Bathymetric preference of four major genera of rectilinear benthic foraminifera within oxygen minimum zone in Arabian Sea off central west coast of India

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Fifty two surface sediment samples collected from the region off Goa, central west coast of India from water depths of 15–3300 m were analyzed with special emphasis on foraminiferal content. Rectilinear benthic foraminiferal morphogroup shows a high relative abundance within Oxygen Minimum Zone (OMZ), both shallow marine (50–60 m water depth) and intermediate to deep water (150–1500 m water depth). We gave special emphasis on four rectilinear foraminiferal genera, namely *Fursenkoina*, *Bolivina*, *Bulimina* and *Uvigerina* to observe their individual distribution among OMZ. We found genus *Fursenkoina* predominates at the shallow water OMZ, within the water depth zone of 50–60 m. Within 150–1500 m water depth, which is considered as intermediate to deep water OMZ in this region, genus *Uvigerina* shows its highest abundance above 1000 m water depth, whereas genus *Bulimina* shows its affinity with deeper water environment (>1000 m water depth). Genus *Bolivina* does not show any such depth preference, except its higher abundance in only intermediate to deep water OMZ. This depth differentiation among four rectilinear benthic foraminiferal genera presents the basic data for palaeoclimatic study based on the extent and intensity of OMZ along with the palaeobathymetry study.

1. Introduction

The formation of a stable mid-water (150–1400 m) Oxygen Minimum Zone (OMZ) in the Arabian Sea is the product of both the high primary productivity and a pronounced thermohaline stratification (Wyrtki 1973; Olson *et al.* 1993; You and Tomczak 1993; Helly and Levin 2004). The oxygen concentrations within this OMZ exhibit a range below 0.5 ml/l (Levin 2003) or less than 50 μmol/l (Fuenzalida *et al.* 2009). Oxygen consumption by decay of organic matter, supply of less oxygenated intermediate water-masses from the south and west (Swallow 1984; Olson *et al.* 1993) and the semi-enclosure morphology of the northern Arabian Sea (Wyrtki 1973; Shetye *et al.* 1994) are the main factors responsible for this low oxygen concentration. Apart from this OMZ, a shallow water oxygen depleted zone (∼50–60 m) has been reported from different parts of world (Turner and Rabalais 1994; Sen Gupta *et al.* 1996; Malakoff 1998; Rabalais 2000; Osterman 2003), including eastern Arabian Sea (Naqvi *et al.* 2000). The level of oxygen concentration of this shallow water OMZ is much less than (<5 μmol/l) the conventional deep water OMZ (Donoso and Escribano 2013).

Benthic foraminifera have long been used as a very valuable tool to reconstruct paleoceanographic characters (Gooday 2003), including paleo-oxygenation (Kaiho 1994; Bernhard *et al.* 1997;

Keywords. *Fursenkoina*; *Bolivina*; *Bulimina*; *Uvigerina*; Oxygen minimum zone; Arabian Sea.

Jorissen 1999; Den Dulk *et al.* 2000; Gooday 2003). It was seen earlier that the faunal diversity and density of benthic foraminifera have a general dependency on the oxygenation of bottom- and sediment pore-water (Jorissen *et al.* 1995; Fontanier *et al.* 2002).

Higher percentage in abundance of certain benthic foraminifera groups, *viz.*, the species under the genus *Bolivina*, in oxygen-depleted environments have been reported (Phleger and Soutar 1973; Mackensen and Douglas 1989; Bernhard 1993; Sen Gupta and Machain-Castillo 1993; Alve 1994, 1995; Bernhard *et al.* 1997; Jorissen *et al.* 1998; Bernhard and Sen Gupta 1999; Gooday *et al.* 2000; Fontanier *et al.* 2002). Another rectilinear benthic foraminiferal genus *Uvigerina* has also widely been used for palaeoenvironmental and palaeoceanographic studies (Boersma 1984; Lutze 1986; Raju and Dave 1996; Cannariato *et al.* 1999; Asioli *et al.* 2001; Lokho *et al.* 2004; Schweizer *et al.* 2008). Bandy (1960) correlated the test morphology of uvigerinids and bathymetry. Spencer (1992) studied 12 benthic foraminifera species, including two species of *Bolivina* and a single species of *Uvigerina*, with the bathymetrical variation from the northern Gulf of Mexico. But there is no attempt to correlate the total population of any important genus of rectilinear foraminifera with the change of bathymetry within oxygen-depleted zone. However, several other reports indicated that some rectilinear forms of benthic foraminifera, *viz., Bolivina, Fursenkoina, Uvigerina, Bulimina, Buliminella, Stainforthia, Brizalina, Loxostomum,* etc., are the most abundant genera present in hypoxic regions (Kaiho 1994; Bernhard and Sen Gupta 1999).

In eastern Arabian Sea region, composition and abundance of benthic foraminifera were studied with respect to changes of oxygen concentration (Den Dulk *et al.* 2000; Nigam *et al.* 2007, 2009; Schumacher *et al.* 2007). Nigam *et al.* (2007) reported the abundance (>40%) of a rectilinear morphogroup among benthic foraminifera within OMZ of central eastern Arabian Sea. Mazumder *et al.* (2003) reported the noticeable abundance of *Bulimina costata* within OMZ. But no major attempt has yet been made to demark the generic importance to delineate the presence of both OMZs in Arabian Sea region.

The main objective of the present paper is to observe and compare the spatial variation of a few important genera of rectilinear benthic foraminifera between the shallow- and deep-water OMZ off central west coast of India to define the generic importance in detecting the characterization of oxygen-depleted environment in accordance to the bathymetric depth of ocean.

2. Materials and methods

During the cruise of *ORV Sagar Kanya* (SK-117), 52 sediment samples were collected by Spade Corer from the region off Goa (Vijaydurg to Bhatkal) of central west coast of India from water depths of 15–3300 m, which were used for this study (figure 1). Sediment samples of 0–2 cm each was processed through 63 μm sieve after treating with Sodium Hexa-metaphosphate and Hydrogen Peroxide to remove the clayey particles and organic matters, respectively. Total (non-stained) benthic foraminifera were picked from the +63 μm (sand) fraction of each sample. A minimum of 300 specimens of benthic foraminifera were picked, identified up to species level and counted with respect to total benthic foraminifera population. The samples were labelled and preserved at the National Institute of Oceanography, Goa repository. The presence of agglutinated benthic foraminifera species confirm that the used samples are of recent age.

Special emphasis was placed on rectilinear benthic foraminifera, a particular morphological form of benthic foraminifera reported as indicator of OMZ in Arabian Sea region (Nigam *et al.* 2007). Within this group, we gave more importance to four important genera which show high abundance; namely, *Bolivina*, *Bulimina*, *Fursenkoina* and *Uvigerina*. The relative percentages of these four genera among the total rectilinear benthic foraminifera were plotted against the depth profile of the study area (figure 2).

3. Result

In the present study, we found 21 species of *Bolivina* (+*Brizalina* +*Bolivinella* +*Bolivinita*), 8 species of *Bulimina* (+*Buliminella*), 18 species of *Uvigerina* (+*Euuvigerina* +*Neouvigerina* +*Siphouvigerina*) and 9 species of *Fursenkoina* (+*Virgulina* +*Virgulinella* +*Stainforthia*), among 423 species of foraminifera under 163 genera (table 1). Relative abundance of all species under these four major groups of genera of rectilinear foraminifera shows distinct characters with respect to OMZ (figure 2). Genus *Uvigerina* shows a relative abundance >10% among all rectilinear groups within the intermediate OMZ up to ∼1000 m water depth. On the contrary, genus *Bulimina* shows a higher percentage (>20%) within intermediate OMZ but below ∼1000 m water depth. Genus *Bolivina*, however, shows its peak in abundance with >20% within and around the intermediate OMZ. On the other hand, genus *Fursenkoina* shows a distinct peak (>60% abundance among all rectilinear forms) within the shallow water oxygen-depleted zone. From this

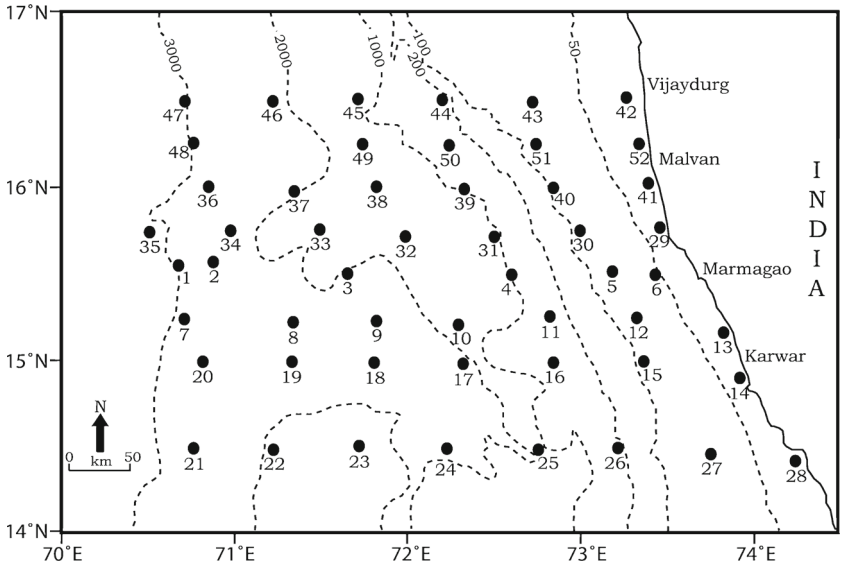

Figure 1. Location of 52 surface sediment samples from eastern Arabian Sea used for the present study.

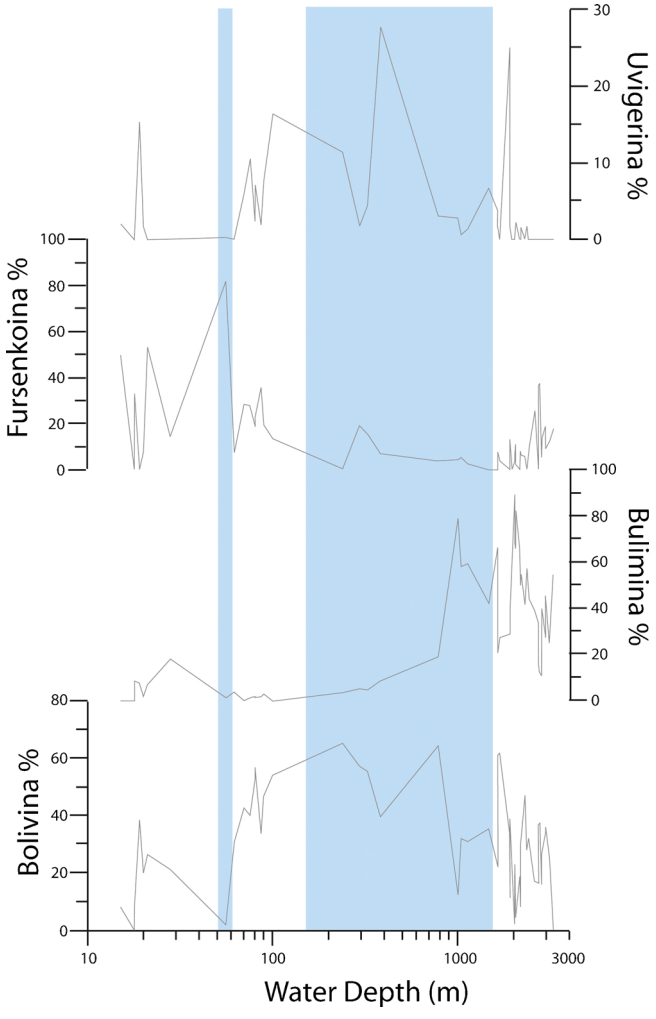

Figure 2. Surface abundance of genera *Uvigerina*, *Fursenkoina*, *Bulimina* and *Bolivina*. The shaded areas show the depth of OMZ (shallow and intermediate-deep water).

result, it is postulated that among rectilinear forms of benthic foraminifera, the abundance of genus *Fursenkoina* is triggered by less oxygen concentration in the shallow water environments (50–60 m water depth). On the other hand, the genera *Bolivina*, *Uvigerina* and *Bulimina* show their high abundance within the intermediate OMZ, but *Uvigerina* is abundant above ∼1000 m water depth, whereas *Bulimina* is predominated below ∼1000 m water depth.

4. Discussion

Regions of less oxygen concentration in different parts of world oceans have been reported and studied in different aspects (Wyrtki 1962; Sen Gupta *et al.* 1980; Turner and Rabalais 1994; Osterman 2003). Low oxygenated water with the concentration of oxygen <0.5 ml/l predominates in the water depths of ∼100 m to ∼1000–∼1250 m worldwide (Stackelberg 1972; Sen Gupta *et al.* 1976; Naqvi 1994; Levin *et al.* 2000). Moreover, Turner and Rabalais (1994), Malakoff (1998) and Rabalais (2000) reported the presence of shallow water oxygen depleted zone with the oxygen concentration of <5 µmol/l (Donoso and Escribano 2013). Similar type of shallow water oxygen depletion was recorded along central west coast of India (Sen Gupta and Naqvi 1984; Naqvi *et al.* 2000). Nigam *et al.* (2007) proposed the relative abundance of rectilinear morphogroups of benthic foraminifera as a good indicator for oxygen depleted zone in both shallow (50–60 m water depth) and intermediate water depths (90–1200 m water depth).

The abundance of genus *Uvigerina* is reportedly dependant on water depth (Schnitker 1979;

Table 1. *List of rectilinear foraminifera grouped under four major genera.*

Sl. no.	Name of the genus	Name of the species	Genus clan
1	*Bolivina*	*B. dilatata*	*Bolivina*
2		*B. doniezi*	
3		*B. cf. B. inflata*	
4		*B. kuriani*	
5		*B. lowmani*	
6		*B. marginata*	
7		*B. cf. B. oceanica*	
8		*B. ordinaria*	
9		*B. cf. B. pacifica*	
10		*B. persiensis*	
11		*B. pseudoplicata*	
12		*B. robusta*	
13		*B. seminuda*	
14		*B. silvestrina*	
15		*B. spinata*	
16		*B. spinescens*	
17		*B. variabilis*	
18		*Bolivina* sp.	
19	*Brizalina*	*B. difformis*	
20	*Bolivinella*	*B. elegans*	
21	*Bolivinita*	*B. quadrilatera*	
22	*Bulimina*	*B. aculeata*	*Bulimina*
23		*B. alazanensis*	
24		*B. biserialis*	
25		*B. exilis*	
26		*B. gibba*	
27		*B. marginata*	
28		*B. mexicana*	
29	*Buliminella*	*B. cf. B. milletti*	
30	*Euuvigerina*	*E. aculeata*	*Uvigerina*
31	*Neouvigerina*	*N ampullacea*	
32		*N. interrupta*	
33	*Siphouvigerina*	*S. porrecta*	
34	*Uvigerina*	*U. asperula*	
35		*U. cf. U. auberiana*	
36		*U. bassensis*	
37		*U. bifurcata*	
38		*U. brunensis*	
39		*U. canariensis*	
40		*U. hollicki*	
41		*U. mediterranea*	
42		*U. peregrina*	
43		*U. proboscidea*	
44		*U. vadescens*	
45		*U. schwageri*	
46		*Uvigerina sp. A*	
47		*Uvigerina sp. B*	
48	*Fursenkoina*	*F. bradyi*	*Fursenkoina*
49		*F. complanata*	
50		*F. pontoni*	
51		*F. cf. F. schreibersiana*	
52		*F. texturata*	
53	*Virgulina*	*V. aff. V. badensis*	
54		*V. cf. V. hemitemma*	
55	*Virgulinella*	*V. pertusa*	
56	*Stainforthia*	*S. concava*	

Streeter and Lavery 1982; Caralp 1987). For example, one species of *Uvigerina*, *U. semiornata* was reported abundantly from the water depth of 233 m at the Indo-Pakistan Continental Margin (Maas 2000) and *U. phlegeri* along with *U. peregrina* was reported at the water depth of 500 m off Karachi region (Jannink *et al.* 1998). *U. peregrina* shows abundance below 500 m water depth, both in the northwestern (Hermelin and Shimmield 1990) and in the northeastern part (Jannink *et al.* 1998; Maas 2000). Jannink *et al.* (1998) surmised that the particular depth zone of maximum abundance of *U. peregrina* is within 1000 to 1254 m water depth in northeastern Arabian Sea. *U. semiornata* was reported to decrease significantly with water depth after 500 m (Schumacher *et al.* 2007). This genus was also reported with high percentage from the oxygen depleted areas. Two species of *Uvigerina*, namely, *U. auberiana* and *U. peregrina* show their dominance in the upper to uppermost lower continental slope area (Szarek *et al.* 2009), *i.e.,* less oxygenated conditions (Jian *et al.* 1999; Kuhnt *et al.* 1999). In Atlantic Ocean sediment cores, high abundance of *U. peregrina* has been reported during the Last Glacial (Lutze 1986; Caralp 1987), which can be attributed to the presence of less oxygen deep-water (Streeter and Shackleton 1979; Caralp 1987). *U. peregrina* was reported in moderately oxygen-depleted areas, e.g., off California (Bernhard 1992) and in the Angola Basin (Van Leeuwen 1989). *U. auberiana* is among the few most important species reported from the OMZ of Sunda Shelf, South China Sea (Szarek *et al.* 2009). But, surprisingly, species of *Uvigerina* are comparatively rare in most previously described faunas from less oxygen water from other parts of the world, than in the Arabian Sea OMZ (Schumacher *et al.* 2007). In our study area, the genus *Uvigerina* shows the higher percentage (>10% among all rectilinear) within the bathymetric depth of ~100 m to ~1000 m, which is in concordance with both the bathymetric restriction for this genus

and characteristic effect of lower concentration of oxygen. However, the important finding of the present study is that *Uvigerina* is mainly restricted within ∼1000 m water depth, except for a single location below 1000 m. So the presence of this genus, irrespective of its species constituents, demarcates the oxygen-depleted water mass with a depth restriction of 100–1000 m.

Bolivina dilatata has been reported from the northeastern Arabian Sea at 230 m (Maas 2000) and 550 m water depth (Jannink *et al.* 1998), and *B. seminuda* from Oman margin at 412 m (Gooday *et al.* 2000). Jannink *et al.* (1998) reported that *B. dilatata* and *B. exilis* were dominant around 500 m in northeastern Arabian Sea. *Bulimina exilis* was reported as an important component within the water depth of 306–738 m off Pakistan region (Schumacher *et al.* 2007). Hermelin and Shimmield (1990) noted that the upper bathyal (440–640 m) assemblages were predominated by higher population of species under *Bulimina* and *Bolivina*. In Santa Catalina basin oxygen depleted zone, *Bolivina spissa* was reported to be one of the predominant species (Mackensen and Douglas 1989), while in the Santa Barbara basin oxygen depleted zone, *Bolivina seminuda*, *B. argentea* and *Bulimina tenuata* are a few common taxa (Bernhard *et al.* 1997). Sen Gupta and Machain-Castillo (1993) reported small thin-shelled forms of *Bolivina* and *Bolivina*-like species from the southern East Pacific margin OMZ. Szarek *et al.* (2009) reported abundant *Bolivina robusta* from the OMZ of Sunda Shelf, South China Sea. *Bolivina decussate* is one of the important species found within the OMZ from northern Japan (Shibahara *et al.* 2007). In the present study, genus *Bolivina* shows its higher abundance between ∼70 and ∼1500 m, which overlaps the intermediate OMZ in this region. Therefore, *Bolivina* can be considered as a very good indicator of intermediate oxygen depleted zone in the study area. On the other hand, *Bulimina* shows its peak highest abundance from ∼800 to ∼2000 m water depth. In this case, genus *Bulimina* shows a tendency to flourish within less oxygenated water, towards a greater water depth. Hence, *Bolivina* can be used to detect the total range of intermediate to deep water OMZ, while *Bulimina* can show its restriction to only deeper part of OMZ (>1000 m).

Shibahara *et al.* (2007) reported two species of *Fursenkoina*, namely *F. cornuta* and *F. rotundata* which are characteristic forms of benthic foraminifera of suboxic condition in northeastern Japan. *Fursenkoina fusiformis* is reported as the marker for an increased supply of organic matter which indicates the transition from the glacial to the interglacial periods (Ventura *et al.* 2010). The increased supply of organic matter is one of the causes for low oxygen levels in OMZ (Sarma 2002). *Angulogerina angulosa*, *Bolivina costata*, *B. interjuncta*, *B. plicata*, *B. seminuda*, *Bolivinita minuta*, *Cancris carmenensis*, *Fursenkoina fusiformis*, *Nonionella stella*, *Uvigerina peregrine* and *Valvulineria glabra* are very common species in the OMZ off Peru (Mallon *et al.* 2012). In the present study, the genus *Fursenkoina* shows a high abundance (>60% among all rectilinear forms) within the shallow water depth, especially within 50–60 m water depth. As *Furenkoina* is reported from the less oxygenated water from different parts of world, it can be postulated that the water depth zone of 50–60 m shows suboxic condition of water where the *Fursenkoina* shows the maximum abundance over other rectilinear forms. Hence, the genus *Fursenkoina* can be used to establish the correlation between the foraminiferal generic abundance with the least oxygenated water (<5 μmol/l oxygen concentration) in oceanic setting, *i.e.*, shallow water OMZ (50–60 m).

5. Conclusion

The four rectilinear benthic foraminiferal genera, namely *Bolivina*, *Bulimina*, *Uvigerina* and *Fursenkoina* are found to be abundant in the Oxygen Minimum Zone in central part of east Arabian Sea. On the basis of the relative percentage of these genera, their abundance can be distributed within different parts of the OMZ in the study area. *Fursenkoina* shows its highest abundance in shallow marine OMZ (50–60 m water depth). On the other hand, the genus *Bolivina* dominates in intermediate to deep water OMZ (150–1500 m water depth). *Uvigerina* predominates the intermediate water OMZ (150–1000 m water depth), whereas *Bulimina* shows its predominance in deep water OMZ (1000–1500 m water depth). The depth preference of these four genera within the OMZ in the study area is very distinctive for distinguishing the depth range within OMZ in eastern Arabian Sea. This characteristic of depth preference by benthic foraminiferal genera can be well applicable for palaeoclimatic study with a special reference to the bathymetric change of OMZ in the past.

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