part of them? (a) Single shape (e. g. a print of track made by a foot) (b) Several similar shapes repeated to form a pattern. (e.g. a track made during locomotion), (c) a trail (i. e. a continuous groove made during locomotion); (d) a radially symmetrical shape developed in a horizontal plane (e.g. by the resting of a starfish); (e) a tunnel or shaft caused by a burrower seeking food/or refuge; (f) a series of spreiten, which are U-shaped closely related concentric laminae caused by an animal shifting the location of its burrows as it grows or move upwards, downwards, forwards and backwards by excavating and back-filling; (g) a path shape, for example caused by the resting of bivalves ; (h) a network pattern.

1.9.2 Mode of Preservation

Is the trace fossil preserved as a cast or mould? Is there evidence that the fill was "passive", i.e. by normal sedimentation, or "active" for example, the backfilling action of a burrower? Is the trace fossil preserved as a diagenetic concretion? Chondrites, Rhizocorallium, Thalassinoides and Ophiomorpha are often preserved as calcite and siderite nodules in shales or limestone nodules in sand. Small diameter burrows are often preserved in pyrite which oxidizes to red-brown goethite, in flint or chert. These features are often distinguished by burrow margins with different physical compositions.

1.9.3 Position and Process of Preservation

Is the trace fossil preserved in an interfacial position? The top of the casting medium is an epichnial trace, trace like a ridge (positive feature) or a groove (negative feature). Are there any markers on the top or bottom of the ridges and grooves? Is the trace fossil preserved in an interfacial position on the bottom of the casting medium as a hypichnial trace, e. g. a ridge or groove? If so, is there any evidence that this was sediment/water interface? Was the trace fossil preserved at a sediment/sediment interface, possibly between contrasting lithologies, possibly at concealed junction? Are the underlying and overlying laminae deformed? Is the trace fossil preserved within a bed, but outside the main body of the casting medium as an exichnial trace? Here the traces of one lithology (e.g. sandstone) are isolated in a different lithology (e.g. shale). Is the trace fossil preserved in an internal position with the main body of the casting medium as an endichnial trace? Are the burrows very densely distributed and interpenetrating? If so, the sediments should be referred to as having a bioturbate texture. Are the burrows common but distinct? If so, the term burrow mottling may be more appropriate. Are the structures preserved in full relief? Is the wall of the cast of different composition from the body of the cast; as when a burrow in sand is lined by a layer or layers of mucus and/or feacal pellets made of mud? Does the trace contain internal structures, e.g. spreiten? Is the trace preserved by burial following erosion, i.e. is it a derived trace fossil? This arises when, after burrowing, erosion takes place and currents winnow away a soft matrix leaving the mucus bound burrow lining as sediment filled "gloves". These can be covered by later, possibly different sediments. Alternatively currents may scour out burrows made in mud and afterwards fill them with sand.

1.10 TRACE FOSSILS IN CLASTIC VERSUS NONCLASTIC SEDIMENTS

Shallow marine clastic and nonclastic sediments are known to occur from the Precambrian to the Recent. Carbonate rocks have preserved worthy record of body fossils as well as trace fossils to display animal life in the past geological time. In contrast, clastic rocks have poor preservation of body fossils owing to their higher porosity and shell being dissolved either partially with unrecognizable features or completely leaving moulds.

Most of the trace fossils studies, however, are based on siliciclastic sequences, particularly alternating sand and shale beds in which abundant, well-preserved traces are commonly the only fossil present. In contrast, trace fossils in carbonates generally are inconspicuous and difficult to study, and commonly are overlooked because of abundance of body fossils of both mega and micro organisms (Frey, 1970).

Preservation of the trace fossils in clastic rocks is more favourable as compared to nonclastic rock because it consists of mature detrital grains and deposited by jarring fashion. At greater depth effects of overburden pressure is also negligible and retains their original volume (lithologic character of the rock, especially its textural properties). Intergranular space is not much reduced during the compaction but either filled with clay matrix or filled with cement during the diagenesis. Original shape and size of the structures are not much altered.

Preservation of the trace fossils in carbonate rocks is largely subjected to the following conditions: (a) Mineralogy of the substrate and the mean grain size of the sediments. (b) Mode of deposition, whether continuous or non-continuous. (c) Susceptibility of carbonates to early and late diagenetic modifications which may even alter the trace formation. (d) The carbonate rocks are further subjected to a wide variety of microfacies and several geo-chemical features that operate differentially in each of its subenvironments. (e) Much reduction in volume or compaction of the carbonate sediments during the burial process may alter the dimension of the trace. (f) Fabric selective solution may alter the trace while non fabric selective solution forms caving, total loss of trace.

There are thus a large number of intrinsic difficulties to recognize and interpret trace fossils, from the carbonate rocks. As a result the corresponding literature on carbonate trace fossils is restricted to very few detailed investigations as compared to clastic counterpart.