CHAPTER - IX

RESUME

The marine Jurassic carbonate sequences of Kutch, India offer an excellent scope for study of Palaeontology, Stratigraphy and Sedimentology. Most of the previous study emphasized on Palaeontological aspects and established Litho-, Bio- and Chronostratigraphy based on regional lithological variations as observed in the field and on palaeontological evidences. Hence the sediments which hosts the fossils, on the other hand, received only cursory glance. Besides, the diagenetic and microfacies studies of these carbonate sequences have not been dealt with anywhere and very little has been published on their depositional environments.

With this in view, the author has chosen to study the sedimentological aspects of exposed sequences of carbonates. The present work pertains to the Jurassic carbonate formations of the age ranging from Upper Bathonian to Oxfordian, developed in the north western corner of the Indian Subcontinent, in Kutch. This includes Jhurio Formation ranging in age from Upper Bathonian to Lower Callovian and Jumara Formation from Middle Callovian to Oxfordian. In order to impart regional validity to the conclusions, the study has been carried out in three areally apart sections, Jumara, Jhura and Habo along the E-W axis of the depositional basin in the Mainland of Kutch.

REGIONAL GEOLOGICAL SETTING:

Kutch basin is a pericratonic basin developed in an east-west alignment deepening towards west (Biswas, 1982). The total thickness of Mesozoic sediments in Kutch varies from 1525 to 3050 m (Biswas and Deshpande, 1983) deposited on a crystalline basement composed of Archean and Proterozoic rocks (Biswas and Deshpande, 1968). The sequences were developed due to repeated marine incursions during the Middle Jurassic to Lower Cretaceous period followed by major tectonic movement and Deccan trap volcanism in the Late Cretaceous times.

The Kutch basin was primarily developed due to rifting of Africa and India in the Late Triassic time during the fragmentation of the Gondwana Superplate (Biswas, 1991). The basin is bounded by Nagar Parkar uplift on the north, Radhanpur-Barmer Arch on the east (which separates the Kutch basin and Cambay graben) and Kathiawar uplift on the south (Biswas, 1980, 1982, 1991; Biswas and Deshpande, 1983).

A basement high (Median High) marks the basin hinge zone that came into existence in Post-Oxfordian time during the earliest tectonic movement in the basin (Biswas, 1982) and is considered as an extension of the Indus Shelf hinge (Biswas, 1987). This structural high cuts across the Mainland uplift, Banni Basin and Patcham uplift and seems to be continuing to the north.

Regional structural elements of the area are indicated by three parallel anticlines in the NW-SE direction. Jurassic rocks are best developed in the central anticline. A set of zone of culmination is observed along this anticline with zones of depression between them. These zones of culmination stand out in domal forms at Jara, Jumara, Nara, Keera, Jhura, Habo etc., where inliers of relatively older rocks occur at the core of the domes. These domes form a part of Kutch Mainland. Other uplifts where Mesozoic rocks are exposed are Wagad and the belt comprising Patcham-Khadir-Bela-Chorar chain of 'islands' in the Rann.

RESUME OF PRESENT STUDIES:

The study area comprising Jumara Dome lies between east longitude 69^0 02'50" and 69^0 05'10" and north latitude 23^0 40'50" and 23^0 42'00"; the Jhura Dome lies between east longitude 69^0 30'00" and 69^0 40'00" and north latitude

$23^0 22'20''$ and $23^0 26'00''$ and the Habo Dome lies between east longitude 69^0 $45'00''$ and 69^0 $54'00''$ and north latitude $23^0 20'00''$ and $23^0 23'30''$ forming part of Survey of India Toposheet Nos. 41 E/2, 41 E/11 and 41E/15.

During the present study, a broad geological mapping of Jumara dome in the scale 4.4 cm.= 1 km. was carried out ; tracing the outcrop boundary of the carbonates with the younger siliciclastic Jhuran Formation as well as plotting the boundary between the Jhurio & Jumara Formation. For study of Jhura and Habo domes, the available maps of Biswas et al (1977) were referred. Four traverses of Jhura dome and two of Habo dome including the traverse along Kalajar nala section were taken. Close and systematic sampling was done along the traverses of two carbonate sequences i.e. Jhurio and Jumara after recognising the juctions between the various rock types in the field. A section along a traverse north of Jhura dome was also made. Nearly 300 samples were collected and studied for microfacies analyses.

The field studies in Jhura, Jumara and Habo domes have revealed that the facies variation in Jhurio Formation is nominal and gradational whereas the same is frequent and sharp in case of Jumara Formation. The facies recognition in Jhurio Formation is based solely on the lithological variations because sedimentary structures are rarely discernible. This formation is identified in the field by its characteristic lithological association of limestone, shale and golden oolitic rocks. This is the only formation in the Kutch Mainland where pure crystalline limestones are encountered (Jhura dome).

The well developed Jhurio Formation in Jhura dome is due to existence of Jhura dome along the axis of Median High which has made it possible to expose the older members of Jhurio Formation. Here, five major lithofacies (KJH-I to KJH-V) have been identified. In Kutch Mainland, Jhurio Formation is exposed in Jumara and Habo domes. In Jumara dome, three major lithofacies (KJ-I to KJ-III) have been identified. In Habo, only one (KH-I) major lithofacies has been identified and this may be due to large intrusive body, below the facies, that has prevented the older members to get exposed to the surface.

The lithology of Jumara Formation is varied and ranges from carbonate sequence of oolitic limestone with association of shales/ironstones, calcareous sandstones, to conglomerates and pebbly grit rocks (Jhura and Habo dome). Hence the rocks constituting the Jumara Formation can be divided into several lithofacies in accordance to their distinctive lithologies, associations and internal structures wherever preserved. Jumara Formation is best developed in Jumara dome where each member is well exposed and can be approached easily especially from the southern limb of the dome. In Jhura dome the Jumara Formation is well exposed in the north western part, south-west of Jhura village. The rocks of this formation occupy the central part of the Jhura dome encircling the core of Jhurio Formation. In Habo dome the Jumara Formation shows a complete sequence in Kalajar nala section, located to the north of Dhrang village. The Jumara Formation is described within five different major lithofacies in all three domal structures.

Petrographic studies have revealed a variety of microfacies ranging from Mudstone to Rudstone (Dunham, 1962; and Embry & Kloven, 1972) in Jhurio and Jumara Formations. The main skeletal particles observed in different microfacies are echinoids, pelecypods, gastropods, brachiopods, corals, calcispheres, sponge spicules and smaller forams. The non skeletal particles include pellets, oolites, intraclasts, lithoclasts and other terrigenous particles constituting mainly quartz. Based on microfacies analyses, it has been found that the average grain size becomes coarser from Jumara to Jhura and Habo dome. The average percentage of micrite is more in Jumara dome than that in Jhura and Habo dome. The same is reversed in case of percentage of sparite which shows that the rocks of Jhura and Habo have been subjected to later stages of diagenesis. In these analyses, bioclasts have been utilized mostly as sedimentary particles; their identification has been extended only upto the level of phylum or class for gaining atleast a broad idea about the paleoenvironmental conditions.

To understand the amount of influx of non-carbonate detritus during the deposition of carbonate rocks, the representative samples of each lithofacies from both the formations of Jumara, Jhura and Habo domes were subjected to dilute HCL (10%) treatment and the weight percentage of insoluble residues were calculated. The variation has been plotted in the form of pie diagrams and bar chart.

The above study has revealed that the terrigenous influx in Jhurio Formation is very low whereas disruption by the clastic influx in the carbonate sequence of Jumara Formation reflects frequent changes in shoreline conditions during depositions. The percentage of terrigenous influx is more towards eastern part i.e. in Jhura and Habo dome which is also supported by microfacies analyses. The study in Jhurio Formation has revealed that the average percentage of insoluble residues increases from 18.96% in Jumara dome to 25.2% in Jhura dome and 36.72% in Habo dome. In Jumara Formation the average percentage of insoluble residues is more than that in Jhurio Formation. It is 52.83% in Jumara; 58.86% in Habo and 65.89% in Jhura dome. This is due to existence of more non-carbonate facies in the eastern part of the Mainland. Besides, the dominance of carbonate percentage within the Jhurio Formation of all the three domes indicates the process of transgression. Whereas, the Jumara Formation is suggestive of both transgressive as well as regressive cycles.

X-Ray Diffraction pattern of selected whole rock samples has been carried out for confirming the mineralogy of different microfacies under Jhurio and Jumara Formation. During the present work, carbonate powder packs are scanned by X-ray diffraction technique between 20° to 40° of 2Θ. However, this range has been expanded as and when needed for identification of additional minerals. Besides, few insoluble residues were also examined for possible clay mineralogy after preparing the oriented sections between 4° to 40° of 2Θ.

The powdered packs of representative samples of selected lithofacies have indicated the presence of mainly calcite and quartz. The presence of hematite and goethite as iron minerals has also been established. Presence of dolomite and anhydrite has been indicated only in the bedded limestone facies (KH-I) under Jhurio formation of Habo dome. The XRD curves of selected samples of insoluble residues have shown the presence of clay minerals like kaolinite, chlorite and illite.

The presence of kaolinite indicates a near coastal shallow sea sedimentation (Bausch,1971). Illite is the most abundant marine clay mineral. An interpretation of illite in carbonates is difficult, because a diagenetic origin cannot be ruled out. Deeper offshore depositional areas often exhibit association of illites and chlorites (Rateev et. al., 1969).

Since the changes that take place are largely chemical, the study of carbonate diagenesis has been substantiated by geochemical analyses i.e. trace element analyses and the concentrations of ratios of Stable Isotopes of Carbon ($^{13}C/^{12}C$) and Oxygen ($^{18}O/^{16}O$).

Diagenetic features as also the different stages of diagenesis observed in the thin sections are complex but can be interpreted as representing depositional and post depositional changes that took place mostly under the phreatic conditions in the marine as well as freshwater environments. The evidences also suggest diagenetic conditions in mixing marine-freshwater and burial environments.

Trace element studies assume vital importance in interpreting the diagenetic environment alongwith the study of stable isotopes of carbon and oxygen. The most significant among trace elements are strontium (Sr) and magnesium (Mg) because metastable suites from modern shallow marine environments are dominated by aragonite (Sr rich) and magnesian calcite (Mg rich). Stabilization of these shallow marine carbonates to calcite and dolomite involves a major reapportionment of these elements between the new diagenetic carbonates and the diagenetic fluids.

Strontium is taken up to maximum concentration of about 10,000 ppm in aragonite. Aragonite precipitated in warm shallow seas is likely to contain between 2500-9500 ppm of Sr. When marine sediments of aragonitic composition are transformed to calcite (low in Mg) during mineral stabilization in the near surface meteoric realm, where waters are low in Sr, it is depleted in the resulting limestone. In Jhurio formation of the study area the concentration of strontium varies from 752 ppm to 2211 ppm with average concentration of 1463 ppm, whereas in Jumara formation the concentration is low and varies from 225 ppm to 1608 ppm with an average concentration of 612 ppm. This may be because of its stratigraphic position and complete exposure to the meteoric diagenetic environment. Similar to Sr, Mg also shows a depleting trend with diagenesis. However, the trend is not significant in the case of Jhurio and Jumara Formation.

Marine carbonate sediments have very low levels of iron and manganese. Modern aragonitic sediments in tropical warm shallow-marine waters have low Mn and Fe (-20 ppm) concentration (Milliman, 1974). In Jhurio Formation, the concentration of Fe (319-5723 ppm; mean 2182 ppm) and Mn (280-984 ppm; mean 525 ppm) suggests appreciable gain of both during diagenesis. Similarly, in Jumara Formation, the concentration of Fe (480-2324 ppm; mean 1129 ppm) and Mn (389-1113 ppm; mean 682 ppm) indicates late stages of diagenesis. This increased value of Fe and Mn in the Jhurio and Jumara Formation of the study area may be due to extensive meteoric diagenesis. The higher concentration of Fe over Mn may be due to higher partition coefficient of Fe than Mn.

Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotope data have become an integral part of most modern studies of carbonate diagenesis. The oceans form a relatively well mixed carbon reservoir, so marine carbonate should typically have a $\delta^{13}C$ value around zero. The variation should be relatively minor (a few per mille) compared to the variations in non-marine waters.

Shallow marine limestones commonly show a small range of $\delta^{13}C$ values (a few $^{o}/oo$ around 0) compared to a pronounced change towards lighter $\delta^{18}O$ values (from 0 to -15 $^{o}/oo$; Hudson, 1977). This range is due to a variable mixture of original marine carbonate and diagenetic alterations and/or addition. The enrichment of ^{16}O has been equated with the diagenetic component being added at progressively higher temperature with increasing burial, with evolving $\delta^{18}O$ of the pore waters or a combination of both.

The Jhurio formation of the study area has indicated $\delta^{13}C$ value ranging from 2.11 to -2.01 with an average of 0.51, and hence represents a shallow marine environment. However, the $\delta^{18}O$ value varies from -1.9 to -11.01 with an average of -5.82. This may be due to diagenetic alterations. The isotopic data has revealed that the Jhurio formation at Jumara dome is subjected to less diagenetic alterations in comparison to that in Jhura and Habo domes. This has already been supported by microfacies analyses and insoluble residue studies.

The Jumara formation of the study area has shown the $\delta^{13}C$ value ranging from 1.99 to -9.7 with an average of -1.95, and hence represents diagenesis in marine, meteoric and burial environment. However, the $\delta^{18}O$ value varies from -1.84 to -8.62 with an average of -5.42. This may be due to diagenetic alterations/additions. The interpretation shows that the Jumara Formation at Jumara dome is subjected to less diagenetic alterations in comparison to that in Jhura and Habo domes. Besides, the impact of meteoric diagenesis is more in the Jumara formation of Jumara and Habo domes.

Knowledge regarding porosity evolution in lateral and vertical sequences of carbonate rock is essential to predict the favourable zones of potential reservoir in a sedimentary basin. The origin and types of porosity are important considerations because different environmental and diagenetic setting favour different pore formation. Different primary and secondary porosities have been identified in the study area. The primary porosity present in the study area is destroyed by effects of diagenesis. However, secondary porosity is observed within the carbonate facies of Jumara as well as Jhurio Formation. The development of this diagenetic porosity is better in the Jhurio Formation. However, the lateral variation is erratic due to variation in the intensity of meteoric diagenesis. Based on microfacies and later diagenetic studies, it can be surmized that the Jhurio Formation is a potential carbonate reservoir.

From the foregoing account, it is obvious that there exists a correlation in terms of lateral and vertical facies variations between Jumara, Jhura and Habo domes. These can be attributed to a number of factors e.g. sea level fluctuations, changes in sediment supply and sediment distribution pattern in a shallow marine environment. Under Jhurio formation the lithofacies KJ-II and KJ-III (limestone & marl and white limestone) of Jumara are correlatable with lithofacies KJH-V (bedded limestone) of Jhura and KH-I (bedded limestone) of Habo dome. The lithofacies KJ-I (coralline limestone) of Jumara is equivalent to KJH-IV (limestone & golden oolite) of Jhura dome. The other lithofacies of Jhurio formation are not exposed in Jumara and Habo domes.

The upper boundary of Jumara formation in all the three domes is represented by Dhosa oolite facies which is a marker in the entire Kutch Mainland. The facies changes are distinct. The predominant carbonate facies of Jumara dome has laterally changed to clastic facies in Jhura and Habo domes.

The different microfacies of carbonate sequences identified under both the formations can be accomodated within 7 Standard Microfacies Types of Wilson (1975) and Flugel (1972,1982). These are SMF Type 8, 9, 10, 11, 15, 16, and 24. The microfacies of Jhurio formation is represented by SMF type 8, 9, 11, 15, & 16 whereas microfacies of Jumara formation is accomodated within SMF type 9, 10, and 24 within the studied area. These standard microfacies types represent a particular set of depositional environments.

Based on above, paleoenvironmental reconstruction indicates that a major transgressive marine cycle is responsible for the deposition of Jhurio and Jumara formations. This transgressive megacycle consisted of transgressive-regressive microcycles which are correletable with the different lithofacies in a vertical column.

The depositional history began in Upper Bathonian. During this initial transgression, the sea advanced cyclically, and during stillstands, deposited interbedded shales and limestones of Jhurio formation. The Jhurio formation of Jumara dome is deposited in a subtidal open outer shelf marine environment of outer shelf whereas carbonate sequences of Jhura and Habo dome are deposited in an intertidal shallow outer shelf marine environment. Therefore, the corals of Jumara are coeval with the Limestone and golden oolite facies of Jhura dome and formed in lower bathymetry.

The sea advanced further in Lower Callovian time when shales of Jumara formation were deposited in a subtidal outer shelf environment. The subsequent regression in Upper Callovian was short and is indicated by the Ridge sandstone facies of Jhura dome and sandstone facies of Habo dome. The transgression that followed in Lower Oxfordian marks the highest stand of the sea in Kutch basin when upper Jumara shales were deposited over shoreline deposits of previous cycle in Jhura and Habo domes. This was followed by a regression in Upper Oxfordian and is marked by the deposition of silty oolitic limestone bed of Dhosa oolite facies. The unconformity above the Dhosa oolite facies marks a sharp environmental break in the vertical sequence. Huge thickness of clastics were deposited in Upper Jurassic onwards in marked contrast with the shales and carbonates of Middle Jurassic.