# Sediment Story

**Sediment Setting**

The geology of the Salton Sea region provides a foundation and source for the detritus accumulating in the Salton basin, which today continues to fill in the Salton Sea itself. The characteristics of these sediments are influenced greatly by the setting in which they are found, including climate, topographic character of the landscape through which these sediments have been transported, the underlying bedrock from which the sediments were derived, and the nature of the final depositional environment for the detritus, such as lake, shoreline, dry wash, alluvial fan, etc. Distance from the source and method of transport determine the degree of sorting of the detritus, the grain size of the detritus, and the amount of rounding present on the detritus grains. The bottom sediments in the Salton Sea are important because they provide the substrate on which the organisms of the Sea live.

**Sediment Sources**

The sediments being deposited in the Salton Trough are either eroded from the Colorado Plateau, or are locally derived from the margins of the Salton basin. Detritus derived from the Colorado Plateau is composed of sand, silt and clay, and is generally deposited in deltaic and lacustrine facies in the southern part of the watershed. These sediments are also being filtered through the agricultural drainage system prior to deposition in the Salton Sea (Schroeder, 2001). Locally derived detritus consists of alluvial fan, braided stream or wash (fluvial), barrier beach, aeolian, and lacustrine deposits (Van de Kamp, 1973).

Regardless of source, all sediment can be deposited from bedload within any inflowing stream, and later reactivated as a suspended load. The predominant minerals represented in all sedimentary facies in the region are quartz and plagioclase, which are indicative of a granitic source rock. Various criteria indicate that most of the sediments (75%) have been derived from the suspended load of the Colorado River, and the remainder is of local origin (Arnal, 1961).

**Sediment Volume**

Total sediment accumulation within the main part of the Salton Sea since its formation between 1905 and 1907 is estimated to be 25 cm, based on sediment core data. The thickness of deltaic deposits in the Sea have never been determined by coring, but they are known to be greater in volume and more variable in grain size distribution than other sedimentary deposits found elsewhere in the Sea, and so have been estimated to be on the order of one meter in thickness.

Arnal (1961) estimated that 4000 acre-feet of sediments are being deposited in the Salton Sea each year, which amounts to only 4% of the total holding capacity of the Sea in 50 years of deposition. The sediment accumulation rate ranges from one inch (Schroeder, 2001) to two inches per year (Arnal, 1961) in the central part of the lake to 39 (Schroeder, 2001) to 190 inches per year (Arnal, 1961) in the New and Alamo River deltas. Without compaction of sediments and perhaps, crustal thinning and subsidence, the Sea at its present elevation would be filled with sediment in approximately 1250 years.

**Sediment Composition**

The sediments currently being deposited in the Salton Sea are comprised chiefly of silt, clay and finer sands, with abundant barnacle shells and occasional fish bones in the shallower areas. Sediment texture is sandier near the mouths of the New and Alamo Rivers, but finer grained and organic-rich towards the center of the lake. The percentage of coarser sand is greater in the deltaic deposits at the mouths of the New and Alamo Rivers due to the higher velocity of inflows emanating from those rivers, as opposed to the Whitewater River delta, which is composed primarily of silt, due to the generally lower velocity of the Whitewater (Vogl, 1999). The interior of the Sea receives a greater proportion of organic matter generated by the biota of the Sea, and calcium carbonate precipitating out of solution from the water of the lake itself (Schroeder, 2001).

The organic content of the bottom sediments in the lake is determined by phytoplankton distribution, sediment textures, and the circulation patterns of the Sea. Organic material is generally found to be at a low concentration (less than 1% of the sediments) in the nearshore areas, of high concentration (greater than 6%) in the deepest parts of the lake, and of moderate concentration (4 to 6%) in the areas between.

Seasonal variations in inflows to a lake as well as its biotic production are typically preserved in lake bottom sediments as visually distinctive annual patterns or layers. These strata are especially prominent where there are large differences in the climate between winter and summer, resulting in large variations in the biotic production that generates organic matter that is later incorporated into the accumulating detrital layer. Schroeder (oral communication, 2000) indicates that such seasonal layering is probably not readily distinguishable in the sediments of the Salton Sea, presumably due to the relative homogeneity of the climate for the region.

**Sediment Distribution**
The forces that drive the circulation of the Salton Sea are unable to transport coarser grained sediments for much distance beyond the inflow source points, but can move very fine mineral and biological particles around the lake (Vogl, et al., 1999). It is the proximity and size of the incoming rivers that determines grain size and the texture of the sediments, not transportation and sorting from lake circulation (Schroeder, 2001). Sandy facies dominate near Salton City, and extend into the deeper parts of the lake. Silt is common in the nearshore area along the southwest part of the Sea, and in the back bays near the New and Alamo River deltas. A clay layer blankets the southwest corner of the floor of the lake, and extends into the central parts of the Sea (Vogl, et al., 1999).

**Groundwater in the Salton Trough**
The sediments on the margins of the Salton Sea are highly impermeable, due to a composition high in finer grained particles and calcite. Because of the impermeability of these sediments, there is little exchange between the groundwater in the region and the water of the lake. A USGS study from the 1960's concluded that groundwater input to the Sea was less than one-half of one percent of the surface water input to the Sea.

The groundwater in the Salton basin is composed of two zones, an upper zone, which is usually less than 10 meters in depth, and a lower zone that predates the development of irrigated agriculture. The water in the upper zone is of highly variable salinity, and relatively high selenium content, since it is derived largely from infiltrating irrigation drain water that has been used to flush the agricultural fields in the vicinity. Freshwater runoff in the region is limited in volume, and locally can be the result of seepage from rivers and unlined canals. The lower zone has a relatively constant salinity, approximately one-third that of the Sea itself, and almost no selenium content, whose removal is accredited to microbial action (Setmire, et al., 1993).

The flow velocity of the groundwater in the Salton Trough is quite low, and interestingly enough, irrigation drainage apparently has not penetrated the lower groundwater zone. Depth of penetration by irrigation water does not extend beyond 50 feet anywhere in the valley, and in the artesian areas located in the north end of the valley, depth of penetration is considerably less. Groundwater recharge throughout the Salton basin is from precipitation in the local mountains, Colorado River underflow on the east side of the valley, and imported water from northern California (Setmire, et al., 1993).

**Chemicals in the Lake Bottom Sediments of the Salton Sea**
Inorganic chemicals found to be at concentrations of potential ecological concern in the Salton Sea region were cadmium, copper, molybdenum, nickel, zinc, and selenium, of which the most elevated relative to background levels were selenium and molybdenum. Cadmium and molybdenum were found at their greatest concentrations in the deepest part of the north basin, copper was highest near the mouth of the Whitewater River (also in the north basin), nickel in the deepest areas of both the north and south basins, zinc at the mouths of both the Whitewater River and Salt Creek, and selenium over much of the north basin. The highest concentrations of these contaminants were limited to the upper one foot of sediment, which given the sedimentation rate in the Salton Sea, indicates that most of these contaminants have been rafted into the Sea since the re-creation of the lake between 1905 and 1907. Many of the heavy metals have actually been associated with specific mineral assemblages and particular sediment grain sizes. Chromium and copper, for example, have been linked to fine-grained sediments, including silt, clay, and total fines. Molybdenum and cadmium are associated to coarser-grained, sandy sediments (Vogl, et al., 1999).

The most common organic compounds found in the sediments of the Sea included so-called volatile organic compounds, namely acetone, 2-butanone, and carbon disulfide, which are typically associated with natural biological processes. The sediments of the Sea are unique in that they have a high concentration of both organic carbon and sulfur, which probably affects the reduction or oxidation of these compounds. All three were most common in the deeper parts of the north basin, although carbon disulfide was also abundant at the mouth of the Alamo River, and 2-butanone in the deep part of the south basin. Acetone and 2-butanone are chemically very similar and are probably the result of decomposition of organic matter contained in the lake floor sediments (Vogl, et al., 1999).

Most of the organic chemicals commonly used in agriculture earlier in this century, such as DDT, were not detected in appreciable concentrations in the most recent studies. Most pesticides and herbicides commonly in use today were also not found in detectable concentrations. In fact, historical comparisons show that many of the organic and inorganic chemicals, especially pesticides, copper, and zinc, show a broad decrease in concentration in the area, although cadmium and selenium show a definite increase. Historical comparisons are somewhat limited in usefulness, however, because earlier studies tended to be focused on "hot spots" rather than being broad-based surveys. Some of the reductions in pesticide concentrations are likely the result of the chemistry of the Salton Sea, whose reducing environment, which becomes essentially all-pervasive during the frequent mixing events in the Sea, probably causes many chemicals to be sequestered through conversion into insoluble compounds (Vogl, et al., 1999).

**Selenium Transport**

Selenium is brought to the Salton Sea primarily in the Colorado River water used for irrigation in the Imperial and Coachella Valleys. Both nitrogen and selenium are brought to the Sea as oxy-anions, or in other words, attached to oxygen molecules. The water at the mouths of the New and Alamo Rivers is typically very high in dissolved oxygen, providing a mechanism for transporting nitrogen and selenium to the Salton Sea. Phosphorus, on the other hand, is usually attached to suspended sediments during its transport. Thermal stratification actually favors deposition and sequestering of selenium and nitrogen in the bottom sediment by maintaining low dissolved oxygen levels, which forces the selenium and nitrogen to precipitate out of solution as dissolved oxygen is depleted (Setmire, 1993).

The amount of selenium present in bottom sediments cannot be anticipated from the concentration of selenium in the water column, since rapid changes in flow rate can readily resuspend previously deposited materials. Adsorption is the key in the removal of heavy metals (such as selenium) from water; as the grain size of sediments decreases, heavy metal concentration increases (Setmire and Schroeder, ****). Thus, selenium is generally associated with finer-grained sediments (principally detritus less than 0.062 mm in diameter, or in other words, silt and clay), which require a lower water velocity to become resuspended than coarser sediments, that more readily allow fluctuations in the concentration of selenium in the water column.

**Selenium Accumulation**

Selenium accumulation is visible throughout each stage of hydrologic transport in the region. Soils of the region contain 0.2 ppm (parts per million) with an overall range of less than 0.1 ppm to 1.3 ppm observable, but bottom sediments in agricultural drains retain 0.5 ppm with an overall range of 0.1 to 1.7 ppm. Lake bottom sediments contain 2.7 ppm with a range of 0.58 to 11 ppm (Setmire, 1993), showing an accelerating rate of accumulation. Some selenium is undoubtedly lost in both the bottoms of the agricultural drains and in the lake itself, probably through reduction and bioaccumulation. High selenium concentrations correlate best to sediment areas with a very low particle size, especially less than 0.002 mm, and are found in the deepest parts of the lake, especially in mucky, fluffy lake bottom deposits, which are of low density and exceptionally rich in organic matter. The presence of high concentrations of selenium in fine-grained deposits rich in organic detritus is a direct indicator that the selenium was actually part of the biomass that decomposed and was deposited on the floor of the lake.

**Selenium Reduction**

Once the selenium and nitrogen are transported within the Sea via hydrodynamic circulation to areas low in dissolved oxygen, selenium and nitrogen are integrated with anoxic sediment on the floor of the Sea. Such sequestering of elements occurs through mineralization, or the formation of an insoluble compound that precipitates onto the floor of the Sea. Selenium and nitrogen concentrations should be present on the order of 100 parts per billion (ppb) and 400 ppb, respectively, but instead, are found at 1 ppb and 5 ppb, respectively (Schroeder, 2001). Selenium concentration in the water at the mouth of the Alamo River ranges from 0.2 to 0.3 mg/kg, but the sediments in the delta show a concentration of 0.2 to 2.5 mg/kg, and the embayments around the delta display concentrations ranging from 1.3 to 2.5 mg/kg, strongly indicating a natural removal mechanism for selenium in the Salton Sea, at least near the mouths of the New and Alamo Rivers at the south end of the Sea (Setmire, 1993).

The removal mechanism for selenium could simply be the "reducing conditions" that appear in the bottom waters of the Sea virtually throughout the year, but which are exacerbated during mixing events in the summer. Common evidence of these "reducing conditions" are the presence of black sediment and the generation of hydrogen sulfide gas, producing a "rotten egg" smell that is often detectable around the Sea. (Hydrogen sulfide is the result of the "reduction" of sulfate to hydrogen sulfide.) Another likely mechanism for sequestration of the selenium in the Salton Sea is the accumulation of selenium in the biomass of the region, with a perceptible increase in concentration as one ascends the food chain. Important concern to the publ[ic] buildup in fish tissue, et[c]

Selenium species include both selenite, which is reduced selenium, and selenate, which is oxidized selenium. Reduced selenium may be incorporated into selenite gypsum or similar minerals, which is common in depositional environments in which evaporation is a major player. Reduced species of selenium, including selenite, can adsorb onto finer-grained sediments as they settle out of suspension, thereby increasing the concentration of selenium present in lake bottom sediments. Selenate, or oxidized selenium, is virtually unavailable in the water column of the Salton Sea.

**Selenium Volatilization** definition

Once removed from the Sea via precipitation, substances can also be remobilized and reintroduced to the water column, a process known as internal loading. Remobilization can occur through a reversal of mineralization, such as if dissolved oxygen levels were to rise significantly, we would expect for nitrogen to be oxidized and turned into nitrates that can be used by the biota of the Sea for biologic production. Some of this nitrogen, however, could also be volatilized into ammonia gas, releasing nitrogen formerly pent up in the sediments directly into the water column, some of which might ascend to the surface of the lake and be released into the atmosphere. This particular process is one way the lake and lake sediments could be denitrified. Similar processes are expected to apply to selenium given the correct chemical conditions. So what, what would occur?

However, under current conditions, little or no selenium or nitrogen is being volatilized and lost to the atmosphere. Some bacteria are present in the Sea, which can, in theory, facilitate volatilization, but no nitrogen losses from this sort of process have been observed. Ironically, the anoxic conditions which are responsible for the odor problem around the Sea and which often lead to massive fish die-off events through the generation of hydrogen sulfide and similar products, actually inhibit selenium and nitrogen from being released back into the water column. High salinity also inhibits volatilization through chemical buffering of the waters of the Sea. Thus, all the selenium and nitrogen discharged into the Sea currently remains in the lake, probably sequestered in the bottom sediments or biota. Any actions taken that would affect the volume and chemistry of the Salton Sea must be concerned with these sequestering processes, and reactivation of contaminants that have been previously inactivated.

**Bioaccumulation of Selenium**

Unfortunately for the biota of the Salton Sea area, selenium bioaccumulates in the lower trophic organisms (those at the base of the food chain), and biomagnifies in the remainder of the food chain, causing the highest residues to be found in the upper trophic levels (peak of the food chain). Invertebrates in the Sea, such as pileworms (which are at the base of the food chain), have a critical dietary threshold of 5 ppm for selenium, yet the concentration of selenium in pileworms ranges from 0.8 to 12.1 ppm by dry weight, demonstrating that the pileworms often far exceed their safety threshold. Fish in the Sea retain higher concentrations of selenium than fish in the freshwater agricultural drains and rivers. Moreover, selenium concentrations are distributed such that the highest freshwater trophic levels are half those present in the highest trophic levels of the Salton Sea, showing that selenium is biomagnifying through the biota of the Salton Sea (Setmire and Schroeder, ****).

So what is the risk in concentrating selenium in the organisms in and around the Salton Sea? Selenium concentrations are already high enough to present potential hazards to the reproductive success of the indigenous wildlife in the region, particularly in the upper food chain organisms, like piscivorous birds that feed on the fish of the Salton Sea. High selenium concentrations can contribute to hatching failures via embryotoxicity (death or deformity of embryos) or teratogenesis (embryo and developmental abnormalities), although there is currently no evidence of teratogenetic problems at the Salton Sea. Nonetheless, hatching failures are sufficient to be depressing reproduction in selected species by a rate of approximately 5% (Setmire and Schroeder, ****).

Human consumption hazards?