Accumulation of As, Pb, and Cu Associated with the Recent Sedimentary Processes in the Colorado Delta, South of the United States-Mexico Boundary

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Abstract Sediment cores from the Colorado River (CR) remnant delta were used to assess the changing sedimentation and pollutant deposition processes in response to extensive human manipulation of the river. The cores are formed of alternating layers of clays and silts, with isolated sandy horizons. The clayey units are interpreted as periods of flood flows into this low gradient and meandering estuary after dam construction in the United States. The geochemistry of these sediments is particular because of the association of MnO with CaO rather than with the Fe_2O_3-rich clays. Past pollution of the CR delta by As, and probably also Pb and Cu, is recorded in some cores. Enrichment factors (EFs)[1 for these elements and their statistical association suggest anthropogenic inputs. The most likely sources for these element enrichments (especially As) are the arsenate-based pesticides used intensively in the area during the first half of the 20th century. The transport of these elements from the nearby agricultural lands into the present river reaches appears to have been driven in part by flooding events of the CR. Flushing by river and tide flows appear to be responsible of a lower pollutant deposition in the CR compared to the adjacent Hardy River (HR). Arsenic in the buried clay units of the HR has concentrations above the probable toxic effect level (PEL) for dwelling organisms, with maximum concentrations of 30 lg g^{-1}. Excess ^{210}Pb activities ($^{210}Pb_{xs}$) indicate that fluxes of this unsupported atmospheric isotope were not constant in this estuarine environment. However, the presence of $^{210}Pb_{xs}$ does indicate that these sediments accumulated during the last *100 years. Approximate sediment ages were estimated from the correlation of historic flooding events with the interpretation of the stratigraphic record. They are in fair agreement with the reported onset of DDT metabolites at the bottom of one core.

Estuaries are natural sinks of dissolved fluvial ions in the mixing zone with seawater (Hunter 1983). A drastic modification in the magnitude of river flow may affect the rates and paths of several chemical, biological, and geochemical processes in an estuary. During the last hundred years human intervention has modified water and sediment flows to the Colorado River (CR) delta. Since 1932 the water crossing the Mexican-U.S. boundary was significantly reduced by the construction of the Hoover Dam, and during 1960–1979 practically no water flowed across the southern international boundary (SIB) due to filling of the Glenn Canyon Dam. Water surplus above the official quota for Mexico was only recorded until 1980, after Glenn Canyon dam was filled and excess water from unusual rainfall was sporadically released into the delta region (Fig. 1). The inflow of agricultural, geothermal, and municipal sewage discharges in addition to the high evaporation rates make the Colorado delta estuary an area that is especially sensitive to the accumulation of inorganic and organic pollutants. This area receives the agricultural return waters from the Mexicali Valley, which contain high concentrations of agrochemicals, as suggested from the 70,000 tons of fertilizers and 400,000 L of insecticides used alone during the 1990–1991 cycles in the Mexican part of the river basin (DGE 1993). Unlike the CR, the adjacent Hardy River (HR) derives its headwaters not only from agricultural returns and sewage, but also from the wastewater of the Cerro Prieto geothermal wells (Fig. 2). This geothermal power station started to operate in 1973 to export energy to the United States. High Hg, As, Sb, and B levels can be found near geothermal installations (Bargagli et al. 1997). Air and water pollution by Hg from the Cerro Prieto geothermal field has been reported (Acosta y Asociados 2001, in Yarto-Ramirez et al. 2004). Nevertheless, mean Hg levels in clam and fish tissue throughout the wetlands were below the 1.0 mg kg-1 FDA safe limits (Gutie´rrez-Galindo et al. 1988). In the nearby Salton Sea developmental defects in fish embryos have been suspected to be related with pollutants from municipal sewage and agricultural discharges (Matsui et al. 1992). An increased exposure to Se, B, and Zn in birds from the delta region was observed by Mora and Anderson (1991), who did not find evidence for Zn, Cd, Cu, or Cr in liver tissue above the known thresholds for biological effects in birds. According to García-Hernández et al. (2001), only Hg and Cd slightly exceeded the potential toxic threshold in few biota samples from the delta region. Shumilin et al. (2002) suggested that no pollution by metals occurs in the upper Gulf of California. However, their results on a single studied core indicate a twofold increase in As concentrations toward the older (bottom) part of their core, compared with its top half. Because of the strong influence of tidal

currents and the absence of freshwater flowing into the ocean, it is thought that any pollution was most likely recorded in the freshwater-estuarine unit of the delta region, rather than in the marine areas.

The present research is based on the hypothesis that the major fluctuations in river flow during the 20th century were recorded in the sediments from the Colorado delta. The main flooding events registered after 1935 and 1980 (Fig. 1) carried a significant load of sediments via the flushing of previously deposited material from the upstream reaches and dams. The sedimentation of the transported fine-grained particles partially took place in the lower reaches of the delta, where hydrodynamic energy was dissipated by the low gradient and meandering streams. The aim of the present study is to assess the historic variation in sedimentation and sediment geochemistry in the lower delta, as well as the deposition of inorganic pollutants, including As, Pb, Cu, Cr, and Hg, which are known to be potentially toxic.

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