indicate the proximity of these villages and towns to the epicentral zone compared to Pipalkoti, Chamoli or Mawana.

Further, large horizontal compression caused by shallow thrust faulting may result in intense release of pore waters from the highly fractured rocks. This possibly explains the presence of numerous new and reactivated streams with increased flow and also the drying up of already existing ones in the region.

According to USGS details of the chosen fault plane NP1, reverse thrust motion occurs on the causative fault dipping at a shallow angle (9°) along 12°N direction. During such a motion while the rocks of the footwall would be displaced in a near-northerly direction, those of the hanging wall would be displaced in a near-southerly direction (Figure 6). This should cause higher incidence of slope failures and sliding of rocks on the weak southern slopes of the mountains. This has indeed been evidenced in the satellite data examined in our study.

Results of investigation of the earthquake-related damage from ground and satellite data as reported in this study, provide observational constraints which lend support to the hypocentral location and fault plane solution as given by USGS.

Several geological and geophysical investigations have provided conflicting evidences both for an active MCT[18,19] as well as for an inactive MCT[20,21]. This study indicates that the damage induced by the Chamoli earthquake is more pronounced nearer the MCT, rather than the MBT.

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New record of *Mytilus viridis* Linn., its density, growth and accumulation of heavy metals on Saurashtra coast, Arabian Sea

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The occurrence of green mussel *Mytilus viridis* was recorded for the first time in the Gujarat coast. The assessment of mussel density, growth and biomagnification of heavy metals from its natural beds were performed from September 1998 to June 1999. The mussel density was maximum both in number and biomass at low tide level and minimum at high tide level. The specific growth rate of mussel was 13.25 (length), 31.16 (total weight) and 3.38% per month (meat weight) during the study period. Data regarding accumulation of heavy metals reflected that the metal load was increased with increasing mussel size and the peak values were observed at an average size of 6.21 mm. The mean concentration of Cu, Fe, Pb, Cd, Zn, Co, Mn and Hg were 3.91, 9.40, 20.10, 1.53, 37.34, 67.35, 1.01 μg g^{-1} dry wt and non-detectable, respectively. Since the mussel showed considerable biomagnification of heavy metals, it can be used for marine pollution monitoring.

THE green mussel *Mytilus viridis* (Syn. *Perna viridis*) is an important food for the people of southern India. It supports substantial fishery of some consequence along the coast of Karnataka and Kerala[1]. Though green mussels

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are widely distributed in marine and estuarine regions of India, they are fairly abundant on the coasts of Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. However, green mussel has not been previously recorded from the Gujarat coast[2]. Furthermore, Trivedi *et al.*[3] attempted to transplant the green mussel for cultivation from Calicut to Okha in Saurashtra coast. Gujarat is the largest maritime state in India having a 1600 km long coastline with potential estuarine, mangrove and coral reef ecosystems. With the clarion call for 'liberalization' in Gujarat, the speed of industrialization has increased and has led to more urbanization. Chemical industries have also led to increasing load of sewage and effluents on the aquatic biosystem along the Saurashtra coast of Arabian sea[4]. In our extensive survey along the coastal waters of Gujarat the occurrence of the green mussel *M. viridis* was recorded for the first time at Mocha (lat 21°20′N; long 69°53′E) near Porbandar during September 1998.

Since the establishment of a 'mussel watch programme'[5], *Mytilus* sp. has been widely used to evaluate the quality of coastal and estuarine ecosystems[6] and also fulfils two objectives; first an assessment of marine environmental contamination of the accumulation of contaminants in different tissues and second, the detection of environmental effluents on organisms by measuring biological responses such as growth or reproductive processes[7]. The genus *Mytilus* offers most of the requisite features of a biological indicator such as strong resistance to environmental pollution[8], wide distribution, sessile species of long life, reasonable size and easy to sample, tolerance to polluted water and fluctuations of physico-chemical parameters. A study was initiated at Mocha to monitor the density, growth and accumulation of heavy metals in its natural beds.

Mocha is a rocky shore located on the Saurashtra coast of Gujarat, Arabian Sea (Figure 1). *M. viridis* is distributed in patches, in a 1.5 km long and 50 m wide area of intertidal rocky substratum along with other molluscs such as *Thais haemastoma, T. bufo, Drupa* sp., *Trochus niloticus* and *Chiton* sp. Seaweeds like *Gracilaria corticata, Gelidiella acerosa, Ulva lactuca* and *Enteromorpha prolifera* were also seen growing in that area.

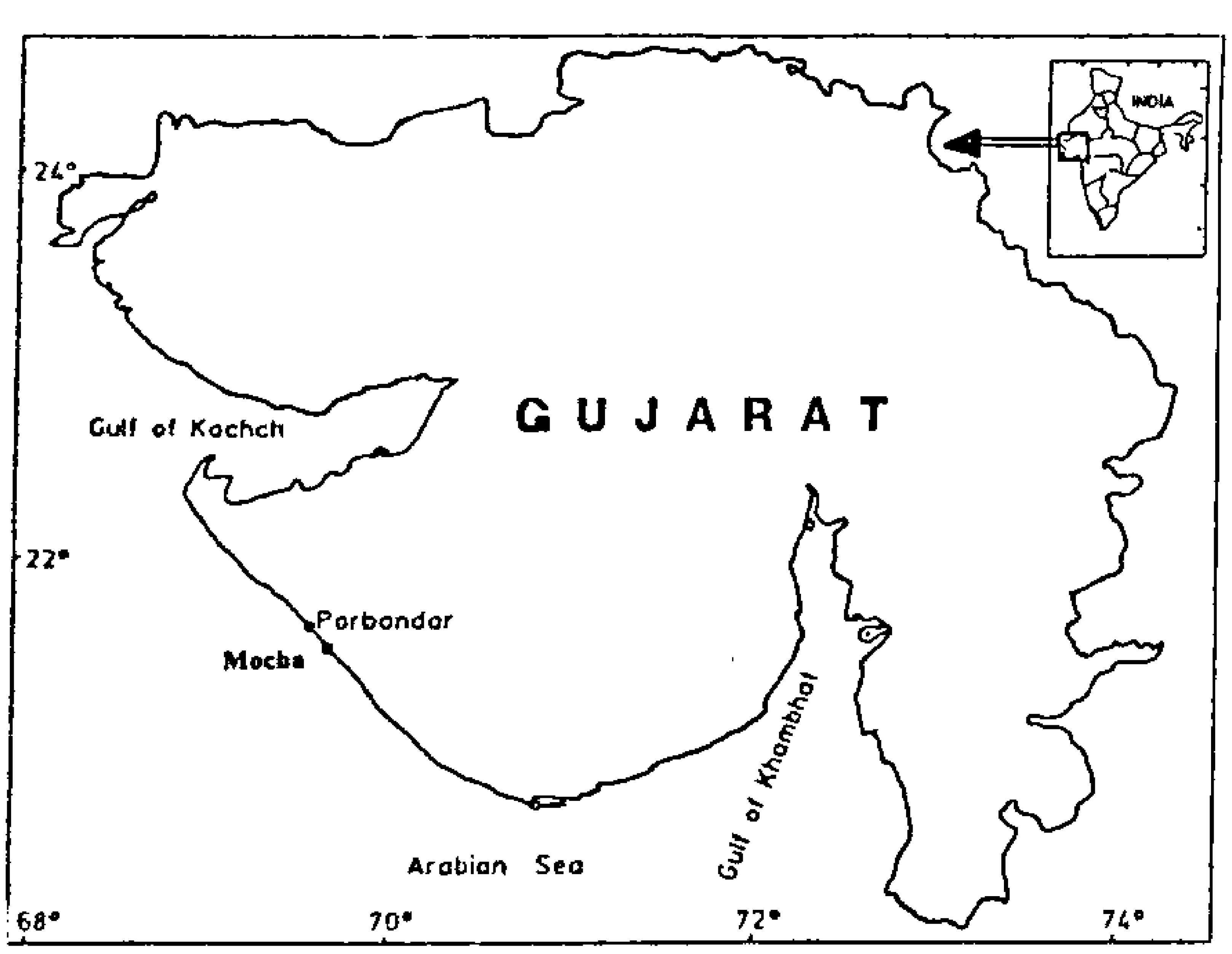

Figure 1. Location of the study area.

Density of *M. viridis* was determined by 0.5 sq m^2 quadrat having 10×10 cm sub quadrats. Data were collected at every 10 m interval starting from 0.32 m above the zero of the *chart datum* (low tide) from September 1998 to June 1999 at three different locations. The density in terms of numerical abundance and biomass is expressed in 1 m^2 of the rock surface. Monthly observations on growth in terms of length, width, total weight and meat weight were measured from September 1998 to June 1999 from 25 specimens randomly collected. The specific growth rate (SGR) on monthly basis was determined by the formula $SGR = (W2/W1 - 1)^{1/T} \times 100$, where $W1$ is the initial weight, $W2$ the final weight, and T the time in months elapsed between two data.

For heavy metal monitoring studies, 10 mussels were randomly collected every month, washed and kept in filtered seawater to purge the gut content. Whole soft tissue of mussels were removed using a stainless-steel scalpel, rinsed with deionized water and frozen in a deep freezer at – 20°C for further analysis. During the course of analysis, the tissue was washed and dried in an oven at 95°C and ground to a fine powder using an electrically operated grinder and sieved through 200 µm mesh-sized sieve. One gram tissue powder was digested with 15 ml of concentrated acid (60% HNO_3 : 40% $HClO_4$) at room temperature for 12 h. Digested samples were heated slowly to 180°C. The sample volume was reduced to 2–3 ml and then cooled. After reheating and cooling, the final solution was diluted to 20 ml volume with deionized water[9]. Blanks were run along with test samples throughout the digestive process. Samples were analysed for Cu, Fe, Pb, Zn, Cd, Co, Mn and Hg and quantified using atomic absorption spectrophotometer (AAS-680 SHIMADZU). Simultaneously, heavy metals were also determined in the oyster tissues (Standard Reference Material) supplied by the American National Institute of Standard Reference Material.

Water samples were also collected to measure temperature, salinity, pH, dissolved oxygen and biological oxygen demand following the method of Strickland and Parsons[10].

The present report on the occurrence of *M. viridis* (Figure 2 *a* and *b*) on the Gujarat coast is a new record, since no report has been made on this coast[2]. This species was collected during September 1998 from Mocha coast and at that time all the mussels were similar sized and ranged between 30.13 and 40.45 mm in length. The sudden occurrence of this species might be due to release of ballast waters by the ships and similar sources. During the study period the physico-chemical parameters like temperature, salinity, pH, dissolved oxygen and biological oxygen demand ranged from 22.8 to 30.8°C, 35.42 to

Figure 2. Green mussel *M. viridis*. *a*, young mussel; *b*, adult mussel.

37.63%, 8.20 to 8.31, 4.15 to 5.89 ml l^{-1} and 0.87 to 1.6 mg l^{-1}, respectively.

Density in terms of numerical abundance and biomass of *M. viridis* at three locations of the study area is depicted in Table 1. No remarkable variation was observed in the density of mussels at different locations. However, in location III, higher density was recorded to a very meagre extent. During September 1998, of the 50 m wide exposed intertidal area, the mussel density was maximum (63–70 No m^{-2} and 275.94–357.00 g m^{-2}) at 10 m above the low tide level. The density gradually decreased to 50 m (high tide) and it was minimum at this level (19–23 No m^{-2} and 95.00–105.11 g m^{-2}). The density at zero meter level (low tide) ranged from 22 to 25 No m^{-2} and 94.82–108.75 g m^{-2}. The numerical density of mussel drastically decreased during June 1999. During the same period a maximum density of 39–43 No m^{-2} and 1856.40–2068.30 g m^{-2} was observed at 10 m and a minimum of 10–12 No m^{-2} and 378.50–463.68 g m^{-2} at 50 m level. The numerical abundance and biomass at zero meter level were 11–15 No m^{-2} and 419.32–588.75 g m^{-2}, respectively. The maximum total biomass of 270 g m^{-2} observed in Cheshkaya Bay in *M. edulis* community[11] coincided with the present results. The low density at zero meter level might be due to the severe wave action prevailing in the lower tidal area which is not conducive for the attachment of mussels. Generally, *Mytilus* sp. are found in the mid levels of the littoral and the uppermost sublittoral in sheltered places or where there is little surf action[11]. This is a reason for the maximum density of mussels noticed at 10 m level at the Mocha coast. In the present study, the mussel density decreased from low to high tide level, because the higher intertidal area is exposed to air for a long period than the low intertidal region. Animals which depend on water currents for feeding get greater rations with decreasing level in the

Table 1. Density of *M. viridis* during September 1998 and June 1999

Distance from low tide mark (m)	Location I		Location II		Location III	
	Mussel (No m^{-2})	Biomass (g m^{-2})	Mussel (No m^{-2})	Biomass (g m^{-2})	Mussel (No m^{-2})	Biomass (g m^{-2})
September 1998						
0	22	94.82	23	103.73	25	108.75
10	63	275.94	67	309.54	70	357.00
20	56	242.48	56	253.68	55	264.55
30	48	216.96	43	202.53	47	221.84
40	37	163.91	30	145.50	35	170.45
50	21	96.60	19	95.00	23	105.11
June 1999						
0	11	419.32	13	483.08	15	588.75
10	41	1948.32	39	1856.40	43	2068.30
20	30	1368.90	29	1331.68	31	1434.99
30	27	1168.29	21	845.25	26	1101.36
40	20	844.60	15	580.35	19	736.00
50	12	463.68	10	378.50	11	406.45

Table 2. Growth of *M. viridis* between September 1998 and June 1999

Month and year	Length (mm)	Width (mm)	Total weight (g)	Meat weight (g)	Percentage of meat
September 1998	32.13	17.52	4.31	1.09	25.29
October 1998	37.23	22.14	6.25	1.60	25.60
November 1998	47.28	24.82	8.86	2.02	22.80
December 1998	51.53	28.27	14.22	3.82	26.86
January 1999	60.63	31.39	23.61	7.98	33.79
February 1999	69.38	35.77	34.80	8.61	24.74
March 1999	73.80	38.56	40.77	11.16	27.37
April 1999	79.16	40.21	47.40	12.85	27.11
May 1999	85.36	42.08	48.53	13.92	28.68
June 1999	98.51	43.23	49.52	14.85	29.98
Growth rate (% $month^{-1}$)	13.25	10.55	31.16	3.38	–

Table 3. Accumulation of heavy metals by *M. viridis* ($\mu g\ g^{-1}$)

Month and year	Cu	Fe	Pb	Zn	Cd	Co	Mn	Hg
September 1998	2.29	6.98	10.31	30.04	1.47	59.79	1.03	nd
October 1998	2.36	6.63	10.82	30.06	1.47	65.32	1.02	nd
November 1998	2.36	8.08	20.06	31.58	1.49	68.88	1.10	nd
December 1998	2.56	8.98	20.11	32.21	1.50	70.66	1.04	nd
January 1999	2.83	9.73	20.31	42.09	1.51	74.82	1.03	nd
February 1999	2.88	10.36	20.19	42.16	1.57	77.20	1.12	nd
March 1999	5.68	10.04	20.38	71.71	1.57	81.35	1.15	nd
April 1999	6.21	12.42	20.38	42.65	1.57	81.95	1.27	nd
May 1999	5.98	10.40	20.38	42.67	1.55	74.82	1.20	nd
June 1999	5.92	10.38	20.09	37.77	1.56	77.79	1.26	nd
Mean value	3.91	9.40	20.10	37.34	1.53	67.35	1.01	nd

nd, not detectable.

tidal zone[12]. It is also supported by the experiment of Harger[13] who determined growth differences in the intertidal mussels *M. californianus* and *M. edulis* and found that both species grew more slowly in the high intertidal than the low intertidal region.

The rapid reduction of mussel density during June 1999, is due to predation of carnivorous gastropods. As mentioned earlier, *T. haemastoma, T. bufo* and *Drupa* sp. were associated with *M. viridis* in the study area and their principal prey are mussels, oysters and barnacles. Lubchenco and Mange[14] reported that the thaid gastropod *T. lapillus* and the star fish *Asterias forberi* and *A. vulgaris* prey heavily on *M. edulis*. The higher values of biomass during June 1999, is due to increase in growth of mussels after 10 months.

The mean values of growth of *M. viridis* are shown in Table 2. There was an increase of 66.38 mm in length and 25.71 mm in width from an initial size of 32.13 mm and 17.52 mm, respectively. Correspondingly, the increase in weight was observed from 4.31 g to 49.52 g during the study period. This corresponds to the specific growth rate of 13.25 and 31.16% per month, respectively. However, the increase in meat weight was 3.38% per month. The better growth rate in mussel mainly depends on the ambient environment and availability of primary producers for forage. Growth of *Perna viridis* was 45 mm in 5 months at Kakinada[15], 54 to 65 mm in 6 months at Calicut[16], an average monthly growth rate of 12.8 to 13.0 mm at Kovalam Bay[17] and 7.3 mm at Thailand [18] when the mussels were grown by rope culture methods on the sea. In the present study growth of mussels in natural beds was lower than that in rope culture, and this observation is in good agreement with the findings of Qasim *et al.*[2] in natural beds of green mussel at Velsao Bay. In the present study the percentage of meat weight was recorded as 24.51%. Comparatively, Rao *et al.*[19] obtained the average meat yield of *P. viridis* as 21.6% of the total weight.

Monthly metal concentration in the tissues of mussel for the entire study period is given in Table 3. These values of metals in the oyster tissue of Standard Reference Material tallied with our values. The concentration of all the metals gradually increased from September 1998 with peak values obtained during April 1999. The mean concentration of Cu, Fe, Pb, Cd, Zn, Co and Mn was estimated as 3.91, 9.40, 20.10, 1.53, 37.34, 67.35 and 1.01 $\mu g\ g^{-1}$ dry wt respectively. Hg was not detected in any of the samples. The higher value of Fe, Co, Zn and Pb may be due to higher concentration of these metals in ambient seawater. The concentration of Cu and Zn was less while Pb and Cd were much more in mussel from Mocha than the *Mytilus* from Cuddalore waters[20]. However, the bio-magnification of Fe and Mn was much more in the present study compared to the study by Rivonker and Parulekar[21].

The present study revealed that the accumulation of metal increased with increasing the size of the mussel. This coincided with the observations of Rivonker and Parulaker[21]. The peak value for all the metals was observed at the size of 79.16 mm mean length. The metal level in the molluscan species usually varied with size, sex, feeding habits, reproductive condition, routes and mechanisms of uptake, intracellular compartmentation and other aspects of cellular metal homeostasis, season and extent of pollution in the ambient medium[22,23]. Indeed, the metal concentrations recorded here were of a similar estimate of the metabolic requirements of marine molluscs for copper[24]. A positive correlation was observed between length, total weight and meat weight and the concentration of all the metals in *M. viridis* from Mocha.

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