Anuário do Instituto de Geociências - UFRJ
ISSN 0101-9759 Vol. 29 - 1 / 2006 p. 431-432

FORAMS 2006

San Francisco Bay foraminifera: What have natural and human changes wrought on them?

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To use modern foraminifera for reliable interpretations of ancient paralic environments (Tertiary and older), the fauna must be representative of general ecologic conditions and not of natural or human changes imposed on it. The site of modern San Francisco Bay (SFB), over the past million years, has chiefly been a fresh-water river valley up to 70 m below the modern bay and 42 km from the ocean. At least four major but short-lived incursions of sea water to levels close to modern sea stands created different bays in time. The last of these ancient bays was 125 kyr ago. Since then the major natural changes have been the lowering and subsequent rise in sea level by ~120 m by glacio-eustasy, the fluctuating cooler and warmer temperature regimes, and significant changes in precipitation and outflow. In the last 13 kyr, ancient and modern humans have lived along the edges of the modern SFB as it formed from beyond and through the Golden Gate to the present shoreline configuation. These people induced biotic changes by harvesting of organisms for food, increasing the sediment and pollutant loads, introducing exotic species, and destroying habitats especially the marginal marshes. The modern SFB is relatively young, perhaps only 4000 years old. Humans have been actively impacting the Bay's biota for about 11,000 years, and Europeans began changing the bay with new impacts only in the last 200 or fewer years. What has this complex of impacts, both natural and human, had on the fauna of the modern SFB?

To answer this question, we compare the modern foraminiferal assemblages from SFB with fossils from an older bay represented by the ~125 kyr Yerba Buena mud to provide guidelines for using them for interpreting the deeper past. The Yerba Buena mud is up to ~35m thick and extends over much of the southern bay; hence it may represent several environments, not all of which are directly comparable to the modern one in the south bay. All the common foraminiferal species (*Ammonia beccarii* (Linne), *Buliminella*

elegantissima (d'Orbigny), *Bolivina striatula* Cushman, *B. vaughani* Natland, *Elphidium excavatum* (Terquem), *E. gunteri* Cole, *Elphidiella hannai* (Cushman and Grant), *T. inflata* (Montagu), and *T. hadai* Uchio) found in this study are estuarine and/or shallow-water species that now occur commonly in SFB.

The biodiversity and species composition of the two assemblages are nearly identical, suggesting that overall physical changes have not had significant affects. The dynamic nature of estuaries on a spatial and temporal scale may limit species that can inhabit them and not be conducive to changes in species diversity over either geologic or shorter time scales. Human pollution and sediment loading likewise have had little or no observable effects. However, population changes within species are significant between the ~125 kyr and modern bays. In particular, *T. hadai*, introduced from Japan about 1983 and absent from the older bay, now dominates the modern assemblage (56% of all foraminifera in South SFB). This introduction changed the species proportions in the modern assemblages. A large number of dead *E. gunteri* and *E. hannai* occur in the modern SFB, but live populations are largely absent, making interpretations of their presence in similar abundances in the Pleistocene and modern assemblages difficult. The introduction of *T. hadai* decreased the former Pleistocene dominance of *E. excavatum*.

These data show that comparisons between modern and fossil foraminiferal assemblages are powerful tools in interpreting paleoenvironments as most of the ecologic characters are maintained through significant changes. Because introductions of non-native foraminifera may change species proportions significantly, they must be identified before comparisons are made, and they and species proportions must be excluded from paleoecologic interpretations.

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ISSN 0101-9759 - Vol. 29 - 1 / 2006 p. 431-432