tron microscopy reveals the accumulation of electron-dense metals within the cells, thus confirming their metal-accumulating ability (Figure 5). Molecular characterizations of the isolates are currently underway [GenBank DQ256262 – DQ256264].

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Do gas seepage sites support distinct macrofaunal community? – an observation in the tropical shelf region of Goa, Arabian Sea, India

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We examined the macrofaunal community in the shelf region (depth 15–50 m) of Goa, Arabian Sea, India, at seven sites in the gas seep and seven sites in non-seep areas during March 2005. A total of 56 species were recorded, among which 21 were found in the seep sites, 12 in the non-seep sites and 23 species were common. The faunal community differed between these two areas and community indices were relatively higher in seep sites, whereas the population density was higher in non-seep sites. Such difference is largely due to relatively high organic carbon and clay content in the seep sites. Polychaetes, *Heteromastus similis*, *Pulliella armata* and *Capitella capitata* belonging to family Capitellidae, were found only at all the seep sites and can be considered as good indicator species.

Keywords: Goa coast, indicator species, macrofauna, seep areas.

DISCOVERIES of gas seepage areas and hydrothermal vents in the ocean floor and the associated fauna have fascinated marine biologists all over the world due to the unique

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characteristics of temperature and pressure difference and high organic carbon and sulphide from the nearby ambient environment[1–4]. Numerous studies have been carried out to document this unique ecosystem[3]. One of the recent findings is clustering of polychaete worms, *Hesiocaeca methanicola* in the methane seep area in the Gulf of Maxico[4]. Such studies are limited only to the region of eastern and western Pacific Ocean, Atlantic Ocean and Mediterranean Sea. Some of the investigations show varied results of benthic community that differ with taxon and geographical location[3]. Though considerable work has been carried out on macro benthos of shelf region of the Indian coast[5–8], no information is available on gas seep areas, except that of Levin *et al.*[9,10] in the Indian Ocean region. In view of this, we undertook an investigation to examine the macrofauna between seep and non-seep areas, identify indicator species and compare the results with the other geographical regions. Such information on benthic fauna may facilitate in the assessment of the environmental impact due to human perturbation, such as hydrocarbon exploitation.

A total of 42 macrobenthic samples were collected onboard FRV *Sagar Sukti*, in triplicate, during the SASU cruise-89 at seven seep and seven in non-seep sites (Figure 1) with plastic cores (15 cm diameter, 20 cm deep), by operating van Veen grab up to penetration of 15–20 cm (0.04 m^2) during March 2005. The seep and non-seep areas were identified earlier from high-resolution shallow seismic surveys[11]. The samples were washed separately through 0.5 mm nylon bags at sea, transferred to plastic containers and preserved in 5% formalin in sea water containing rose Bengal stain. Later, the fauna were identified to species level using microscope in the laboratory and available keys for the Indian coast. Numerical abundance of each species was recorded under stereo zoom microscope and population density converted into nm^2. Separate sediment samples were also collected and analysed in triplicate for sediment organic carbon[12], and grain size-analyses by wet pipette method[13]. Depth was also recorded at each site.

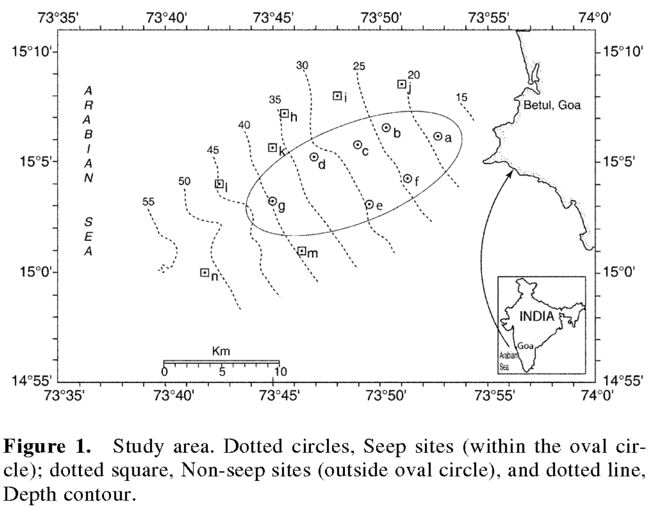

Figure 1. Study area. Dotted circles, Seep sites (within the oval circle); dotted square, Non-seep sites (outside oval circle), and dotted line, Depth contour.

The benthic community indices which reflect the ecological and environmental status, were calculated in terms of number of species (*S*), total abundance (*A*), Margalef species richness (*d*), Pielou's eveness (*J′*), Shannon index (*H′*) using $\log_2$ scale and Simpson index $(1 - \lambda')$ at each site. Site versus species presence/absence matrix was arranged and multidimensional scaling (MDS) plots were drawn to discriminate the sites between the seep and non-seep areas. These analyses were carried out using the Primer software[14]. Species rank abundance for two most abundant species was arranged in order of numerical abundance[15] to understand dominant and co-dominant species in the study area. Species that were dominant and occurred at all the seep sites were considered as indicator species.

The depth varied between 15 and 50 m. Sediment texture was largely silty clay in seep sites, whereas it was a mixture of sand, silt and clay in non-seep sites (Table 1). Similarly, organic carbon varied between 1 and 2.28 and average value was relatively higher at the seep sites (Table 1).

A total of 56 macrofauna were recorded belonging to polychaetes, crustacea and molluscs, of which 21 were found in seep sites, 12 in non-seep sites and 23 were common to both sites (Table 2). Dominant and co-dominant species varied from site to site (Table 3). Dominant species included *Heteromastus similis*, *Pulliella armata* and *Capitella capitata* in seep sites, and *Prionospio cirrifera* and *Aricidea assimilis* in non-seep sites, which were also common for both sites (Table 3). Distribution of indicator species (Figure 2) in seep sites showed consistent density at all the sites, except at site b due to high abundance of *P. armata*. Community indices varied between the seep and non-seep sites and the average values were higher in

Table 1. Sediment texture and organic carbon (OC)

Sites	Sand (%)	Silt (%)	Clay (%)	Texture	OC (%)
Seep sites					
a	6.3	34.6	59	Silty clay	2.28
b	2.19	35.5	62	Silty clay	2.27
c	2.4	35.6	61.9	Silty clay	2
d	5.5	41.5	53	Silty clay	1.7
e	5.74	37.85	56.4	Silty clay	1.9
f	12	33	55	Silty clay	1.9
g	12	43	45	Clayey silt	2.1
Average	6.59	37.29	56.04		2
Non-seep sites					
h	6.6	38.8	54	Silty clay	1.22
i	15	42	43	Clayey silt	1.24
j	11	47	42	Clayey silt	1.24
k	25	37	38	Sand silt clay	1.19
l	8.8	42.5	48.7	Silty clay	1.16
m	16	36	48	Silty clay	1.00
n	22	45	33	Sand silt clay	1.9
Average	14.91	41.18	43.81		1.2

Table 2. Occurrence of macro-benthic species

Seep site	Non-seep site	Both sites
Polychaeta	Polychaeta	Polychaeta
Heteromastus similis	*Cirratulus filiformis*	*Lumbriconereis latreilli*
Lumbriconereis bifilaris	*Aricidea fragilis*	*Cossura coasta*
Goniada incerta	*Levinsenia* sp. B	*Ancistrosyllis constricta*
Pulliella armata	Oligochaeta	*Prionospio pinnata*
Petaloproctus terricola	Amphipoda	*Prionospio cirrifera*
Glycinde oligodon	*Ampelisca* sp.	*Nephthys polybranchia*
Levinsenia kirbyae	*Grandidierella* sp.	*Mediomastus capensis*
Flabelligera diplochaitos	*Paracalliope* sp.	*Aricidea assimilis*
Ninoe bruuni	*Listriella* sp.	*Glycera alba*
Paralacydonia weberi	Decapoda	*Aricidea hartleyi*
Nephthys oligobranchia	*Squilla nepa*	*Magelona rosea*
Notomastus sp. A	Isopoda	*Lumbriconereis simplex*
Clymene sp.	*Cyathura* sp.	*Magelona capensis*
Goniada sp. A	Bivalvia	*Notomastus* sp. B
Aricidea sp. A	*Mactra cuneata*	*Aricidea* sp. B
Capitella capitata	Hydrozoa	Amphipoda
Nereis sp. A	*Sertularia* sp.	*Melita* sp.
Levinsenia sp. A		*Paracalliope indica*
Heteromastus sp.		Decapoda
Harpacticoida		*Portunus sanguinolentus*
Scottolana sp.		*Metapeneaus dobsoni*
Cumacea		Minor group
Paradiastylis sp.		*Thalassema* sp.
		Dendrostomum sp.
		Nemertea sp.
		Pisces
		Bregmaceros mcClellandi

Table 3. Population density (nm^2) and species rank abundance for two most abundant species (in parentheses)

Seep sites	a	b	c	d	e	f	g
Species							
Heteromastus similis	100(1)	–	–	–	–	–	–
Clymene sp.	75(2)	–	–	–	–	–	–
Pulliella armata	–	275(1)	–	–	–	–	–
Cossura coasta	–	100(2)	–	–	–	–	–
Aricidea assimilis	–	–	200(1)	–	–	–	–
Capitella capitata	–	–	125(2)	–	–	150(1)	–
Prionospio cirrifera	–	–	–	600(1)	775(1)	–	375(1)
Prionospio pinnata	–	–	–	250(2)	275(2)	–	–
Ancistrosyllis constricta	–	–	–	–	–	100(2)	–
Aricidea sp. B	–	–	–	–	–	–	175(2)
Non-seep sites	**h**	**I**	**j**	**k**	**l**	**m**	**n**
Species							
Prionospio cirrifera	1500(1)	950(1)	700(1)	375(1)	375(1)	–	100(1)
Prionospio pinnata	350(2)		400(2)	175(2)	250(2)	175(2)	100(2)
Cossura coasta	–	125(2)	–	–	–	–	–
Aricidea assimilis	–	–	–	–	–	275(1)	–

the seep sites, except population density (Table 4). Average population density was higher in non-seep sites and *P. cirrifera* was dense compared to other species at different sites (Tables 3 and 4). MDS analyses of macrofauna showed distinct assemblages of fauna between the seep and non-seep areas, except at site 'a' due to the presence of *Notomastus* sp. A and *Clymene* sp. only at this site (Figure 3). Such difference is largely due to relatively high organic carbon and clay contents in seep sites (Table 1).

Earlier studies at seep and non-seep areas indicated varied macrofaunal communities at different geographical locations, which has been reviewed by Sibuet and Olu[3].

Some locations show specialized fauna, whereas others show no substantial difference[3]. Usually, reduced macrofaunal diversity occurs in seep sites due to physiological stress environment[16]. Presence of the specialized fauna could not be observed, perhaps due to the non-stressed environment. Our observation indicates higher species diversity in the seep sites and they differed from the non-seep sites, which is in agreement with the observation of northern California continental shelf[10]. Similarly, dominance of polychaetes *H. similis*, *C. capitata* and *P. armata* belonging to the family Capitallidae, in seep sites, was similar to the observation of Thiermann *et al.*[17] and Gamenick *et al.*[18,19], which is largely due to high organic carbon and sulphide tolerance species. Absence of many amphipoda species in seep sites (Table 2), is in agreement with earlier findings[20], likely due to sensitivity to sulphide. It has been reported that dominance of species varies at different geographical locations[3]. Environmental properties such as flow, particle size or localized terrestrial input coupled with high organic input from seep sites appear to influence benthic communities around the seep area in the shelf region of Goa.

Table 4. Benthic community indices in seep and non-seep sites

Seep sites	*S*	*N*	*d*	*J′*	*H′*	1 – λ′
a	7	375	1.01	0.92	1.8	0.81
b	19	1150	2.55	0.85	2.52	0.88
c	17	1075	2.29	0.9	2.56	0.9
d	25	2200	3.11	0.84	2.71	0.89
e	23	2050	2.88	0.75	2.35	0.82
f	17	850	2.37	0.92	2.63	0.91
g	15	1400	1.93	0.84	2.29	0.86
Average	17.57	1300	2.30	0.86	2.40	0.86
± SD	5.85	647.27	0.06	0.06	0.30	0.03
Non-seep sites						
h	16	3050	1.86	0.68	1.89	0.72
i	16	1675	2.02	0.63	1.77	0.66
j	17	2300	2.06	0.78	2.23	0.84
k	14	1050	1.86	0.8	2.12	0.81
l	13	1350	1.66	0.84	2.15	0.84
m	25	1575	3.25	0.91	2.92	0.92
n	9	400	1.33	0.9	1.99	0.83
Average	15.71	1628.6	2.00	0.79	2.15	0.80
± SD	4.88	856.16	0.60	0.10	0.37	0.08

S, Total number of species; N, Total population density nm^2; *d*, Species richness (Margalef), *J′*, Pielou's evenness; *H′*, Shannon index, 1 – λ′, Simpson index.

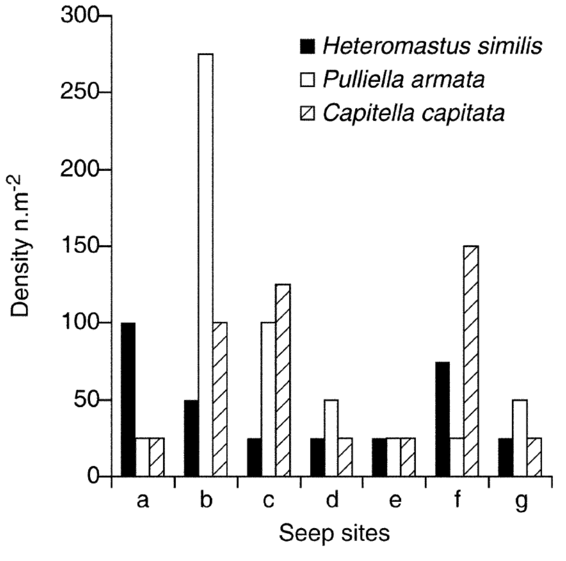

Figure 2. Distribution of indicator species ($n.m^2$) in seep sites.

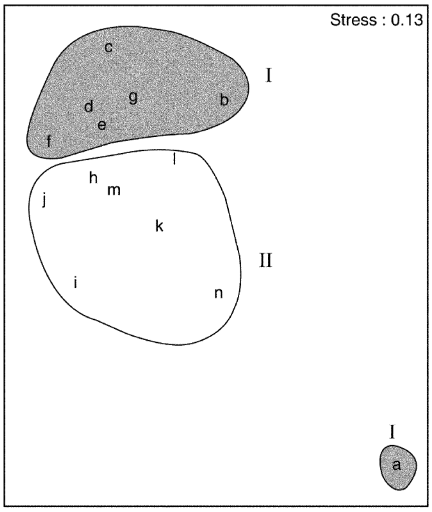

Figure 3. MDS plot for seep (I-shaded) and non-seep (II) sites.

Information on macrofaunal density and community indices showed difference between seep and non-seep sites. *H. similis*, *C. capitata* and *P. armata* can be considered as good indicator species due to their dominance in the seep sites. More systematic studies are required to establish such indicator species in seep areas in the shelf of the Indian coast.

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Record of *Metagoniolithon* (Corallinales, Rhodophyta) from the Burdigalian of western India

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Well-preserved *Metagoniolithon* (Corallinales, Rhodophyta) identified as *Metagoniolithon* sp. has been recovered in thin sections of limestone of the Burdigalian age, the Chhasra Formation, India. By its small size, *Metagoniolithon* sp. differs from *M. radiatum* (Lamarck) Ducker, a living species. *Metagoniolithon* sp. is associated with rich dasycladacean algae, and this points out that the species was thriving in shallow, warm, tropical environments. The present fossil discovery of *Metagoniolithon* sp. is significant, as prior to this, two species of *Metagoniolithon* were dubiously documented from the Oligocene and the Aquitanian of Cuba. The present finding of the fossil representative of *Metagoniolithon* has enabled us to extend the stratigraphic range of this genus to the Burdigalian.

Keywords: Burdigalian, fossil coralline algae, Rhodophyta, palaeoenvironment, western India.

CORALLINES are strongly calcified red algae of the order Corallinales, division Rhodophyta[1] and are important components of shallow water sedimentary sequences throughout the Cenozoic[2]. Corallines are dominant carbonate sediment producers and major reef builders[3,4]. The Corallinales is a monophyletic group comprising three families (Sporolithaceae, Corallinaceae and Hapalidiaceae) with living species and one family (Graticulaceae) with fossil species[5]. The Corallinales is architecturally subdivided into two groups, the geniculate and nongeniculate forms[6]. The thallus of the geniculate corallines is composed of the intergenicula alternating with the genicula, while the thallus of the nongeniculate corallines lacks the intergenicula and the genicula[7]. There are seven geniculate coralline genera, namely *Amphiroa*, *Arthrocardia*, *Calliarthron*, *Jania*, *Metagoniolithon* and *Subterraniphyllum* reported from fossil records[8]. However, out of these seven genera, fossil records of six genera are explicit and the record of *Metagoniolithon*, subfamily Metagoniolithoideae as a fossil is dubious.

Hitherto, the only provisional and tentative fossil record of *Metagoniolithon* as *Metagoniolithon* (?) *gaschei* and *Metagoniolithon* (?) sp. indet. A exists from the Oligocene and the Aquitanian of Pinar del Rio and Oriente Provinces, Cuba[9]. Prior to that, some fossil species described under *Jania* from the Miocene of the Western Pacific were thought to resemble *Metagoniolithon*[10]. Without proper

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