Synthesis Document
of Current Information on the
Sediment Physical Characteristics and Contaminants
at the Salton Sea
Riverside and Imperial Counties, California

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Prepared for
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CONTENTS

1.0 INTRODUCTION

LFR Levine · Fricke (LFR) has completed a review of records contained within the archives of the University of Redlands Salton Sea Database Program (SSDP). A list of the reference documents requested and reviewed from the SSDP is presented in Section 5.0 of this report. For some of the references, only abstracts were available. References not received or that did not pertain to the Salton Sea ("the Sea") bottom sediment characteristics are not listed. All of the information presented below was obtained from the references listed.

1.1 Background

Extensive research has been performed in and around the Sea to characterize water quality and to evaluate biological impacts from contaminants. Even more geotechnical research has been conducted on the tectonics and geologic setting of the Salton Trough. However, information on the bottom sediment characteristics and contaminants of the Salton Sea is limited.

Previous studies on the Salton Sea bottom sediments have identified a variety of inorganic and organic chemicals including organochlorine pesticide residues of banned DDT [1,1,1-trichloro-2,2-bis (p-chlorophenyl)-ethane] and its derivatives, DDD [1,1-dichloro-2,2-bis (p-chlorophenyl)-ethane], and DDE [1,1-dichloro-2,2-bis (p-chlorophenyl) ethylene]. Many of these same chemicals, plus some additional ones, have been identified in the riverbeds feeding into the Sea, including DDT, DDD, DDE, dichloromethane, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), pesticides, selenium, and boron. Little is known about the current concentrations of these contaminants in sediments throughout the entire Salton Sea. Limited chemical data were collected by Bechtel (1997) at the Salton Sea Test Base, which comprises 13,462 acres of water located along Highway 86 at the southwest corner of the Sea and approximately 6 miles south of Salton City, and from Setmire and Stroud's (1990) irrigation study of the deltas and tributaries of the New and Alamo Rivers. Other documents which have provided the best available information to date on bottom sediment contaminants include Bechtel (1997), Eccles (1979), Hogg (1963), and Setmire [et al] (1993).

The geologic setting of the Salton Sea occurs in an area known as the Salton Trough. Some of the major contributors to the understanding of the tectonic systems present within the Salton Trough include Moran (1977), Babcock (1974), Thornton and Seyfried (1975), and Johnson et al (1994). Babcock (1974) noted that prior to deposition of the Borrego Formation, beds of the Shavers Well Formation were tilted and eroded, creating an unconformity upon which the Borrego lacustrine sediments were deposited and resulting in the current formation of the Salton Trough. It underwent repeated periods of desiccation interspersed with influxes of clayey/silty sediments, largely derived from the Colorado River. Thornton and Seyfried (1975)

In 1968, Van de Kamp (1973) investigated all the major facies within outcrops of the entire basin including lacustrine deposits, meandering channel deposits, alluvial fans and braided-stream deposits, and Aeolian sand deposits. Although none of the 18 core borings were collected from the Salton Sea bottom sediment, these cores provide information about the distribution and sources of sand and sediments within the Salton Sea watershed. The two major sources of sediments identified include the Colorado River and the basin margins. The Colorado River carried eroded debris from the Colorado Plateau to the southern part of the basin, depositing sand and mud in deltaic and lacustrine facies. The sediment deposits from sources at the basin margins were deposited in alluvial fans, braided streams, barrier beaches, and lacustrine beds.

Stephen (1972) investigated the New River delta and found it to have an extent greater than 15 km^2, draining 6,500 km^2 over its 150 km length. The suspended sediment load carried within the New River was estimated to be approximately 5.0×10^8 kg per year. This document provides descriptions of sediment mineralogy and grain size, and elaborates on the correlation of sediment size distribution with distributary patterns. Three years later, Stephen et al (1975) revisited the New River and reported on subaerial deposits comprising distributary channel, levee, and interdistributary subaerial flat and crevasse deposits. The investigators identified subaqueous deposits as largely prodelta clay and delta-front fine silt.

General conditions that affect sediments and distribution were best presented in Arnal (1961). The Sea's lowest elevation is -276.7 feet below sea level, with an annual temperature range from 10 to 34.5 Celsius. The Sea's currents move in a counterclockwise, gyral motion around the lake due to the influence of prevailing winds. Sand, silts, and clays are deposited in that order from the shore toward the center of the lake, where more fine sediments accumulate. The water content, amount of calcium carbonate, and natural characteristics indicate that most of the sediments (75 percent) were derived from the suspended load of the Colorado River, whereas the mineralogy suggests that some of the sediments have a local origin. The water content of the sediments varies in inverse ratio to the grain size, high (>50 percent) in clay depositions (the deepest lake sediment; grain size less than 4 microns) and low (~20 percent) where sand is deposited. The water content decreases with depth. The pH of the sediments is regulated by a variety of physical and chemical properties and reactions including carbonates, organic matter, carbon dioxide, and organic acids from the decomposition of plant and animal matter. The distribution of the organic content of the sediments is influenced by phytoplankton, the texture of the sediments, and currents. The distribution shows a low organic content (<1 percent) along the shore, with higher values (4 - 6 percent) found in the central part, and a maximum content (>6 percent) found 3 miles offshore, near Fish Spring. In all sediments, quartz and plagioclases are the dominant primary minerals.

Inflow rates to the Sea were calculated using limited suspended sampling data and historical suspended sediment sampling data observed from other major reservoirs in the southwestern United States (United States Department of the Interior, 1970). The Salton Sea watershed is approximately 8,360 square miles. The long-term average sediment inflow volume calculated was 4,000 acre-feet of sediment per year. Over a

2.5 mg/kg at sites throughout the Alamo River delta. Relatively high levels of selenium (1.3 to 2.5 mg/kg) were found in the embayments, without any discernable pattern of distribution. This area of investigation is depicted in Figure 1. Analytical results are summarized in Table 2.

The Bechtel (1997) report stated that organochlorine pesticides, PAHs, and volatile organic compounds (acetone, carbon disulfide, ethylbenzene, toluene, and xylenes) were detected in sediment samples collected from the shoreline disposal area. Elevated concentrations of copper (68.7 mg/kg), barium, and thallium were also detected.

Elevated concentrations of cadmium (maximum 1.6 mg/kg), arsenic (maximum 27.4 mg/kg), antimony (maximum 9.9 mg/kg), molybdenum (maximum 14.5 mg/kg), selenium (maximum 8.4 mg/kg), and vanadium (maximum 52.5 mg/kg) were detected in the offshore aeroballistic marine target area sediment. A localized area of elevated uranium (maximum 14.2 mg/kg) was also identified. The report concluded that: 1) these contaminants were naturally occurring, with the exception of cadmium; and 2) based on the limited source and nature of the cadmium release (nickel/cadmium battery), no further action was warranted.

Organochlorine pesticides (DDE, Dieldrin, gamma-Chlordane, and/or Heptachlor) were detected in 3 of the 14 sediment samples collected from the Imhoff Tank area. Phenol was also detected in one of the samples, and thallium (maximum 0.26 mg/kg) was detected in two samples. Bechtel concluded that except for the organochlorine pesticides (attributed to irrigation drainage), the presence of these contaminants in sediment did not present a significant risk. It is unclear if the data presented in Bechtel (1997) were reported in dry or wet weights. Table 2 summarizes these findings.

Hogg (1973) performed some of the earliest pesticide work on the bottom sediments. He collected 6 substratum samples using SCUBA gear and 16mm (inner diameter) by 23cm long coring tubes. Mean values (reported in micrograms per kilogram; µg/kg) for pesticide residues of Dieldrin, DDT, DDD, DDE, and combined samples for the upper and lower layers of the core samples are summarized in Table 2. Based on his small data set for sediment contaminants, Hogg calculated the presence of 10,400 pounds of total DDT and its metabolites in the upper 12 cm for the entire Sea.

Eccles (1979) provided values for DDE concentrations in bottom sediment samples collected in tributaries to the Salton Sea. Eccles collected samples in 1977 and found concentrations of DDE at Avenue 64 Evacuation Channel (67 µg/kg) and at Trifolium Drain 1 (110 µg/kg).

4.0 CONCLUSIONS

Limited data representing current conditions of the Salton Sea bottom sediment types and contaminants are available. However, sufficient data have been collected over the past 26 years to show that the Salton Sea and surrounding tributary bottom sediments

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Table 1: Concentrations of Inorganic Chemicals in Sediment from the Salton Sea and Surrounding Tributaries Determined to be of Concern

Location	Chemical (concentrations in mg/kg)													
	Antimony	*Arsenic*	*Barium*	*Cadmium*	*Chromium*	*Copper*	*Molybdenum*	*Nickel*	*Selenium*	*Thallium*	*Thorium*	*Uranium*	*Vanadium*	*Zinc*
Max. Baseline Value mg/kg *(a)*		22	1,700		200	90	4	66	1.4		20	5.3	270	180
Salton Sea median conc.(mg/kg) *(b)*		5.6	550		58	28		25	0.7		10.6	4.9	77	78
Whitewater River upstream from HWY 111 *(b)*		2.4	690	<2	81	34	<2	30	0.1		56	14.6	140	110
Whitewater River at outlet *(b)*		5	710	<2	210	64	3	170	0.5		18.9	5.5	130	510
Alamo River at international boundary *(b)*		6.3	510	<2	58	26	<2	26	1.6		12.2	4.8	77	97
Trifolium Drain 1 *(b)*		5.8	550	<2	53	28	<2	24	1.9		9	4.4	72	78
Ave 64 Evacuation Channel at HWY 195 *(b)*		4.4	620	<2	75	61	2	2	0.4		21.3	5.1	120	130
New River at midpoint (08/11/86, 08/14/86) *(b)*		5.4, 11.0	580, 780	<2, <2	63, 73	30, 27	<2, 2	25, 35	0.6, 1.3		10.6, 12.0	6.1, 7.5	77, 96	75, 120
New River at outlet *(b)*		4.7	720	<2	70	23	<2	22	0.6		19.2	7.7	82	71
East Highline Canal *(b)*		4.5	690	<2	50	23	<2	22	0.9		12.7	5.9	60	70
Alamo River delta *(c)*									0.2 - 2.5					
Shoreline Disposal Area *(d)*		0.9	315		33.9	68.7				0.31			2.6	8.6
Offshore aeroballistic marine target SSTB *(d)*	9.9	27.4		1.6			14.5		8.4			14.2	52.5	
Imhoff Tank *(d)*										0.26				

NOTE:
(a) Shacklette & Boerngen, 1984
(b) Setmire & Stroud, 1990
(c) Setmire [et al.], 1993
(d) Bechtel, 1997 (maximum concentrations reported)

Table 2: Concentrations of Organic Chemicals in Sediment from the Salton Sea and Surrounding Tributaries Determined to be of Concern

Location	Chemical (concentration in ug/kg)															
	Acetone	*Carbon disulfide*	*Chlordane*	*DDT*	*DDD*	*DDE*	*Dieldrin*	*Ethylbenzene*	*gamma-Chlordane*	*Heptachlor*	*Methoxychlor*	*PAHs **	*PCBs*	*Toluene*	*Toxaphene*	*Xylenes*
Whitewater River upstream from HWY 111 *(b)*			<1.0		<0.1	0.6					<0.1		<1		10	
Alamo River outlet *(b)*			<1.0		20	64					<0.1		<1		<10	
Alamo River at international boundary *(b)*			<1.0		2.3	18					<0.1		9		<10	
Trifolium Drain 1 *(b)*			<1.0		3.7	41					<0.1		<1		<10	
Trifolium Drain 1 *(e)*						110										
Trifolium Drain 4 *(b)*			<1.0		12	56					<0.1		<1		40	
Vail Drain 4 *(b)*			<1.0		7.8	57					45		<1		<10	
Ave 64 Evacuation Channel at HWY 195 *(b)*			1		5.8	56					<0.1		<1		<10	
Ave 64 Evacuation Channel at HWY 195 *(e)*						67										
New River at midpoint (08/14/86) *(b)*			5		3.5	7.4					<0.1		4		<10	
New River at international boundary *(b)*			20		24	7.6					<0.1		24		<10	
East Highline Canal *(b)*			<1.0		2.3	18					<0.1		9		<10	

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Table 2: Concentrations of Organic Chemicals in Sediment from the Salton Sea and Surrounding Tributaries Determined to be of Concern

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		Acetone	*Carbon disulfide*	*Chlordane*	*DDT*	*DDD*	*DDE*	*Dieldrin*	*Ethylbenzene*	*gamma-Chlordane*	*Heptachlor*	*Methoxychlor*	*PAHs **	*PCBs*	*Toluene*	*Toxaphene*	*Xylenes*
Shoreline Disposal Area *(d)*		23	2		3.1	4.9	6.6	3	2	3.4	3.5	14	85		15		11
Imhoff Tank *(d)*							3.2	0.6		190	290						
1 mile from Whitewater River outlet *(f)*	0-11.5 cm				<25	5	5	<5									
	11.5-23 cm				<25	<5	<5	<5									
2.5 miles from Whitewater River outlet *(f)*	0-11.5 cm				<25	5	5	<5									
	11.5-23 cm				25	20	23	<5									
5 miles from Whitewater River *(f)*	0-11.5 cm				<25	12	14	<5									
	11.5-23 cm				25	5	5	5									
1 mile from Alamo River outlet *(f)*	0-11.5 cm				25	5	5	92									
	11.5-23 cm				25	5	5	100									
2.5 miles from Alamo River outlet *(f)*	0-11.5 cm				25	5	16	49									
	11.5-23 cm				82	5	18	880									
5 miles from Alamo River outlet *(f)*	0-11.5 cm				25	5	5	60									
	11.5-23 cm				25	5	5	43									

NOTE:

(a) Shacklette & Boerngen, 1984
(b) Setmire & Stroud, 1990
(c) Setmire [et al.], 1993

(d) Bechtel, 1997 (maximum data reported)
(e) Eccles, 1979
(f) Hogg, 1973

* Polycyclic Aromatic Hydrocarbon (PAHs) values are for Benzo(a)anthracene and Chrysene

the reverse of each turn in the process applied in the opposite order, $(\mathbf{XY})^{-1} = \mathbf{Y}^{-1}\mathbf{X}^{-1}$. Any process followed by its inverse produces the *identity*, or do-nothing process in which every piece is left in or returned to its original location.

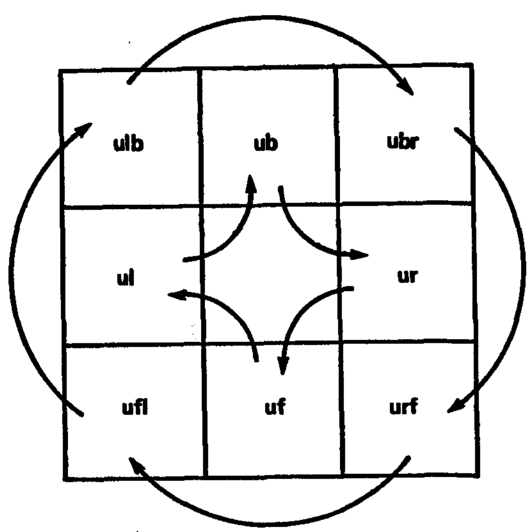
As stated earlier, turns of the Cube faces cause the cubies to change places with one another. Such a rearrangement of a finite set of objects is called a *permutation* [FS]. To describe a permutation of the cubies, we create a list showing where each piece is move and specifically indicating the new location of each facelet. For example, if the cubie in the up front left corner is moved to the right back down location we write

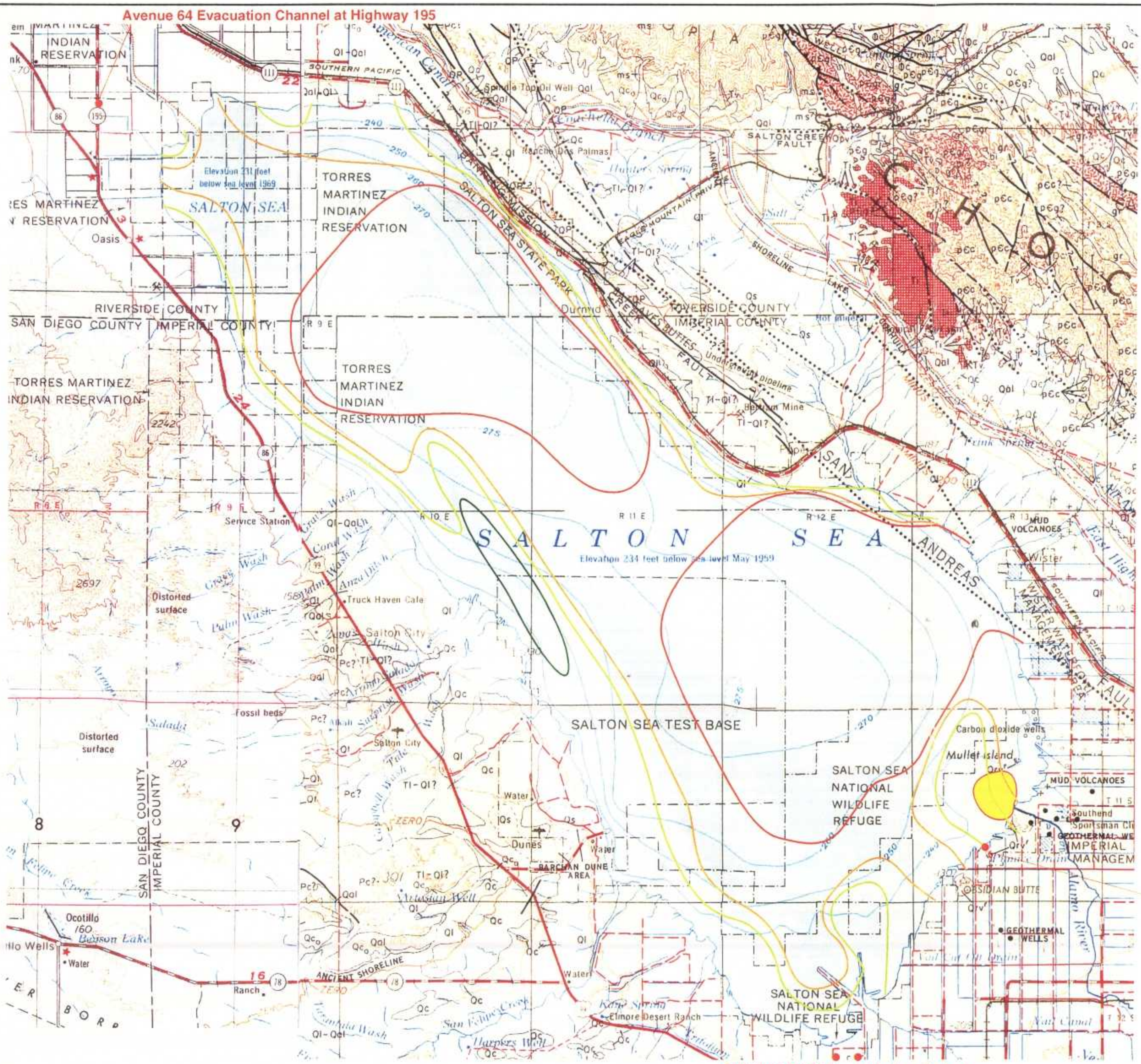
$$\mathbf{ufl} \rightarrow \mathbf{rbd}$$

to indicate that the up facelet is moved to the right facelet position, the front facelet is moved to the back position and the left facelet to the down position. An example of a process that causes this change is $\mathbf{LDR}^{-1}$.

The permutation caused by a single clockwise turn of the Up face would result in moving the pieces from the locations listed on the left below to the new positions listed on the right as indicated by the arrows [FS].

uf → ul
ufl → ulb
ul → ub
ulb → ubr
ub → ur
ubr → urf
ur → uf
urf → ufl





EXPLANATION

Selenium Assessment Area
Setmire [et al], 1993.

Sediment Investigation,
Setmire and Stroud, 1990.

Sediment Grain Size

- Sand 256-1,000 µm
- Fine Sand 64-256 µm
- Fine Sand 16-64 µm
- Silt 4-16 µm
- Clay ≤ 4 µm

NOTE: Grain Size of lake bottom sediments (after Arnal, 1961)

0 6 Miles

MAP SOURCES:

- State of California - *Division of Mines and Geology*, Geologic Map of California (Jenkins), Salton Sea Sheet, 1977.
- U.S.G.S Topographic Map, 1:250,000', Santa Ana, California, 1981.

Salton Sea

Salton Sea
Bottom Sediment Sampling Sites

Figure 1
Project No. 6824

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