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Ostracoda as an aid in identifying 2004 tsunami sediments: a report from SE coast of India

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Abstract Four short core samples were collected from the creek, estuarine regions of southeast (SE) coast of India affected by the 2004 Asian Tsunami. The study is aimed to signify the importance of ostracoda species in identifying major natural events (e.g. Tsunamis) in the coastal regions. The presence of many marine ostracoda species in the beach areas and the comparative studies with earlier reports from SE coast indicate that these species were brought by the high-energy tsunami waves. The depositional feature of ostracoda species in the beach and estuarine region also infers on the nature and force of tsunami waves in a particular region. The results clearly support that microfossils can be used to identify the major natural events close to coastal regions.

Keywords Ostracoda · 2004 Tsunami · Core sample · Deposition · SE coast of India

1 Introduction

The recent 2004 Asian Tsunami has undermined the importance to identify the deposits through various methods to develop a clear image on the nature of this event. The tsunamis often cause extensive damage to the coastal region due to the sudden rush of sea waves which cause erosion and deposition of sediments in many places. These deposits signify the high energy during the major event and sometimes, it also has similar characters to that of storm surge or cyclonic events. However, the recent mircopaleontological studies have made significant inroads in identifying the tsunami deposits in many places and also in past

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natural events (Chagué-Goff et al. 2002; Nagendra et al. 2005; Kortekaas and Dawson 2007; Clague et al. 1999; Williams and Hutchinson 2000).

Studies related to the recent 2004 Asian Tsunami have been made by several authors along southeast coast of India on various geological aspects (Srinivasalu et al. 2005, 2007, 2008, 2009a, b; Yeh et al. 2006). The transport of foraminiferal species from deeper regions to the coastal regions in other areas has been reported by Dominey-Howes et al. (1999) (Western Australia); Hindson et al. (1999) (Algrave, Portugal); Fujiwara et al. (2000) (Southern Kanto region, Pacific coast of Central Japan); Luque et al. (2002) (Bay of Cadiz, Spain); Ruiz et al. (2004) (Doñana National Park, SW Spain); Nagendra et al. (2005) (SE coast of India); Hussain et al. (2006), Malik et al. (2006) (Andaman Islands, Indian Ocean); Nigam and Chaturvedi (2006) (NE Arabian sea); Hawkes et al. (2007), Jankaew et al. (2008) (Malaysia–Thailand Peninsula) and Smedile et al. (2007) (Eastern Sicily, Italy).

The aim of the present article is to report on the presence of ostracoda species from core samples in the tsunami sediments from southeast coast of India. This study further enhances the knowledge on the use of ostracoda as a useful aid in identifying the recent 2004 tsunami deposit in various other regions that has been affected by the natural event.

2 Study area

The study area extends to about 180 km in the southeast coast of India from Ennore creek (North of Chennai city) to Pondicherry in the central part of Tamil Nadu state (Fig. 1). The coastal region is dominated by numerous creeks, backwaters and minor/major rivers (Rivers Korattaliar, Cooum, Adyar, Palar, Kolathur and Sunnambu) that drain into the Bay of Bengal. The coastal tract is also represented by coastal dunes, paleo lagoons, paleo-tidal flats and paleo barriers (beach ridges) (Anbarasu 1994; Srinivasalu et al. 2007). The area is also dotted with many attractive tourist destinations in the coastal region which draw tourists from all over the World.

The coastal region of southeast coast of India was affected in a devastating manner during the 2004 Indian Ocean Tsunami where three large waves hit the Indian coast 3 h after the major earthquake. In many places, the sea waves caused extensive damage to engineering structures and erosion/deposition of sediments. As part of a larger research development program by Department of Geology, University of Madras, the backwater and coastal regions along the southeast coast of India have been extensively studied for various aspects related to distribution of microfauna in the coastal regions by Hussain (1998), Sridhar et al. (1998), Mohan et al. (2001), Ayyamperumal et al. (2006), Hussain et al. (2007), Janaki-Raman et al. (2007) and Stephen-Pichaimani et al. (2008) during the last 10 years. These studies clearly reflect the distribution of microfossils and the nature of substratum in the southeast coast of India. The above studies serve as a database for interpretation on various aspects related to geological side for major interpretations after the tsunami event in 2004.

3 Materials and methods

The sample collection for the present study was done during the month of April 2005. Several sites were selected for core samples, and it was based on previous survey immediately after the disaster in December 2004, after careful examination of the

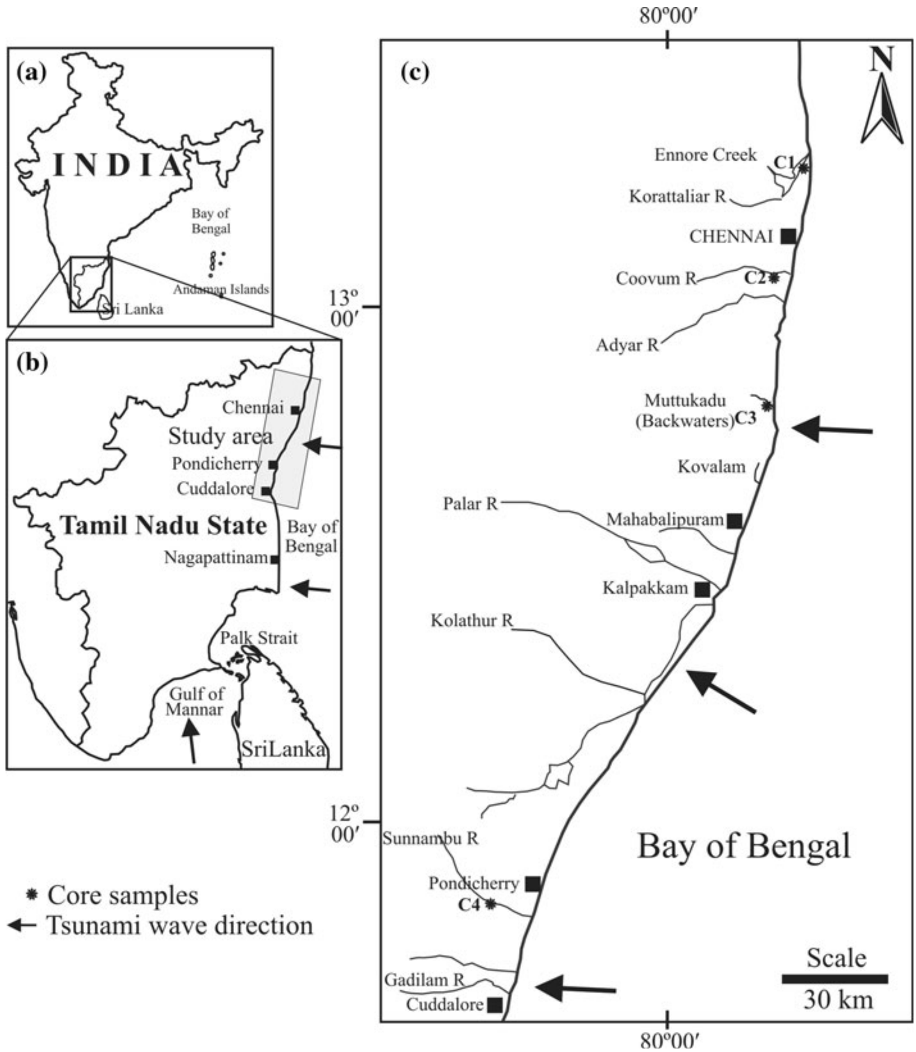

Fig. 1 Study area and core sample locations in southeast coast of India

substratum in the coastal areas. The core samples were collected using a PVC tube of 2.5″ diameter and 2.5 m in length. The PVC tube was pre-cleaned with dilute HCl before the sampling, and it was slowly pushed into the estuarine/river bed until about ~30 cm of the tube remained above the ground. The tube was sealed using a Plumber's dummy, and it was retrieved from the river bed. Subsequently, the top and bottom of the core samples were sealed, transferred to the laboratory and stored in −20°C. On the basis of stratigraphical and depositional sequence, four core samples were selected i.e. C1 (Ennore Creek, North of Chennai City), C2 (Cooum River estuary), C3 (Muttukadu backwaters) and C4 (Sunnambu River, Pondicherry) (Fig. 1). The core samples were sub-sampled at 5-cm interval, and the retrival rate for C1 was 90 cm (18 samples), C2: 80 cm (16 samples), C3: 100 cm (20 samples) and C4: 75 cm (15 samples), respectively.

The ostracodal species were separated, identified and were photographed using a scanning electron microscope (JEOL-JFC 6360) in Department of Geology, University of Madras, India, and all the specimens are indexed and stored in the repository.

4 Results and discussion

The different ostracoda faunal species from the four core samples are presented in Fig. 2a–n.

The core sample (C1) collected from Ennore creek in northern Chennai yields *Neomonoceratina iniqua*, *Basslerites liebaui* and *Hemicytheridea reticulata*. The second core sample (C2 from Cooum River) is dominated by *Calliistocythere flavidofusca intricatoides*, *Mutilus pentoekensis*, *Keijella reticulate*, *Neomonoceratina iniqua*, *Basslerites liebaui*, *Hemicytheridea reticulate*, *Stigmatocythere indica*, *Caudites javana* and *Loxoconcha* sp., respectively.

The presence of *Callistocythere falvidofusca intricatoides* in the C2 indicates that it has been deposited in the low energy region of the Cooum estuary due to the arrival/retrieval of three different tsunami waves. The presence of this species indicates that they are brought in from the continental shelf area as they dwell in the coastal region less than 100-m water depth (e.g. Yassini 1979; Bergin et al. 2006). The ostracodal species recorded in both the core samples (C1, C2) suggest considerable agglutinated forms in the top 70 cm which is due to the fact that they have stayed in the water column for a considerable period of time before deposition indicting a low energy levels (in sea water) in the northern part of the Tamil Nadu state compared to the inundation in the southern regions of the state (e.g. Cuddalore and Nagapattinam). Moreover, in C2 a change in the species color is observed from 70-cm depth, indicating that the tsunami deposits are nearly 0–70 cm thickness which is also very well supported by the change in sediment distribution from sandy-fine sand to clay organic-rich layers in the contaminated river beds of Chennai city (e.g. Covelli et al. 2006; Zúñiga et al. 2007). Eyewitness and scientific articles that reported the 2004 tsunami event have documented three large waves, and in many places the backwash took place only after the third tsunami wave. Hence, the possibility of the small agglutinated forms to stay afloat in the water column is more than expected (e.g. Paris et al. 2007). The above inference is also in accordance with earlier report in the same area by Srinivasalu et al. (2009a), indicating that the tsunami layers are seen above the organic layers in many places.

In the cores C3 and C4 collected from Muthupet backwaters and Sunnambu River (Pondicherry), the following species were recorded: *Xestoleberis variegata*, *Caudites javana*, *Tanella gracilis* and *Loxoconcha sp* respectively. The presence of reworked species especially *Tanella gracilis* and *Loxoconcha* sp. at lower depth (below 40–70 cm) in both the core samples suggests that they are reworked in the sandy sediments due to the churning tsunami waves of very high energy (e.g. Ruiz et al. 2004). In addition, the absence of these two species in the northern part (especially in C1, C2) suggests that the southern part of the study area has borne the brunt of the devastation caused by the tsunami waves as reported by many authors (on erosion, deposition and inundation) (Le Roux and Vargas 2005; Shanmugam 2006; Srinivasalu et al. 2009a, b; Yeh et al. 2006). In both the core samples (C3 and C4), the depositional sequence indicates several inter-bedded fine sand and sand layers in the top 5–70-cm depth which correlates well with the earlier article by Srinivasalu et al. (2007), who had reported similar deposits in various transects in this region.

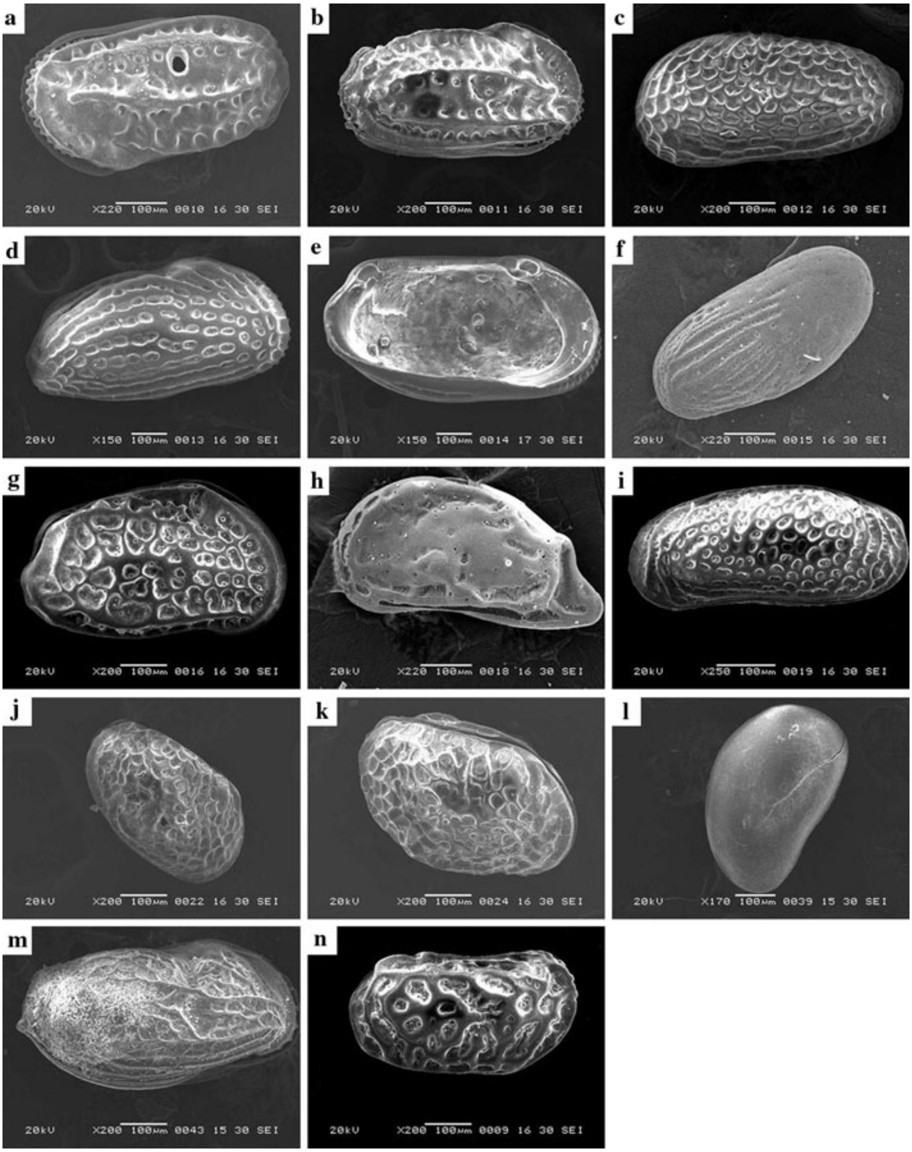

Fig. 2 **a**–**n** Different ostracoda species in core samples (tsunami sediments) from southeast coast of India. **(a)** *Stigmatocythere indica* (Jain 1978)—Left valve external view (*upside down*); **(b)** *Stigmatocythere indica* (Jain 1978)—Right valve external view; **(c)** *Hemicytheridea reticulata* (Kingma 1948)—Left valve external view; **(d)** *Keijella reticulata* (Whatley and Quanhong 1988)—Right valve external view; **(e)** *Keijella reticulata* (Whatley and Quanhong 1988)—Left valve external view; **(f)** *Basslerites liebaui* (Jain 1978)—External view (specimen distorted); **(g)** *Mutilus pentoekensis* (Kingma 1948)—Right valve external view; **(h)** *Caudites javana* (Kingma 1948)—Left valve external view; **(i)** *Tanella gracilis* (Kingma 1948)—Right valve external view; **(j)** *Loxoconcha gruendeli?* (Jain 1978)—Right valve external view (specimen distorted); **(k)** *Loxoconcha* sp.—Right valve external view; **(l)** *Xestoleberis variegata* (Brady 1880)—External view (specimen distorted); **(m)** *Neomonoceratina iniqua* (Brady 1868)—Right valve external view and **(n)** *Callistocythere falvidofusca intricatoides* (Ruggieri 1953)—External view (*upside down*)

4.1 Identifying the origin of ostracoda species using comparative studies

The studies made during the last decade by the Department of Geology, University of Madras in the coastal regions of Tamil Nadu state was helpful to clearly identify and compare the species that has been transported from inner shelf regions [Gulf of Mannar Hussain 1998; Sridhar et al. 2002; South Chennai Mohan et al. 2001] to the beach (as tsunami deposits) (Table 1).

The following species are characteristic of shallow marine habitat *Basslerites liebaui, Calliistocythere flavidofusca intricatoides*, *Caudites javana*, *Hemicytheridea reticulata, Keijella reticulata, Loxoconcha* sp., *Mutilus pentoekensis*, *Neomonoceratina iniqua*, *Stigmatocythere indica, Tanella gracilis* and *Xestoleberis variegate*. These species are reported periodically in the core samples collected from the various landforms along the study area after the tsunami event. The occurrence in the land region and all along the marginal marine environment indicates that they were transported by the tsunami waves. The presence of marine ostracodal species in all the core samples clearly suggests that they have been transported from inner shelf environment due to the strong tsunami waves that hit the coast. Similar observation on the depositional feature of the ostracoda species has already been reported by Nagendra et al. (2005) (Nagapattinam, SE coast of India), Hussain et al. (2006) (Andaman Islands) and Ruiz et al. (2004) (Doñana park, SW Spain).

4.2 Identification of depositional sequence

The use of carapace–valve ratio has been widely used in recent years to identify the depositional environment in the aquatic regions. The main reason for the use of carapace in the present study is to know the speed or the depositional environment in the area as the carapace often sinks to the bottom very quickly during rapid deposition without any destruction to muscles and ligaments. However, when the sedimentation is slow, the carapace opens up and gets separated due to intense bacterial activity.

The observed difference in the carapace–valve ratio is presented in Table 2 (calculated from 0 to 70 cm in each core). The result suggests a ratio of 1.16:7.1 (C1); 1.12:8.99 (C2); 1.46:3.13 (C3) and 1.39:3.56 (C4), respectively. Overall, the results suggest that sedimentation rate in the study area was very rapid supporting the major tsunami event (e.g. McKenzie and Guha 1987; Ahmad et al. 1991; Hussain and Rao 1996). Furthermore, the results also suggest a different picture of depositional pattern for C1, C2 and C3, C4 which indicates that the high-energy waves were very active in destroying (opening up) the carapace in southern part of Chennai and Pondicherry region. The inference is also very well documented by the large number of broken carapace valves signifying high-energy tsunami waves in the southern part of the study area. The above high energy activity is very well supported by the huge tsunami deposits in many places (Srinivasalu et al. 2007, 2009a, b).

5 Conclusion

The present study on the presence of ostracodal species has made significant impact on the use of microfossils to identify recent tsunami deposits.

The following conclusions were drawn from the present study:

Table 1 Comparison of ostracoda species in pre-tsunami locations in Gulf of Mannar, off Karikkattukuppam south of Chennai (from water depth 0–50 m) and post-tsunami sediments (present study) from southeast coast of India

Sl.No.	Name of the species	Pre-tsunami	Post-tsunami
1	*Bairdoppilata (B.) alcyonicola#* (Maddocks)	×	
2	*Basslerites liebaui** (Jain)		×
3	*Bythoceratina mandviensis* (Jain)	×	
4	*Callistocythere falvidofusca intricatoides* (Ruggieri)	×	×
5	*Caudites javana** (Kingma)	×	×
6	*Chrysocythere keiji** (Jain)	×	
7	*Cyprideis sp. cf. mandviensis** (Jain)	×	
8	*Cytherelloidea leroyi** (Keij)	×	
9	*H. reticulata** (Kingma)		×
10	*Hemicytherura subulata#* (Ahmed et al.)	×	
11	*Hemikrithe peterseni* (Jain)	×	
12	*Henryhowella (Neoheryhowella) hartmani* (Jain)	×	
13	*Keijia demissa** (Brady)	×	
14	*Keijella reticulata#* (Whatley and Quanhong)	×	×
15	*K. whatleyi* (Jain)	×	
16	*Loxoconcha megapora indica** (Benson and Maddocks)	×	
17	*L.gruendeli** (Jain)	×	
18	*Loxocorniculum lilljeborgii#* (Brady)	×	
19	*Macrocyprina decora#* (Brady)	×	
20	*Mutilus pentoekensis#* (Kingma)		×
21	*Neocytheromorpha* sp. cf. *N. indoarabica* (Khosla)	×	
22	*N. reticulata** (Mohan et al.)	×	
23	*Neomonoceratina iniqua** (Brady)	×	×
24	*N. jaini** (Varma et al.)	×	×
25	*N. porocostata#* (Howe and McKenzie)	×	
26	*Paijenborchellina prona#* (Lubimova and Guha)	×	
27	*P. keij* (Varma et al.)	×	
28	*P. indoarabica*	×	
29	*Paracytheroma ventrosinuosa#* (Zhao and Whatley)	×	
30	*Paradoxostoma bhatiai* (Shyam Sunder et al.)	×	
31	*Phlyctenophora orientalis* (Brady)	×	×
32	*Propontocypris (P.) crocata#* (Maddocks)	×	
33	*P. (S.) bengalensis* (Maddocks)	×	
34	*Spinoceratina spinosa** (Annapurna and Rama Sarma)	×	
35	*Stigmatocythere indica* (Jain)	×	×
36	*S. kingmai* (Whatley and Quanhong)	×	
37	*Tanella gracilis** (Kingma)	×	×
38	*Xestoleberis variegata#* (Brady)	×	×

Data reproduced from Hussain (1992, 1998), Hussain et al. (1996, 2004, 2005, 2007), Hussain and Mohan (2001), Mohan et al. (2001) and Sridhar et al. (1998)

* Occurs both in brackish and shallow marine environments

Occurs only in marine habitats

Table 2 Distribution of carapaces and open valves in actual numbers in the present study

Sample no.	Carapace	Open valve	Total
C1	61	10	71
C2	71	9	80
C3	96	45	141
C4	41	16	57

1. The presence of marine ostracodal species in the core samples clearly suggests that the tsunami waves have transported these species along with the sediments.
2. The comparative study of pre-tsunami and post-tsunami species from southeast coast of India also indicates the presence of marine ostracodal species in the core sediments indicating the transportation and depositional feature of this major event.
3. The depositional sequence of ostracoda species also suggests that the wave energy in the northern part of the study area is marginally lower compared to the southern region.

The results clearly signify the identification and the study of microfossils (especially ostracoda) can be used in identification of major events in the coastal zone regions.

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