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Short Paper

Ostracods as tsunami tracers in Holocene sequences

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ABSTRACT

This review analyses the ostracod record in Holocene tsunami deposits, using an overview of the 2004 Indian Ocean tsunami impact on its recent populations and the associated tsunamigenic deposits, together with results from numerous investigations of other Holocene sequences. Different features such as the variability of the local assemblages, population density, species diversity, age population structure (e.g., percentages of adults and juvenile stages) or taphonomical signatures suggest that these microorganisms may be included amongst the most promising tracers of these high-energy events in marshes, lakes, lagoons or shallow marine areas.

Introduction

Since the 1990s, numerous studies have been focused on the geological record of tsunamis in both coastal and marine areas. Their main lithostratigraphical, sedimentological, stratigraphic and geomorphic signatures have been reviewed in the last years (e.g., Scheffers and Kelletat, 2003; Dawson and Stewart, 2007).

In addition, the micropaleontological record provides powerful tools to delimitate the tsunami layers. The main groups utilised are foraminifera (Clague et al., 1999; Kortekaas and Dawson, 2007), diatoms (Hemphill-Haley, 1996; Dawson, 2007) or both groups (Williams and Hutchinson, 2000; Abrantes et al., 2005). Pollen, calcareous nannoplankton, chrysophytes, dinoflagellates or silicoflagellates are more rarely included in these analyses (Chague-Goff et al., 2002; Van der Kaars and Van der Bergh, 2004).

Ostracods are amongst the most promising microorganisms in (palaeo-) environmental studies (e.g., Frenzel and Boomer, 2004; Ruiz et al., 2005a), although they are often subordinated to data obtained from other groups in (palaeo-) tsunami studies. This review attempts to analyse the effects of these phenomena on the recent assemblages, abundance and distribution of ostracod species. In addition, we analyse the potential of this group as possible tracers of Holocene tsunamis in different palaeoenvironments (Fig. 1).

A first approach: the 2004 Indian Ocean tsunami

The 26th December 2004 earthquake (3.29°N, 95.77°E; *M* 9.3) and its associated tsunamis killed more than 230,000 people and caused severe damage on structures and infrastructures along the coasts of southern Asia, eastern Africa and northern Oceania (Jain et al., 2005; Ghobarah et al., 2006). In these areas, the analyses of tsunami sediments indicate an entrainment of sediments and faunas from the inner shelf (Nagendra et al., 2005; Bahlburg and Weiss, 2006). In addition, recent investigations have analysed (a) the impact of this high-energy event on the ostracod communities and (b) the ostracod record of tsunami deposits.

Zooplankton and benthos

In pre-tsunami zooplankton collections of the Bay of Bengal (Fig. 2), the average density of these microcrustaceans was higher (8916 per 1000 m^3) in comparison with the post-tsunami data (3583 per m^3), although a general overview indicates a strong disturbance of the pre-tsunami pattern (Stephen et al., 2006). In contrast with these strong effects, the benthonic species showed a prompt recovery in the recolonization process of this area, with a normal density on the fifth day after the tsunami in Chennai, India (Altaff et al., 2005).

Deposits

In tsunamigenic deposits collected in different zones of Andaman Islands (beaches, estuaries/creeks, backwaters and mangrove

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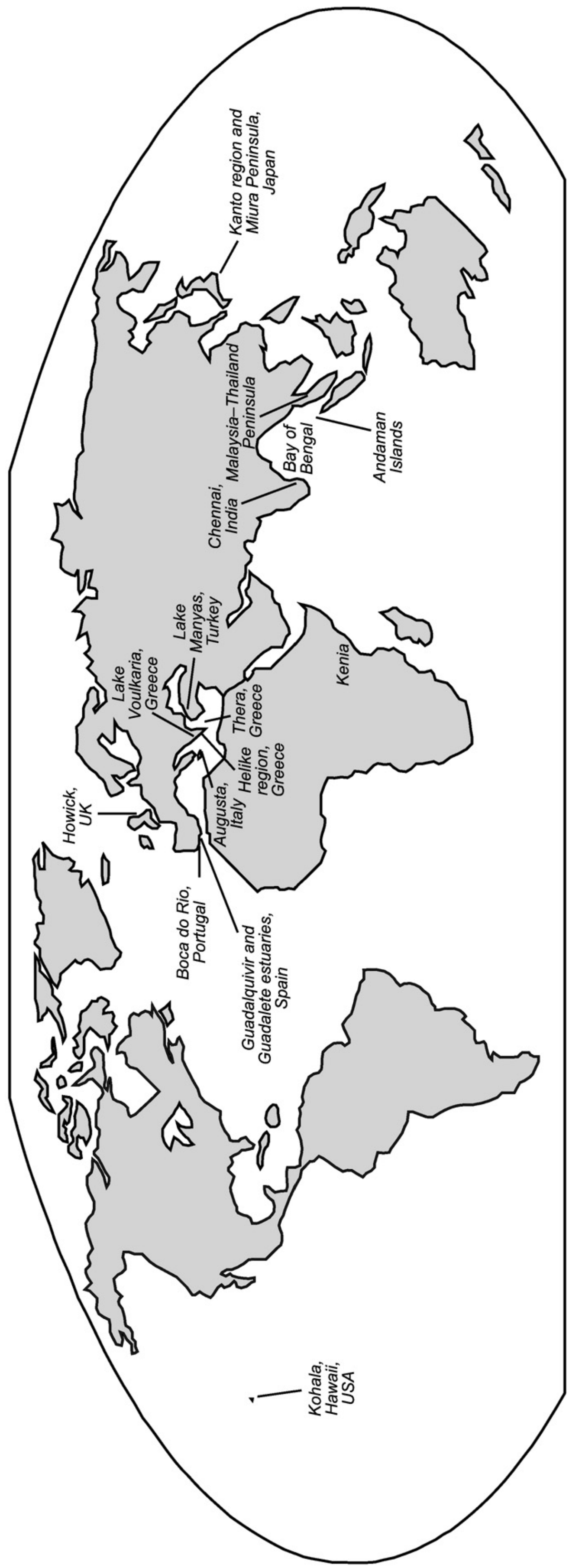

Figure 1. Main coastal and marine areas of the world used in this work to evaluate the potential of ostracods as possible tracers of tsunamis.

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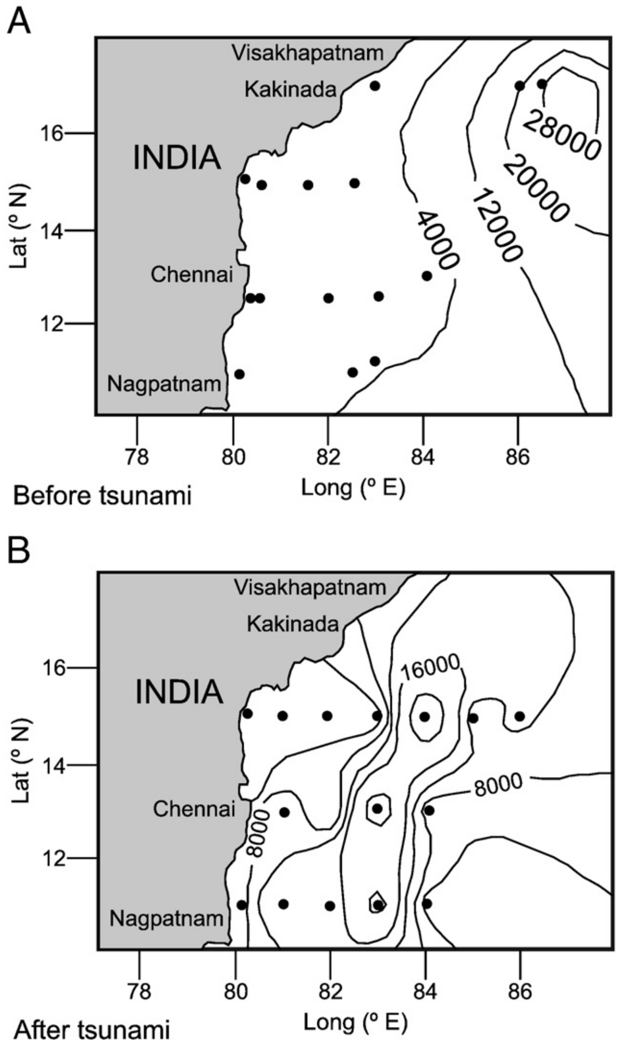

Figure 2. Effects of the 26th December 2004 tsunami on the density of the zooplankton ostracod species (number per 1000 m^3) in the Bay of Bengal (modified from Stephen et al., 2006).

swamps), both ornamented and smooth ostracod species are well preserved and only a few specimens are slightly corroded and abraded (Hussain et al., 2006). These species proceed from the adjacent coastal, shallow marine and outer shelf environments, although most of them live usually in the shallow inner shelf (ca. <50 m water depth), and only a few specimens of outer shelf genera (e.g. *Macrocyprina* and *Paracypris*) have been registered. A similar origin has been found in the foraminiferal assemblages collected along the Malaysia–Thailand Peninsula, southern India and Kenya (Nagendra et al., 2005; Hawkes et al., 2007).

Ostracod record in Holocene tsunami deposits

The search for palaeotsunami deposits is one of the purposes in numerous investigations of Holocene sequences. Some of them include biostratigraphic analyses with specific ostracod studies to draw the temporal evolution of different palaeoenvironments.

Few field investigations have determined the ostracod record in the innermost, landward inundation zone of the tsunami, with interesting conclusions in some cases. In Kohala (Hawaii), a tsunamigenic shelly fossiliferous conglomerate with basal boulders (up to 37 cm diameter), fragments of macrofossils, marine foraminifers and rare marine ostracods was deposited on a paleosol, implying a location inland from the coast (Fig. 3A; McMurty et al., 2004). In Astypalaea Island (Greece), tsunamigenic pebble/gravel deposits include marine foraminifera and molluscs, but no ostracods were recovered from these sediments. The elevation of these coarse deposits and additional topographic observations may indicate an overestimation of recent tsunami run-ups (Dominey-Howes et al., 2000).

In coastal freshwater lakes and marshes, changes in the ostracod assemblages may reflect long-term salinity variations caused by short-lived tsunami inundation (Rhodes et al., 2006). In Lake Voulkaria (Greece), the clayey-silty limnic facies are interrupted by a tsunamigenic, sandy layer with abundant plant remains, marine shell detritus and frequent specimens of the brackish species *Cyprideis torosa* (Vött, 2006). In Lake Manyas (Turkey), this species was used as tsunami tracer, with delicate, smooth specimens preserved within an erosive, silty-clayey layer. This exceptional preservation was probably due to a change in the water chemistry as a result of saltwater inundation (Fig. 3B; Leroy et al., 2002). Nevertheless, these microcrustaceans are absent in a tsunamigenic coarse unit observed at Howick (UK). This layer comprises poorly sorted silts, sands, pebbles and cobbles within a uniform, fine-grained sequence (Boomer et al., 2007).

In salt marshes and brackish lagoons, the ostracod record of tsunami deposits may be very diverse. In the Helike region (Greece), the main signature is the mixture of brackish, marine and even freshwater species within sandy sediments (Álvarez-Zarikian et al., 2008). In the Augusta area (eastern Sicily, Italy), a 1000–800 BC tsunami deposited a distinctive bioclastic layer (abundant shell fragments, broken benthic foraminifera, badly preserved planktonic foraminifera) within a lagoonal environment, with few ostracod valves in comparison with the abundant populations of *C. torosa* that characterized the lagoon bottom (Smedile et al., 2007). In other cases, the ostracod analysis of “event layers” does not provide unequivocal constraints to a tsunamigenic cause (De Martini et al., 2003).

The ostracod content of Holocene tsunami sediments has been tested in different estuaries of southern Portugal and Spain. In Boca do Rio (southern Portugal), the tsunami deposits associated with the 1755 Lisbon earthquake consist of several distinct sub-units (e.g., silty fine sand, yellow marine sand, dark mud and muddy/sandy conglomerate) and include a diverse ostracod assemblage (Fig. 3C) dominated by a mixture of estuarine and marine species, the latter absent from the underlying and overlying horizons (Hindson et al., 1996; Hindson and Andrade, 1999).

In southern Spain, five to six middle to late Holocene tsunamis caused the deposition of bioclastic/sandy ridges and washover deposits during a period of ~3 ka (Fig. 3D). In the Guadalquivir and Guadalete estuaries, these distinctive layers (bioclastic silty sands, yellow aeolian sands) were emplaced over uniform silty-clayey sequences deposited under tidal marsh or tidal flat conditions. Bioclastic ridges show a partial replacement of brackish species (mainly *Cyprideis*, *Loxoconcha* and *Leptocythere*) by reworked specimens (*Palmoconcha*, *Loxoconcha*, *Pontocythere* and *Urocythereis*) transported from shallow marine environments, whereas sandy ridges derived from the erosion of aeolian sediments are characterized by an absence of ostracod record (Luque et al., 2002; Ruiz et al., 2004, 2005b).

In Japan, the Holocene sedimentary record of the Pacific coast provides excellent examples of the tsunami effects in Holocene shallow marine areas. In Kanto, different event deposits have been distinguished, with the presence of fully ostracod assemblages typical of sandy and rocky coasts and an increasing number of species in relation to the bounding, inner bay deposits (Fujiwara et al., 2000). On the Miura Peninsula, the tsunami deposits include ostracod assemblages very similar to those observed in the bounding sediments in some cases and clearly different in others (Iruzuki et al., 1999).

Ostracod taphonomy

The ostracod record of tsunamigenic deposits presents distinctive taphonomical signatures.

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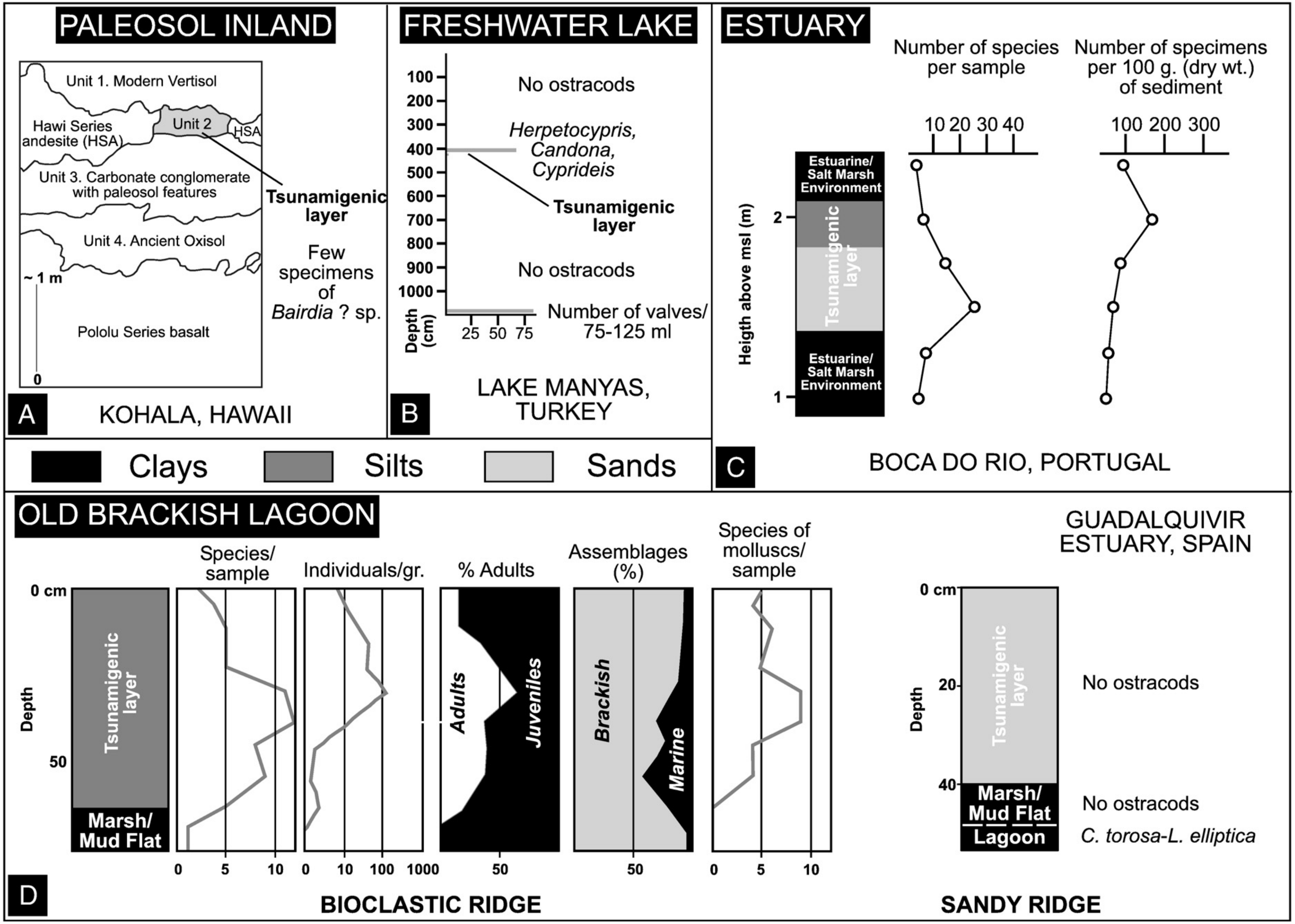

Figure 3. Changes produced by Holocene tsunamis in the abundance, diversity and assemblages of ostracods in different palaeoenvironments. (A) Kohala, Hawaii (modified from McMurty et al., 2004). (B) Lake Manyas, Turkey (modified from Leroy et al., 2002). (C) Boca do Rio, Portugal (modified from Hindson et al., 1996). (D) Guadalquivir estuary, Spain (modified from Ruiz et al., 2004, 2005b). Grain size included for (C) and (D).

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Preservation

Valves tend to be poorly preserved (e.g., Iruzuki et al., 1999) and many are broken or show strong signs of abrasion (Hindson et al., 1999; Álvarez-Zarikian et al., 2008; Vött et al., 2009).

Colour

In some cases, individuals with a red-coloured coating of iron oxide were found (Hindson et al., 1999).

Diversity

Number of species increases generally in the basal horizon of tsunamigenic layers, with the presence of transported allochtonous species derived from brackish or shallow marine environments (Hindson and Andrade, 1999; Ruiz et al., 2005b).

Population age structure

Fossil ostracod assemblages in tsunami deposits are dominated by adults and the last juvenile instars (Toshiaki et al., 1999), coinciding with abnormal concentrations of shell fragments and coarse sediments in some cases (Ruiz et al., 2004).

Ostracod assemblages

In limnic environments, percentages of brackish/euryhaline species can increase remarkably within the tsunamigenic layers (Leroy et al., 2002), whereas shallow marine assemblages are abundant or even dominant within these high-energy layers in brackish environments (e.g., Ruiz et al., 2008).

Some methodological proposals for ostracod studies in tsunami deposits

A review of the methodology used in these investigations permits to sketch some general proposals applicable in the search of Holocene tsunamis.

Recognition of the present-day assemblages

If no previous literature is available, it is desirable to realize an initial sampling campaign to recognize the recent distribution of the ostracod assemblages in the studied zone. The main sedimentary environments of estuaries (main channel, distributary channels, ebb-tide channels, marshes, pounds), lagoons (deep, shallow, intertidal and supratidal areas, outlet) or the adjacent marine shelf (inner, middle, outer) can be tested to delimitate the origin of the ostracod faunas collected in the tsunami deposits (e.g., Luque, 2002).

Transects and cores

If possible, several transects must be selected, each of them with two to four cores (at least). It is necessary to obtain a detailed sedimentary facies distribution, in order to recognize possible tsunamigenic layers (e.g., Hindson and Andrade, 1999; Vött, 2006).

Sampling

In numerous cases, thickness of tsunami deposits is less than 0.5 m and decreases landward. Consequently, it is suitable to obtain samples (>10 g, if possible) each 2–5 cm to analyse the ostracod record of these layers and the bounding sediments. If present, rim-up clasts from the underlying material must be separated and sampled.

Vertical distribution of ostracod assemblages

Once the main ostracod assemblages of the adjacent environments have been defined, their percentages must be calculated in each sample. In a second step, the vertical percentage variations of each assemblage were drew in each core.

Population age techniques

Some useful tools are (a) vertical variations in the population age structures of the main species or the total ostracod population (Ruiz et al., 2004), (b) ratio of left to right valves, and (c) age distribution of left and right valves (Irizuki et al., 1999).

Taphonomy

Possible signs of transport must be investigated, including abrasion, loss of surface ornamentation (spines, ribs, ventral expansions), rupture of the carapace margins, high percentages of adults or presence of bioerosion phenomena in ostracod species of outer environments.

Dating

If possible, the underlying and overlying sediments of each possible tsunamigenic layer must be dated, together with an internal sample (at least) of it in each core.

Conclusions

In the last two decades, the utility of ostracods as markers of Holocene tsunami events in coastal areas has been demonstrated in different palaeoenvironmental investigations. The most common worldwide effects of these high-energy events are (a) salinity changes in freshwater environments, with a temporal colonization of brackish species; (b) the presence of bioclastic layers with an increasing diversity constituted by a mixture of marine and brackish species in salt marshes and lagoons; or (c) the erosion of littoral, sandy spits, with the deposition of azoic ridges. In all cases, the taphonomical analysis reveals robust indicators of palaeotsunamis to be poor test preservation and important changes of the age population structure (e.g., percentages of adults and juvenile stages in each sample) within the tsunamigenic layers.

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