CHAPTER 5

COMPOSITION AND PALAEOECOLOGY OF THE FORAMINIFERAL ASSEMBLAGE

COMPOSITION OF THE FORAMINIFERAL ASSEMBLAGE

A foraminiferal assemblage comprising thirty-three species has been recovered from the Jurassic sediments exposed at Keera hill, Kachchh. The following four species are being described for the first time from Kachchh region: Reophax aff. R. suevica, Ammobaculite nanogyrus, Lenticulina ectypa, Epistomina hechti, Epistomina omninoreticulata. The foraminiferal assemblage also includes three indeterminate species one each belonging to Lenticulina, Vaginulinopsis and Epistomina which do not show resemblance to any known species of these genera. These are probably new species but more specimens are required to assign them new trivial names.

The present foraminiferal assemblage is dominated by the family Vaginulinidae, constituting 54.54% of the total fauna (Figure 5). It comprises eighteen species belonging to eight genera, i.e., Lenticulina, Sarcenaria, Astacolus, Hemirobulina, Marginulina, Vaginulinopsis, Citharina and Citharinella. The family Epistominidae is represented by seven species belonging to genus Epistomina and constituting 21.22% of the total population. Family Nodosariidae includes three species with three genera i.e. Nodosaria, Pyramidulina, and Frondicularia. Family Lituolidae is represented by two species of the genus Ammobaculites. These two families comprising 9.09% and 6.06% of the whole foraminiferal assemblage respectively. Other families in the present assemblage are Hormosinidae, Involutinidae and Spirillinidae which are represented by solitary species belonging to genera Reophax, Trocholina and Spirillina, respectively, each of them forming 3.03% of the entire foraminiferal population (Figure 6).
Figure 5: Composition of foraminiferal assemblage, Keera hill, Kachchh
Figure 6: Frequency distribution of foraminifera in the Jurassic sequence at Keera hill, Kachchh
The Keera hill assemblage also contains a few species of post-Jurassic foraminifera belonging to genera *Cibicides, Nonion, Ammonia* and *Elphidium*. These are represented by a small number of specimens, which are worn out with obliterated morphological features and frosted surfaces and with well rounded shape. On the other hand, the Jurassic foraminifera are abundant, well preserved and clearly show the morphological features.

Post-Jurassic foraminiferal elements have also been recorded by various workers on Kachchh Mesozoic. The presence of Tertiary element, e.g. *Elphidium*, in the Jurassic rocks of Kachchh has been observed by Agrawal and Singh (1960). But they did not provide any explanation for this unusual occurrence. Bhalla and Talib (1978) reported thirteen and nine post-Jurassic foraminiferal genera from Habo and Jhurio hills, Kachchh, respectively. These authors (op.cit) suggested that the post-Jurassic foraminiferal species were brought in by the westerly winds and dust storms from the western and northwestern parts of the region, where marine Tertiary sediments and Recent beach sands are well exposed, and sprayed over the Jurassic exposures. Thereafter, they impregnated the Jurassic exposures through percolating water during monsoon season and got entombed in these sediments.

As discussed earlier, the post-Jurassic foraminifera of the present assemblage show rounded outline, obliterated morphological features and abraded surfaces, these being the characters of wind-borne sediments. Hence, these are not included in the present study, as they are not considered indigenous.

**FORAMINIFERAL PALAEOECOLOGY AND PALAEOENVIRONMENT**

Foraminifers are widely known to be reliable indicators of the environment in which they live. Due to their extreme sensitiveness to the environment and abundance through major portions of the geological column, foraminifera provide valuable tool to interpret past environments at least as far back as Cretaceous (Sliter and Baker, 1972; Murray, 1991; Gebhardt, 1998) and in many cases even up to Jurassic (Barnard and Shipp, 1981; Bhalla and Abbas, 1984; Bhalla and Talib, 1991; Gebhardt, 1998;
Talib and Gaur, 2005). However, when applying Cretaceous and older foraminifera to deduce past environments, interpretations should not be based solely on comparison with modern environments and their fauna, as certain group of foraminifera have changed their environmental preferences through time. Working on ecology and palaeoecology of foraminifera, several authors (Natland, 1957; Skolnick, 1958, Phleger, 1960; Burnaby, 1962; Ager, 1963) observed that with the commencement of Palaeogene Period some groups of foraminifera have changed their habitat and caution must be observed while interpreting palaeoenvironments based on pre-Palaeogene assemblages.

Few workers (Said, 1950; Wall, 1960) consider that ecological studies should be based on individual foraminiferal species rather than genera or families as different species of a genus may thrive in a wider range of environment and, therefore, the palaeoecological interpretation based on genera and families are rather unreliable. However, it is also true that palaeoecological interpretations solely based on individual species is not reliable, especially in the pre-Cretaceous sediments because certain foraminiferal species occurring in older rocks may represent entirely different environmental conditions as compared to their modern counterparts (Phelger, 1960). However, various workers (Shipp and Murray, 1981; Bhalla and Abbas, 1984; Gebhardt, 1998; Bhalla and Talib, 1991; Nagy and Seidenkrantz, 2003; Talib and Gaur, 2005) interpreted the palaeodepositional environments of the pre-Cretaceous rocks based on foraminiferal genera and families because most of the foraminiferal species of this age do not exist in the modern time.

Jurassic foraminiferal assemblages are usually dominated by the families Vaginulinidae and Nodosariidae and both have unequivocally changed their habitat from shallow to deeper waters from Palaeogene onwards (Barnard, 1948; Bhalla and Abbas, 1978; Coleman, 1981; Bhalla and Talib, 1991; Talib and Gaur, 2005). Furthermore, extreme variation exhibited by these families creates problems in their identification and consequently in drawing paleoecological interpretations.

However, in spite of all these constraints several recently developed techniques are being successfully used to draw fairly accurate palaeoecological interpretations based
on foraminiferal assemblages. Few of the important and widely used methods are briefly discussed here.

METHODS OF PALAEOECOLOGICAL INTERPRETATIONS

The following methods are usually used in the palaeoecological studies using foraminifera:

1. Diversity Indices (Fisher–index)
2. Triangular plot of foraminiferal test structure
3. Planktic - benthic (P/B) ratio
4. Tolerance of taxa (mainly at generic level) with respect to some environmental parameters (bathymetry, temperature, salinity levels, calcium carbonate availability, dissolved oxygen levels, substrate conditions, water energy).
5. Occurrence of dominant species in relation to species diversity.
6. Morphogroups

**Diversity indices (Fisher’s α Index)**

Several diversity indices are available but the most commonly used for foraminiferal studies is Fisher’s α index which was introduced by Fisher *et al.* (1943, in Murray, 1991). It takes into account the number of species among a certain number of specimens.

\[ \alpha = n_1; x \]

where \( x \) is a constant having values < 1, \( n_1 = N(1-x) \), \( N \) being the number of individual. Low values of \( \alpha \) suggest some deviation from normal environmental parameters. However, it should be kept in mind that the species diversity in fossil assemblages could be influenced by taxonomical processes.
Triangular Plot for the Foraminiferal Test Structure

It is based on three types of foraminiferal test wall: agglutinated, porcellaneous, and hyaline, corresponding with three suborders – Textulariina, Miliolina, and Rotaliina from the Loeblich and Tappan’s (1964) classification. However, in the revised classification (Loeblich & Tappan, 1988) suborder Rotaliina is divided into four suborders – Spirillinina, Lagenina, Robertinina, and Rotaliina.

Planktic/Benthic ratio

With the increase of depth the percent abundance of planktic individuals also increases. However, there are exceptions – very wide shelves and enclosed epicontinental seas are characterized by low abundance of planktic forms despite the depth. With the approach of carbonate compensation depth (CCD – 3500-4000m) a gradual dissolution of the calcareous tests is observed, and below this planktic forms are not available.

Tau-index was introduced as bathymetrical indicator by Gibson (1988) based on data obtained from the Gulf of Mexico. It could be calculated using the formula

\[ \tau = b \cdot \% p \]

Where \( b \) is the number of benthic species, and \( p \) the number of planktic individuals in a sample. With the increase of depth the values of tau increase.

Tolerance of Taxa With Respect To Some Environmental Parameters

Particular taxa demonstrate different tolerance of depth, temperature, salinity, aeration, calcium carbonate and silica availability, water energy, and substrate conditions. Of great importance are taxa with minimal tolerance of changes in the above mentioned parameters. Data from modern assemblages, as well as data obtained during the deep sea drilling in the Atlantic, Pacific, and Indian oceans are used in the interpretation.
Occurrence of Dominant Species In Relation To Species Diversity

The strong dominance of some species in relation to low species diversity suggests deviation from the norm of some of the parameters. The absence of dominant species in relation to high species diversity indicates stable environmental parameters.

MORPHOGROUPS

Based on the external morphology, the benthic foraminiferal population can be clubbed into two coarser morphogroups namely, angular-asymmetrical and rounded-symmetrical. The distribution profiles of these morphogroups in the surface sediments apparently showed that angular-asymmetrical group is more or less abundant in deeper regions while rounded-symmetrical morphogroup tends to flourish in relatively shallower regions. Such characteristic pattern indicates depth control over the external morphology of benthic foraminifera. Therefore, if these morphogroups are studied in ancient sediments, they may show great potential in generating proxy data for palaeo-depth.

The significance of morphogroups was initially recognized by Chammy (1976), Severin (1983), Jones and Charnock (1985), and Bernhard (1986). Studies of modern and ancient foraminiferal assemblages demonstrate that the morphology of the foraminiferal test (mode of coiling, chamber arrangement, features of aperture, position of perforation) can be directly related to different life styles and trophic strategies (Corliss, 1985, 1991; Nagy, 1992; Tyszka, 1994 and others). According to Nagy (1992), the use of morphological categories in the palaeoenvironmental analyses, rather than species, is advantageous because:

1) The morphogroup approach allows reliable comparisons of assemblages. Belonging to different ages, reducing the effect of taxonomic divergences caused by biological evolution

2) Taxonomical determinations at the species level are not required

3) This approach simplifies analyses by reducing number of variables (as opposed to use of species)
Reolid et al. (2008) identified eleven morphogroups (A-K) differentiated according to test composition, general morphology, number of chambers and mode of coiling and some of them were subdivided into subgroups. Their relations to previously proposed morphological units were also outlined. The agglutinated and calcareous foraminifera were treated separately and arranged in separate morphogroup sets. Following previous interpretations, morphogroup developments were primarily attributed to lifestyle and secondly to feeding strategies. The morphogroup scheme of Reolid et al. (2008) is being followed in the present study. The morphograph scheme of the (Reolid et al. 2008) of Keera hill foraminiferal assemblage displayed in Table 2.

FOR AMINIFERAL PALAEOECOLOGY OF CHARI SEQUENCE

EXPOSED AT KEERA HILL

The Keera hill foraminiferal assemblage includes an overwhelming majority of the species belonging to the family Vaginulinidae. Only calcareous hyaline and agglutinated forms are present in the present foraminiferal assemblage. Porcellaneous species are conspicuously absent from the Keera hill foraminiferal assemblage.

A survey of relevant literature indicated that the depth distribution of vaginulinids is debatable. Some researchers (Norton, 1930, Natland, 1933; Glaessner, 1945) have suggested a moderately deep marine environment for this group while others (Barnard, 1948; Brouwer, 1969) interpreted a shallow-marine environment. However, many workers opined that this group appears to have changed its habitat from near shore shallow marine water in the Mesozoic to deep water from Palaeogene onwards but always preferring open marine environment with normal salinity (Bhalla and Abbas, 1978; Bhalla and Talib, 1980, 1991). The high percentage of vaginulinids in the Keera hill foraminiferal assemblage points towards a shallow water open marine environment, most probably the deeper parts of the shelf. As the present assemblage contains only calcareous hyaline and agglutinated species and porcellaneous forms are absent (Figure 7A), it may be inferred that the Keera hill foraminiferal assemblage was thriving in the mid and outer shelf regions with normal salinity. The high fisher index value of 12.44 for the entire assemblage provides additional support for this view, suggesting a relatively deep shelf sea, most probably in the mid to outer shelf.
region with normal salinity and oxygen level. Abundance of genus Epistomina (included in morphogroup G of Reolid et al., 2008) also points towards an outer shelf environment in the sub-tidal zone (Bernier, 1984; Meyer, 2000; Samson, 2001). Dominance of hyaline foraminifers in the Keera hill assemblage points towards normal salinity conditions, also supported by a high Fisher index value of >5 for the entire assemblage (Murray, 1991). Higher alpha index (>5) and dominance of infaunal genus Lenticulina suggests normal oxygen level, Lenticulina being the most abundant genus in the present assemblage (Figure 7B).

The Keera hill foraminiferal assemblage exhibits the dominance of morphogroups K of Reolid et al. (2008) (Figure 7C). Morphogroup K includes biconvex (lenticular), planispiral multilocular forms. This morphogroup, represented by Lenticulina is adapted to epifaunal to deep infaunal microhabitats and active deposit feeder and grazing omnivore feeding habits (Reolid et al, 2008). Diverse Lenticulina assemblages are indicative of high level of dissolved oxygen (Bernhard, 1986; Koutsoukos et al. 1990). The above discussion reveals that the foraminiferal assemblage recovered from the Chari sequence at Keera hill, Kachchh supports an open marine environment of mid to outer shelf, having normal salinity and high dissolved oxygen level.

However, in order to trace the finer and more subtle palaeoenvironmental fluctuations during the deposition of the Chari sequence of Keera hill, some of the above mentioned palaeoecological methods using foraminifera were employed. For this purpose, Fisher index (calculated using PAST software) was first applied for interpreting bathymetric changes during the deposition of the Keera hill sequence (Figure 8A). Thereafter, fisher index, agglutinated/calcareous ratio, morphogroups after Reolid et al. (2008) (Figure 8B), and dominance of certain palaeoecologically significant taxa were employed to interpret some of the palaeoecological variables including depth, salinity, and oxygen level. This facilitated in dividing the sequence into ten palaeoecological units representing fluctuations in bathymetric and palaeoenvironmental conditions during the deposition of the Chari sequence exposed at Keera hill, Kachchh. The palaeobathymetry and palaeoecology of each one of these units is discussed below in considerable detail:
Table 2: Benthic foraminiferal morphogroups (Reolid et al. 2008) in the Jurassic succession of Keera hill, Kachchh.

<table>
<thead>
<tr>
<th>MORPHOGRAM GROUP</th>
<th>TEST FORM</th>
<th>LIFE-STYLE</th>
<th>FEEDING STRATEGY</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AGGLUTINATES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Tubular and Unilocular</td>
<td>Epifaunal</td>
<td>Suspension feeders</td>
<td>NILL</td>
</tr>
<tr>
<td>B</td>
<td>Plano-convex irregular</td>
<td>Sessile epifaunal</td>
<td>Passive herbivores (suspension feeders?)</td>
<td>NILL</td>
</tr>
<tr>
<td>C1</td>
<td>Elongated uniseral</td>
<td>Shallow to Deep infaunal</td>
<td>Detrivores bacterial scavengers</td>
<td>Reophax</td>
</tr>
<tr>
<td>C2</td>
<td>Elongated uniseral,initial coiled phase</td>
<td>Shallow infaunal</td>
<td>Detrivores bacterial scavengers</td>
<td>Ammobaculites</td>
</tr>
<tr>
<td>C3</td>
<td>Elongated biserial,triserial and high trochospiral</td>
<td>Shallow to Deep infaunal</td>
<td>Detrivores bacterial scavengers</td>
<td>NILL</td>
</tr>
<tr>
<td>D</td>
<td>Rounded, globular and plano-convex planispiral to low trochospiral</td>
<td>Epifaunal</td>
<td>Active herbivores, omnivores, detrivores and bacterivores</td>
<td>NILL</td>
</tr>
<tr>
<td>E</td>
<td>Discoidal coiled(unilocular)</td>
<td>Epifaunal (phytal)</td>
<td>Active herbivores, detrivores</td>
<td>NILL</td>
</tr>
<tr>
<td>F</td>
<td>Plano-convex and meandering initial phase coiled</td>
<td>Sessile Epifaunal</td>
<td>Passive herbivores (suspension feeders?)</td>
<td>NILL</td>
</tr>
<tr>
<td>G</td>
<td>Plano-convex trochospiral</td>
<td>Epifaunal</td>
<td>Primary weed fauna grazing herbivores</td>
<td>Epistomina</td>
</tr>
<tr>
<td>H</td>
<td>Discoidal flattened(planispiral) and plano-convex(trochospiral)</td>
<td>Epifaunal</td>
<td>Primary weed fauna grazing herbivores/phytodetrivores</td>
<td>Spirillina, Trocholina</td>
</tr>
<tr>
<td><strong>CALCAREOUS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Discoidal flattened spiral, elongated</td>
<td>Epifaunal</td>
<td>Active deposit-feeders herbivores, detrivores</td>
<td>NILL</td>
</tr>
<tr>
<td>J1</td>
<td>Elongated uniseral</td>
<td>Shallow infaunal</td>
<td>Active deposit feeders, herbivores, bacterial scavengers</td>
<td>Nodosaria, Marginulina, Pyramidulina, Hemirobulina</td>
</tr>
<tr>
<td>J2</td>
<td>Elongated flattened</td>
<td>Shallow infaunal</td>
<td>Active deposit-feeders grazing omnivores</td>
<td>Frondicularia, Saracenaria, Astacolus, Vaginulinopsis, Citharina, Citharinella,</td>
</tr>
<tr>
<td>K</td>
<td>Biconvex (lenticular) planispiral</td>
<td>Epifaunal to deep infaunal</td>
<td>Active deposit-feeders, grazing omnivores</td>
<td>Lenticulina</td>
</tr>
</tbody>
</table>
Figure 7: Characters of the foraminiferal assemblage, Keera Hill, Kachchh.
Fisher Index

Figure 8: Variation in various attributes of the foraminiferal assemblage throughout Callovian-Oxfordian Sequence, Keera Hill, Kachchh.
**Palaeoecological Unit I (samples K1-1 to K1-3)**

The first palaeoecological unit of the Charhi sequence exposed at Keera Hill, Kachchh comprises lithounits K1. The maximum Fisher index value of this unit is 3.89, considerably higher than the succeeding unit, indicating deposition in relatively deep conditions within the shelf, most probably the outer shelf region. Overwhelming majority of the calcareous hyaline component suggests normal salinity conditions. Dominant morphogroup in this unit is K suggesting high dissolved oxygen level.

The Palaeoecological Unit I appear to have deposited in outer shelf region with normal salinity and high oxygen level.

---

**Palaeoecological Unit II (samples K2-1 to K3-2)**

This palaeoecological unit includes Lithounit K2 and lower portion of Lithounit K3. The Fisher index value is considerably low, maximum being 3.09, suggesting a mid shelf environment. Dominance of calcareous forms suggests normal salinity conditions and good oxygen level is indicated by dominance of morphogroup K.

The sediments belonging to Paleocological Unit II seems to have deposited in shallower shelf settings in the region of mid shelf with normal salinity and high level of dissolved oxygen.

---

**Palaeoecological Unit III (sample K3-3)**

This palaeoecological unit comprises a single sample comprising upper part of Lithounit K3. The Fisher index is highest amounting to 6.59, indicating a transgressive phase in the deepest part of the outer shelf region. Dominance of calcareous hyaline species suggests normal salinity level. A high oxygen level is suggested by high fisher index value and dominance of morphogroup K in this unit indicates good oxygen level.

Palaeoecological Unit III appears to have been deposited in the deepest part of the outer shelf with normal salinity and good oxygen level.
Palaeoecological Unit IV (sample K4-1)

This palaeoecological unit includes a single sample of the lower part of Lithounit K4. There is a substantial lowering of the Fisher index to 1.74, suggesting shallowing of the depositional site to mid-shelf region. Presence of only calcareous hyaline forms suggests normal salinity and dominance of morphogroup K indicates well oxygenated environment.

This palaeoecological unit represents a shallower shelf environment in the mid shelf region, slightly deeper than in unit II, with normal salinity and well oxygenated environment.

Palaeoecological Unit V (samples K4-2 and K5-1)

Palaeoecological Unit V encompasses the Upper part of Lithounit 4 and lower portion of Lithounit 5. The Fisher index is substantially increased than the previous unit with a maximum of 6.33, indicating deepening of the depositional basin to outer shelf region. Presence of only calcareous species suggests normal saline condition which is also supported by the high value of Fisher index. Dominance of morphogroup K suggests well oxygenated water. Palaeoecological Unit V supports a considerably deep outer shelf environment, slightly shallower than unit III, with normal salinity as well as high oxygen level.

Palaeoecological Unit VI (sample K5-2)

It includes a single sample of the upper part of Lithounit K5. The Fisher index is reduced to 2.56 suggesting a minor regressive phase in the mid shelf region. Presence of only calcareous hyaline forms suggests normal salinity. Dominance of morphogroup K supports well oxygenated environment.

The sediments of this unit are presumed to have deposited in a shallow mid shelf environment but deeper than Units II and IV, with normal salinity and high level of dissolved oxygen.
Palaeoecological Unit VII (sample K5-3)

This palaeoecological unit encloses last sample of Lithounit K5. The Fisher index is higher than the previous unit reaching a maximum of 3.67, indicating a relatively deeper environment in the outer shelf, with the water depth being nearly the same as unit I but considerably shallower than units III and V. A normal salinity is interpreted in view of the presence of only calcareous hyaline forms. Dominance of morphogroup K suggests rich oxygen level.

This palaeoecological unit is interpreted to have deposited in a relatively deeper outer shelf environment with normal salinity and rich oxygen levels.

Palaeoecological Unit VIII (sample K6-1)

This palaeoecological unit of the Chari sequence exposed at Keera hill, Kachchh includes a single sample of the lower part of Lithounit K6. It displays a lowered Fisher Index value of 2.71, indicating a shallow mid shelf environment. Presence of only calcareous hyaline forms suggests normal salinity and a well oxygenated environment is inferred in view of the dominance of morphogroup K.

This palaeoecological unit is interpreted to have deposited in the shallow mid shelf region, with water depth nearly the same as unit VI, having normal salinity and well aerated environment.

Palaeoecological Unit IX (samples K6-2 and K6-3)

It includes the last two samples of Lithounit K6 and show an increase in the Fisher index with a maximum of 3.68, indicating deposition in outer shelf. Normal salinity is interpreted in view of presence of only calcareous hyaline forms. Dominance of morphogroup K suggests well oxygenated environment.

Sediments of Palaeoecological Unit IX are interpreted to have deposited in outer shelf with water depth equal to unit VII, having normal salinity and well oxygenated water.
Palaeoecological Unit X (samples K7-1 to K8-1)

The last palaeoecological unit of the Chari sequence exposed at Keera hill includes the entire Lithounit K7 and the lowermost sample of Lithounit 8, as rest of the samples are devoid of foraminifera. The Fisher index value is substantially lowered reaching up to 0 in sample K8-1 and highest being 2.62. This is interpreted as a regressive phase in the mid shelf region. Presence of only calcareous hyaline forms suggests normal salinity whereas well oxygenated environment is interpreted due to dominance of morphogroup K.

The last phase of deposition of the Chari sequence in the studied area took place in the shallowest mid shelf environment with gradual shallowing of the basin, where salinity was normal and the water was well oxygenated.

CONCLUSIONS

In view of the above discussions it may be concluded that the foraminiferal assemblage recovered from Keera hill, Kachchh represents a shallow water open marine environment confined within mid to outer shelf region, with normal salinity and high dissolved oxygen levels. However, minor fluctuations in the depositional environment have been detected on the basis of variations in various attributes of the foraminiferal assemblage (Figure 9).

The deposition of the sediments belonging to Chari Formation commenced in the outer shelf region with normal salinity and oxygen level (Palaeoecological Unit I). This was followed by shallowing of the depositional site to mid shelf region with normal salinity conditions and high oxygen level (Palaeoecological Unit II). Then the depositional site witnessed a transgressive phase with the basin attaining maximum depth in the outer shelf region, having normal salinity and oxygen enriched environment (Palaeoecological Unit III). A regression then followed with the depositional site once again shallowing to mid shelf region, having slightly greater water depth than in unit II, the salinity being normal and oxygen level high (Palaeoecological Unit IV). Again, there was a transgressive phase with the depositional site reaching to the outer shelf region, the water depth being slightly less than unit III, having normal salinity and high oxygen level (Palaeoecological Unit V).
<table>
<thead>
<tr>
<th>For. Age</th>
<th>Litho-unit</th>
<th>Sample number</th>
<th>Litholog</th>
<th>Alpha index</th>
<th>Test composition</th>
<th>Dominant Morphogroup</th>
<th>Salinity</th>
<th>Oxygen Level</th>
<th>Bathymetry</th>
<th>Shelf Zone</th>
<th>Outer Shelf</th>
<th>Palaeoecological Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>K9</td>
<td></td>
<td></td>
<td>2.62</td>
<td>100</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K8</td>
<td></td>
<td></td>
<td>3.68</td>
<td>100</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>IX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K7</td>
<td></td>
<td></td>
<td>2.71</td>
<td>100</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>VIII</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K6</td>
<td></td>
<td></td>
<td>3.67</td>
<td>100</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>VII</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K5</td>
<td></td>
<td></td>
<td>2.56</td>
<td>100</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>VI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K4</td>
<td></td>
<td></td>
<td>6.33</td>
<td>100</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K3</td>
<td></td>
<td></td>
<td>1.74</td>
<td>100</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>IV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K2</td>
<td></td>
<td></td>
<td>6.59</td>
<td>93.33</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K1</td>
<td></td>
<td></td>
<td>3.09</td>
<td>90</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.98</td>
<td>91.66</td>
<td>K</td>
<td>Normal</td>
<td>High</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9. Main faunal parameters and inferred depositional environment of Callovian-Oxfordian sequence, Keera hill, Kachchh
This was followed by another transgressive phase with the depositional site reaching into the shallower parts of the mid shelf region, but considerably deeper than in units II and IV, having normal salinity and high level of dissolved oxygen (Palaeoecological Unit VI). Another minor transgressive phase was then detected with the depositional site reaching to outer shelf region with the water depth being considerably shallower than units III and V but about equal to unit I, having normal salinity and well oxygenated water (Palaeoecological Unit VII). This was followed by a minor regressive phase in the mid shelf region with the water depth about equal to unit VI, where salinity was normal and oxygen level high (Palaeoecological Unit VIII). The depositional basin, once again, deepened slightly reaching the outer shelf and the water depth being about equal to unit VII, with normal salinity and rich oxygen level (Palaeoecological Unit IX). The final phase of deposition of the Chari sequence in the Keera area took place in the mid shelf region with constant shallowing of the basin where salinity was normal and water was well oxygenated (Palaeoecological Unit X).

Although the deposition of the present sequence occurred in an open shallow marine environment confined to mid and outer shelf regions with normal salinity and high levels of dissolved oxygen, a number of minor transgressive and regressive events were detected as indicated by the frequent fluctuations in the water depth and migration of the strandline. This suggests that depositional basin was rather tectonically unstable with frequently fluctuating shoreline. However, the salinity was normal and the dissolved oxygen level remained high throughout the deposition of the studied sequence at Keera hill, Kachchh.