Chapter 2

HISTORICAL SHORELINE CHANGES: NATURAL AND ARTIFICIAL

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Introduction

The East Bay shoreline has undergone many changes since the 1850'a due to the introduction of land fill and piers by man, and the resulting natural reactions, such as shallowing waters and growth of marsh. A description of these changes, as determined from aerial photographs, nautical charts and historical maps, is presented here.

Little of the shoreline under consideration is original (FIGURE 1). For the most part, this is due to man-made land fill, which has extended the shore an average of over 1000 feet (300 meters) into the bay from its original (1850's) position. Construction of piers and marinas has also caused major changes in current, wave and siltation patterns, beach placement, and marsh growth.

Wave and Current Theory

The extension of a land mass into bay waters has an effect on current and wave patterns, and thus on sedimentation patterns. Newly-introduced points of land will obviously affect local currents; they can also alter the direction of, or completely block, incoming waves. The direction and strength of waves (and of currents) is important to the stability of beaches and marshes.

Waves approaching the shore at an angle have a tendency to refract, becoming more parallel with the shore as the water becomes shallower. The portion of the wave's energy that was not directed toward the shore, but rather along it, is transferred into a current which runs parallel to the shore. This is known as a longshore or littoral current (FIGURE 2), and it carries sediment and debris with it down the shore (longshore drift). To prevent this movement of sand (and ultimately its total removal, if there is no replacement), groins can be placed out into the water to trap the sand as it goes by (FIGURE 3).

If a structure is built into water such that waves are completely stopped, or if a protecting headland is already present, the region behind the headland will

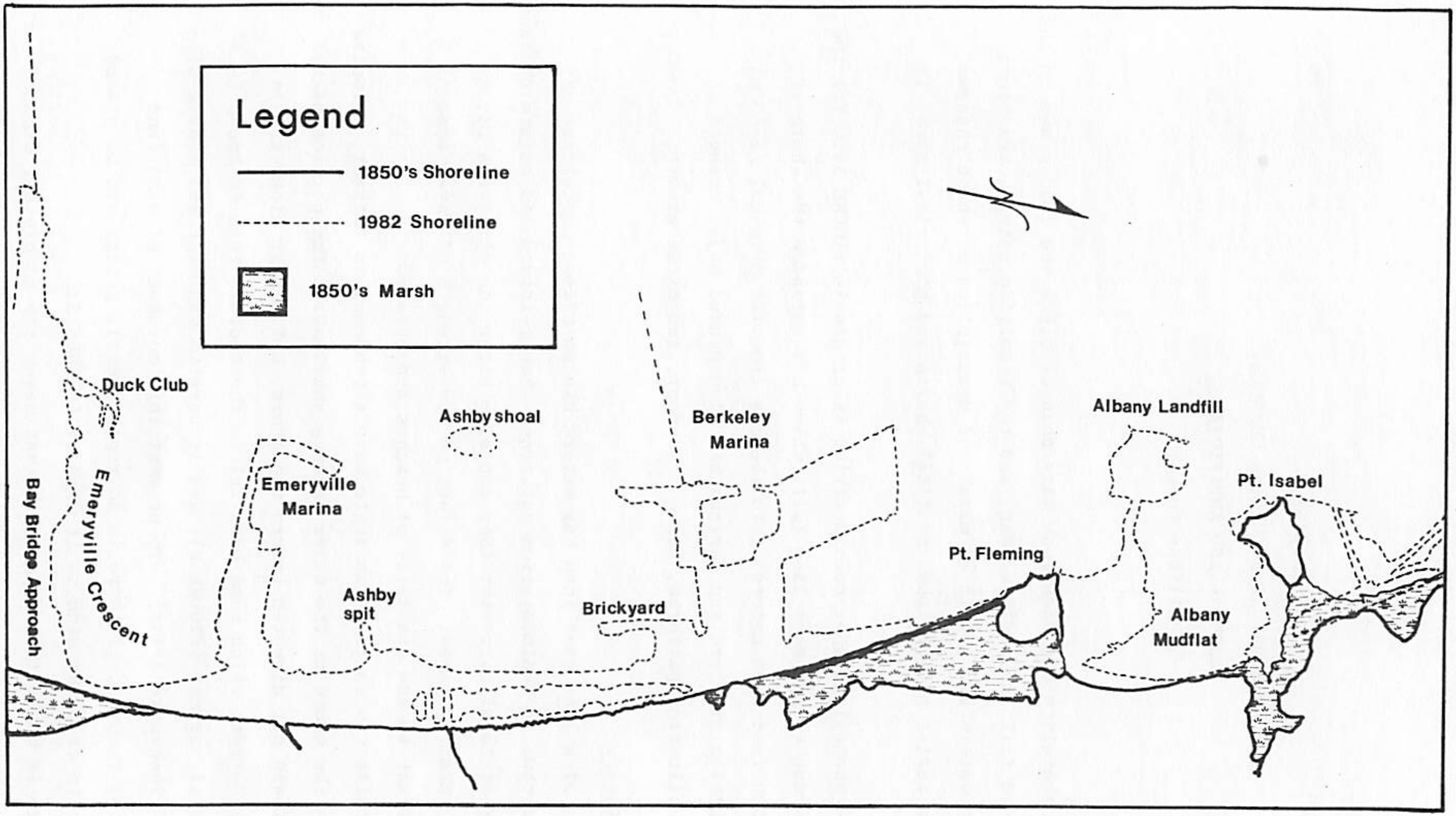


FIGURE 1. The Original East Bay Shoreline. (See FIGURE 5 for approximate dates of fill.)

Source: Nichols and Wright, 1971.

slope gradually as sediment accumulates in these calmer waters, and unprotected shores will drop off more steeply. Thus, any introduced fill which projects into the water could have one of two effects. Either sand will build up on the down-current side, and be removed to some extent up-current, as shown in FIGURE 3, or if the fill is in such a form that it protects the shore from waves almost entirely, sediment will slowly build up in the area behind the fill, making a shallow, gradual slope: a mudflat and, if left long enough with appropriate tidal action, a marsh (Bascom, 1964; Friedman and Sanders, 1978). My research examines the East Bay shoreline for changes such as these.

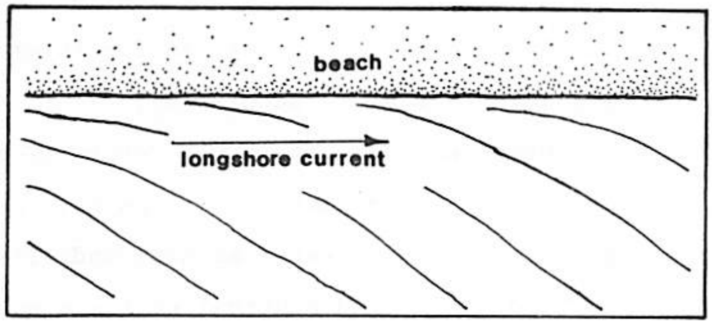


FIGURE 2. Littoral Current produced by waves.

Source: Bascom, 1964; Friedman and Sanders, 1978.

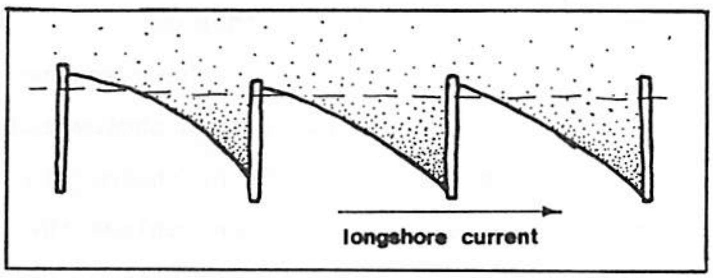


FIGURE 3. Groins reduce longshore movement of sediment.

Source: Bascom, 1964; Friedman and Sanders, 1978.

<u>Sources and Methods of Examining Data</u>

Three different resources were used to obtain data: 25 nautical charts (1903 to 1981), 93 aerial photographs (1931 to 1981), and one historical map (1850's; Nichols and Wright, 1971) (Appendix A). Each of these resources has specific advantages and limitations.

Nautical charts are available for many years and have both depth recordings and an accurate coastline, but do not include wave direction or currents. (Tidal current charts are available, but currents are not given in enough detail to be of value in this study.) Aerial photographs often show waves, but depths are quite difficult to determine, especially in San Francisco Bay where the water is too muddy for direct measurement (see Lundahl, 1948, for discussion of direct measurement of water depth from aerial photographs).

Aerial photographs often do not cover the entire area under consideration, and photos for early dates are not available. In addition, they are occasionally of such a small scale that measurements are difficult to make, and the division between land, marsh and mudflat is sometimes difficult to see. They do, however, give a very accurate description of the land/water division around land fill which has steeply sloping shoreline (where differences due to tides are not extensive). Since most aerial photographs are taken from an approximately vertical position (straight up), all distances on the photograph are to the same scale. Oblique angle photographs do not have this advantage, presenting instead a panoramic view. These photographs are valuable for qualitative information only; distances and areas are almost impossible to measure accurately.

Aerial photographs have a record of marsh, beach and mudflat, which nautical charts do not, and historical maps have only occasionally. Dates for aerial photographs are more accurate, as days and often even the time are recorded directly on the photo. Maps and nautical charts are accurate only within a year at best, as data are compiled over a span of time before publication. Historical maps have many limitations, including all of those described for nautical charts. In addition, they do not have depth recordings and their coastlines are possibly less accurate, especially on older maps.

The data obtained from these sources are not in a readily usable form. Distances and areas measured from photos and maps must be converted to true distances using the scale of the map or photo. In cases where a scale is not recorded on a photograph (usually the case, unless the photo was enlarged or reduced to fit a specific scale), the distance between two prominent objects must be measured on the photograph and compared with the same distance on a map, and a scale calculated. With aerial photographs, wavelengths measured may be converted to water depths, as long as one depth is known to a reasonable accuracy for each set of photographs. (This depth can be obtained from nautical charts.) The formula for this conversion is

$$T^2 = \frac{2\pi\lambda}{g} \cot h \frac{2\pi d}{\lambda} \quad \text{(Lundahl, 1948)}$$

See Appendix B for additional discussion and actual calculations.

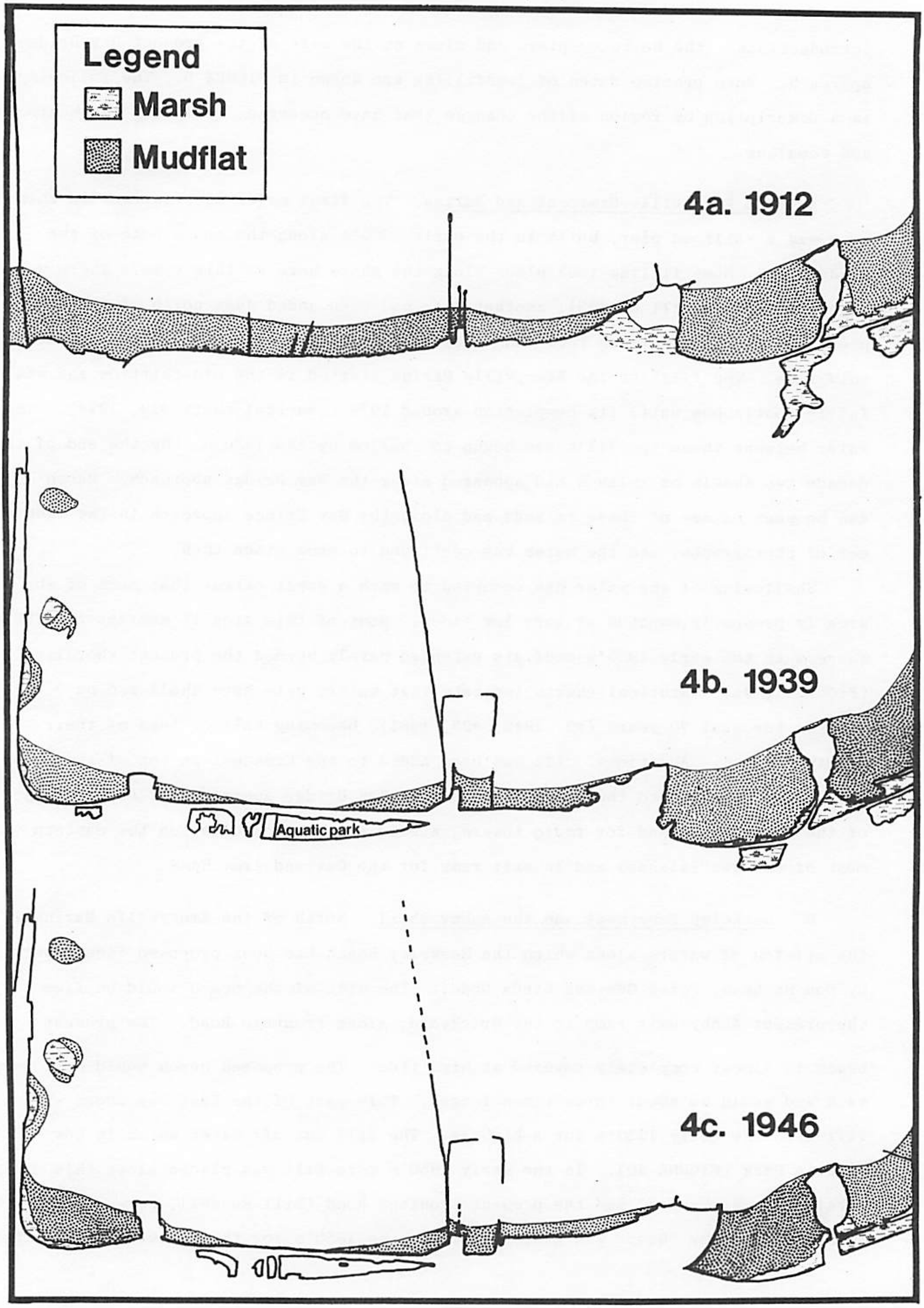
East Bay Shoreline Changes

Examination of charts, maps and photographs shows that the shoreline has changed extensively since man's first major construction of piers in the area. The original shoreline was a fairly smooth sweeping curve south from Point Fleming, with the exception of minor creek deltas (FIGURE 1). FIGURE 4a shows some of the first introductions: the Berkeley piers and piers on the site of the present Bay Bridge approach. More precise dates of landfilling are shown in FIGURE 5. The following is a description by region of the changes that have occurred, including marsh growth and shoaling.

A. The Emeryville Crescent and Marina. The first major construction in this area was a railroad pier, built in the early 1900's along the south edge of the study area. Some filling took place along the shore here at this time. There was a good deal more fill by 1931; another pier had been added just north of the old pier, and the area between them was filled (FIGURE 4b). No marsh was present at this time. The fill for the Emeryville Marina started in the mid-thirties and was fairly continuous until its completion around 1974 (nautical chart #19, 1974). The water between these two fills had begun to shallow by the 1930's. By the end of that decade two shoals or islands had appeared along the Bay Bridge approach. Marsh can be seen on one of these islands and along the Bay Bridge approach in the 1946 set of photographs, and the marsh has continued to grow since then.

Shallowing of the water has occurred to such a great extent that much of the area is presently exposed at very low tides. Most of this area is mudflat (FIGURE 4e), whereas in the early 1900's mudflats extended barely beyond the present shoreline (FIGURE 1, 4a). Nautical charts indicate that waters here have shallowed by 3 to 7 feet in the past 70 years (#2, 1912; #25, 1981), becoming half or less of their original depth. Additional fill has been added to the Crescent on top of new marsh. Fill has been added to the north shore of the Bay Bridge approach for construction of the toll plaza, and for radio towers, a road to the Duck Club (on the eastern most of the two islands) and an exit ramp for the Oakland Army Base.

B. Berkeley Embayment and the Ashby Shoal. North of the Emeryville Marina is the stretch of waters along which the Berkeley Beach has been proposed (see papers by Don Bachman, Peter Gee and Linda Goad). The site of the beach would be from the present Ashby exit ramp to the Brickyard, along Frontage Road. The present beach is almost completely covered at high tide. The proposed beach would have more sand and would be about three times longer. This part of the East Bay shore was filled in the early 1930's for a highway. The fill cut off water which is now Aquatic Park (FIGURE 4b). In the early 1950's more fill was placed along this stretch for Highway 80 and the present Frontage Road (Bill Russell, pers. comm., 1982). The Ashby "Bump" was placed there in the 1950's for the Ashby exit, and the


Legend
Marsh
Mudflat
4a. 1912
4b. 1939
Aquatic park
4c. 1946
Aquatic park

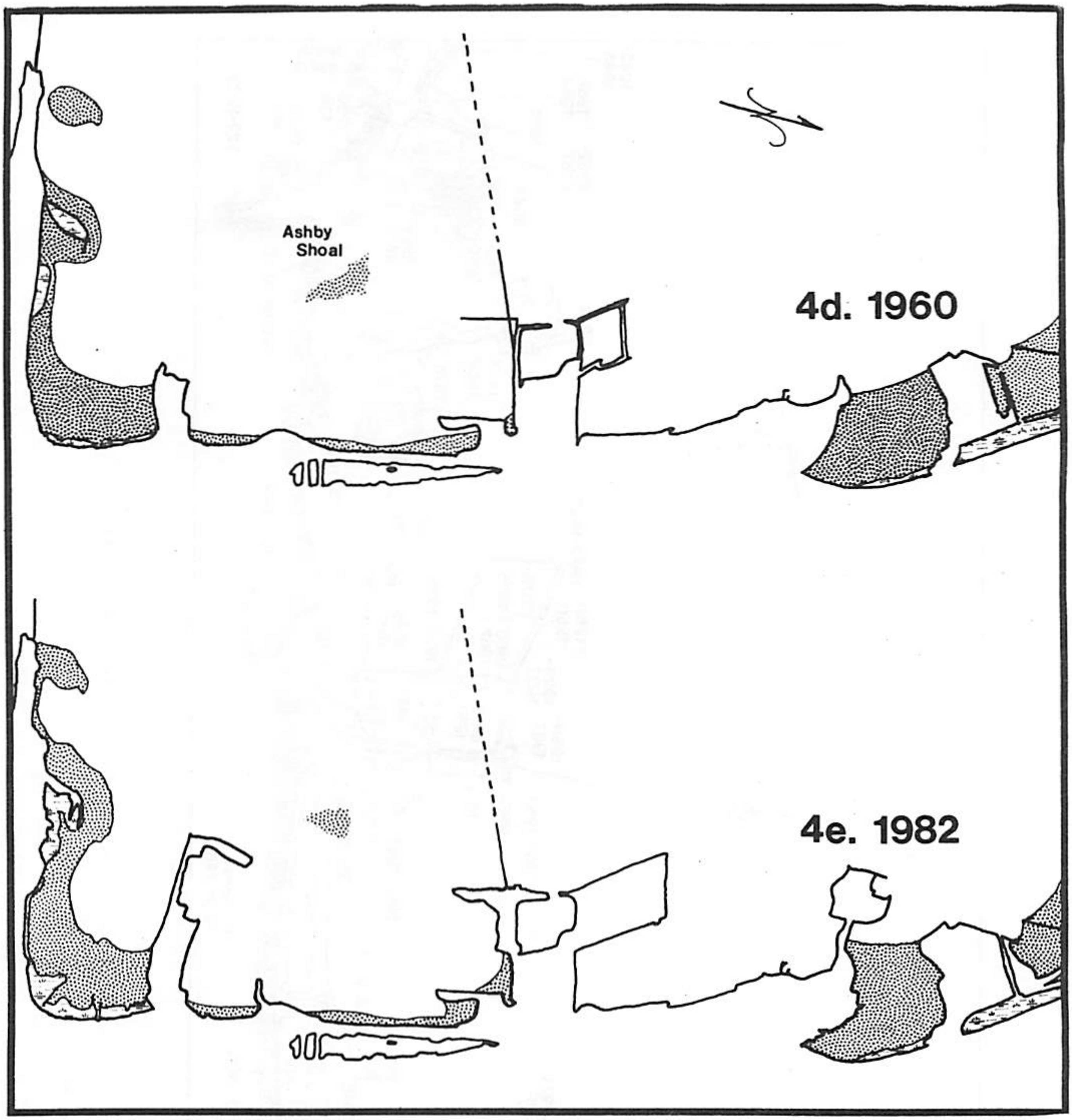


FIGURE 4. Progressive changes to the shoreline, as seen on aerial photographs. Mudflat area was estimated from mean lower low water on nautical charts. FIGURE 4a was determined from nautical charts; the rest from aerial photographs.

Source: Aerial photographs #13-34, 77-90; nautical charts #2, 6, 9, 11, 25.

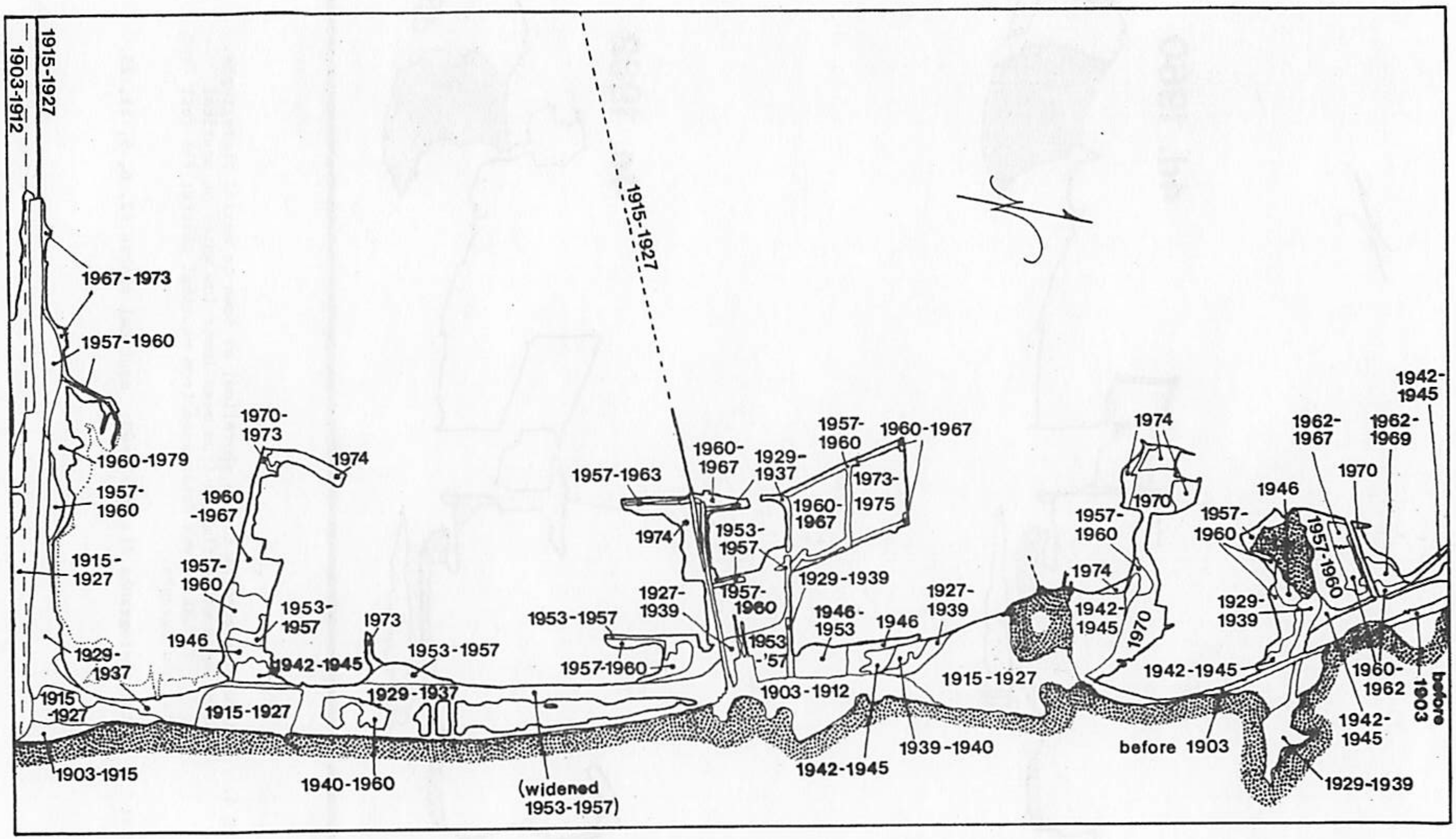


FIGURE 5. Dates of Landfill. Fill occurred between dates listed, not necessarily continuously.

Source: Aerial photographs #1-93; nautical charts #1-25.

Ashby spit went in about 1974. Fill for the Brickyard was completed by 1970 (see paper by Debbie Robinson).

The first appearance of the Ashby Shoal on aerial photographs studied was in 1960 (FIGURE 4d). It may have been formed solely during highway construction. Mud was pumped from the highway site out into the bay and sand pumped from the bay back to the site, since fine bay mud is not ideal for building on (see paper by Mary Dresser). It is possible that the Ashby Shoal is a result of the mud pumped out there and a hole, to the southwest of the shoal, about 25 feet deep (nautical chart #25, 1981) is left from the removal of sand (Bill Russell, pers. comm., 1982). That there was sand in this region indicates that circulation patterns had allowed sand to accumulate, instead of bay mud, prior to highway construction. It is possible that a shoal had also begun to form naturally. The shoal and hole were not present in 1939 (FIGURE 4b); data compiled from photographs shows a slight bar about 1000 feet farther west than the present shoal site (see Appendix B). This bar was smaller and deeper than the shoal. That the bar is the initial appearance of the shoal is possible, but I do not think it likely, due to the differences in location. The bar may well have been the source of sand used in highway construction. Since no waves are shown in 1946 photographs, depths could not be calculated, but no change in tone is present on photographs where the shoal now is. Photos from 1960, in contrast, show marked tonal changes in the region of the shoal (FIGURE 4d). Nautical charts do not record the shoal until after 1968 (nautical chart #14, 1969).

C. Berkeley Marina. The earliest piers were constructed at this site around the turn of the century. The longest one in 1912 was no longer in use by 1927, and fill since then has covered it over. The old pilings run under University Avenue, and have caused some problems of uneven settling. The area known as the Murphy-Santa Fe land, The Meadow, or The Kite Field, was filled between 1953 and 1967, after which the north arm of the marina landfill was started. This area is still being filled and is nearly completed.

D. Point Fleming and the Albany Landfill. Point Fleming is original bedrock, a peninsula connected to the mainland only by marsh in the 1850's. By 1912 some fill had occurred in the form of a road to the point, and two piers had been built off the point. These piers are not the same two which are there at present. One of the original two has since been covered over by landfill. All that is left of the other is a few pilings, south of the present piers which were probably built in the 1930's. The marsh between Point Fleming and the mainland was filled in completely by 1927, and landfill began to the north and south at that time. The Albany landfill has gone in gradually and fairly continuously up until the present. It is nearly finished, except for a proposed marina to the south. There was originally a beach along the southwestern shore of Point Fleming. The sand from this beach was gradually all hauled away for building foundations. The beach has not reappeared, although two other beaches have appeared just north of this site near the two new piers.

Response to Fill

Marsh Expansion: The appearance of the extensive marsh in the Emeryville Crescent is a major natural response to past man-made fill. FIGURE 6 shows the expansion of this marsh from 1931 to the present as shown on aerial photographs. Some inaccuracy is present due to tide levels (high tides cover some vegetation), in addition to inaccuracies discussed under Sources and Methods of Examining Data. Area given in FIGURE 6 is actually that of total vegetation, which includes trees, bushes and introduced plants, such as iceplant on higher ground (inland border of marsh). Some regions which developed into marsh were subsequently covered over by land fill, which is also included in the area on FIGURE 6. The general trend, if the growth of area is approximately linear (solid line, FIGURE 6), is for marsh area to increase at a rate of about 2 acres (7000 m^2) per year. The total area of the Emeryville Crescent region (Bay Bridge approach to Emeryville Marina) is approximately 650 acres (2.7 million m^2), and at present 14% is covered with marsh. The growth of marsh appears to be exponential (broken line, FIGURE 6). If this is the case, then the marsh is expanding at a rate greater than two acres per year, and this rate will continue to increase until some limiting factor, such as deep water, currents, or strong waves, is encountered.

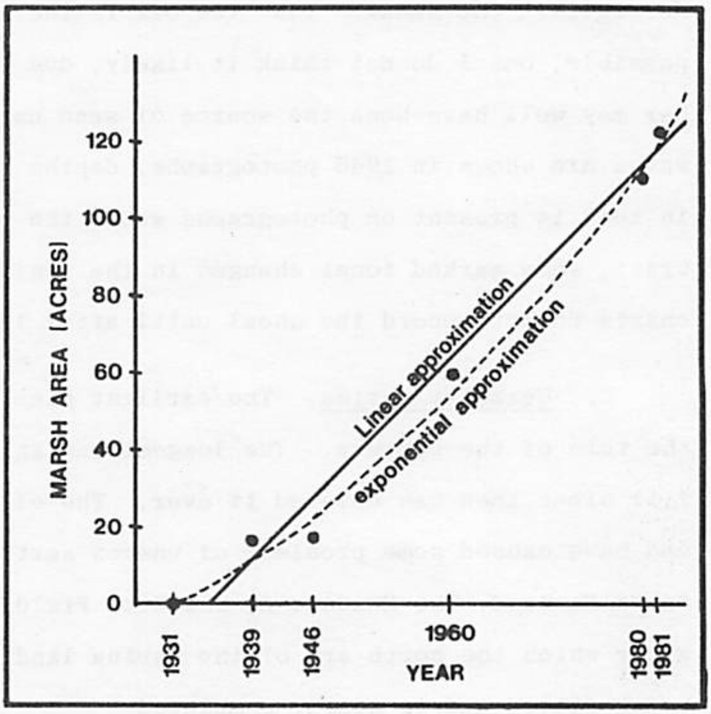


FIGURE 6. Growth of Marsh in the Emeryville Crescent.

Source: Aerial photographs #1-12, 16-18, 32, 89, 92.

Beaches: FIGURE 7 records beaches as seen on aerial photographs. It should be noted that these "beaches" are not necessarily desirable picnic spots: they are sites where silt, sand, pebbles, rocks and debris have collected due to wave and current action. Such sites, while not necessarily desirable at present, might hold sand placed there. They are, therefore, prospective sites for man-made beaches. Other studies must be done, of course: if materials at the sites have a high turnover rate or these materials are not suitable for a beach, providing a constant outside supply of sand may be too costly. If a large amount of debris is constantly washed up on the shore a beach may not be practical there either.

Almost all waves seen on aerial photographs follow a gentle curve along their length which matches the original curve of the shoreline, until they come close enough to shore to encounter the effects of new fill. In these areas, some refraction occurs. These waves indicate that prevailing winds come from the west, if the waves seen on aerial photographs can be assumed to be representative of average waves. Study of the direction of waves in relation to beaches present along the East Bay shoreline reveals that beaches are or have been present only where waves are consistently parallel to the beach. Waves were parallel to the old Berkeley Beach site (FIGURE 7, A) in 1939. In 1977 and 1979 photos (#38, 67) the waves are at about a 30° angle, and in 1978 (#52) the waves are virtually perpendicular to this shore. This change in wave direction may be due to refraction around the Berkeley Sanitary Landfill.

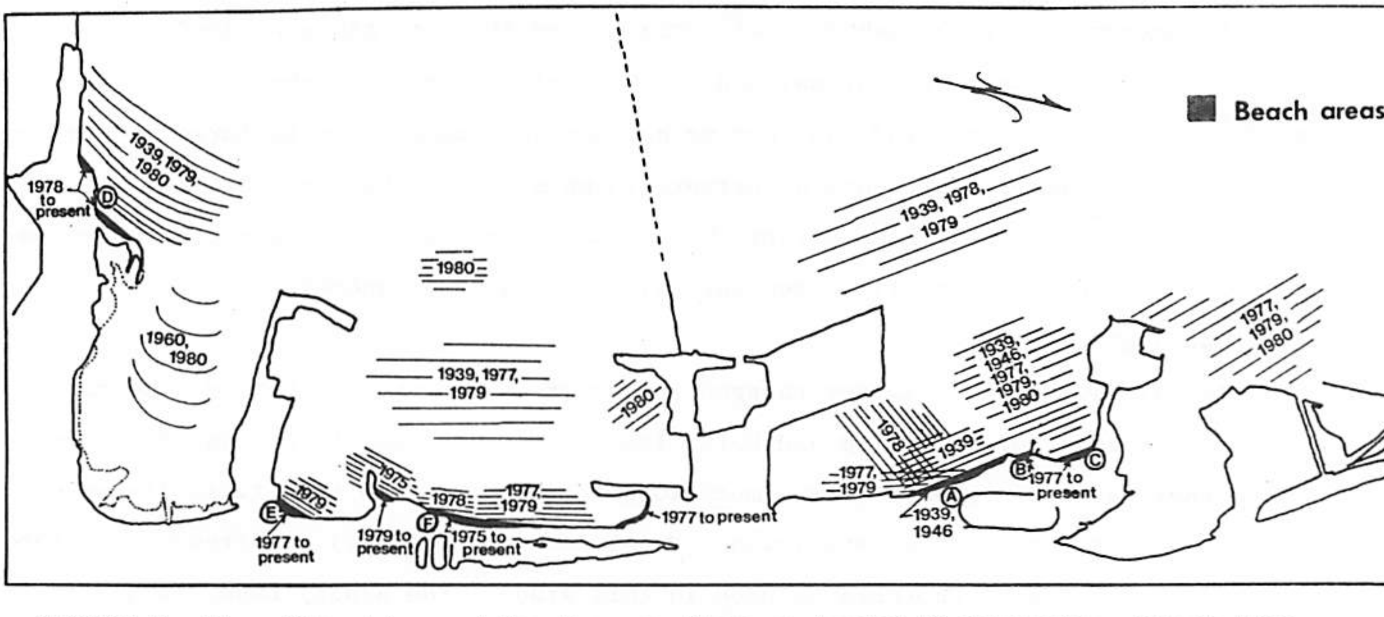


FIGURE 7. Wave Direction and Beaches, as Seen on Aerial Photographs. Beach Size Is Exaggerated for Clarity.

Source: Aerial photographs #13-30, 37-47, 51, 63, 66, 77-93.

The original beach has not returned for two possible reasons: (1) there was not a supply of sand to replace it, or (2) the wave action has prevented replacement. Two small beaches have developed just north of the original site (B, C, FIGURE 7) where the wave action has not been blocked. This wave action has been within 10^{o} of parallel to the shore, as seen in 1977, 1979 and 1980 photographs (#43, 60, 66, 82, 83). Beaches were not present here prior to 1945 because landfill had not yet created this shoreline (see FIGURE 5). Beaches have also developed along the west shore of the Duck Club road (D, FIGURE 7) and at Carlos Murphy's (E, FIGURE 7), where waves are parallel to the shore in 1979 photographs. The beach which has developed on the proposed Berkeley Beach site (F, FIGURE 7) has had waves within 10^{o} of parallel for recent years (1977-81, earlier data are not available).

<u>Summary</u>

Emeryville Crescent waters have shallowed considerably in the past seventy years. The material probably placed there during highway construction has not been removed by wave action or currents, and considerable additional shallowing has taken place since the construction. A protecting headland (the Emeryville Marina) has been present for the past fifteen years. Combined with the Duck Club peninsula, waves are mostly blocked; only a small protion of the wave energy enters these waters and these waves are highly diffracted (see FIGURE 7). The Bay Bridge approach has had solid fill for about fifty years, and has acted as a groin, trapping material.

The Berkeley Embayment has shallowed by only about one foot in seventy years, with the exception of the Ashby Shoal. The Embayment, too, has a projecting fill to the north, the Berkeley Marina, and the Emeryville Marina to the south, but wave action is from the west, and the opening between the two marinas is large enough for the predominantly north-south currents to enter. The Shoal may protect the area from wave action to some extent, but it does not provide as much protection as is provided for the Emeryville Crescent, since it is often submerged by several feet (at high tide).

The Albany Mudflat has not changed to any great extent, and this may be due to the fact that Point Fleming and Point Isabel, which flank it, are natural points: since they have been present for a much longer amount of time than fills discussed above, most of the effects (shallowing; development of mudflat) occurred well before the earliest dates of photographs used in this study. The Albany Landfill may in part be the cause of slight expansion of the mudflat, since it may block waves which would otherwise enter the mudflat.

The greatest change that has occurred along the shoreline is the introduction of large expanses of landfill. This in turn has aided siltation of protected waters. Another development has been growth of large expanses of marsh over the past fifty years, especially in the Emeryville Crescent, which has drawn a great variety of wildlife into this urbanized area.

Appendix A. Source List

Aerial Photographs

No.	Agency Code	Color	Angle	Agency	Date
1	C1600-11	B & W	normal	Teledyne	5/27/31
2	C1600-12	B & W	normal	Teledyne	5/27/31
3	C1600-13	B & W	normal	Teledyne	5/27/31
4	C1600-14	B & W	normal	Teledyne	5/27/31
5	C1600-15	B & W	normal	Teledyne	5/27/31
6	C1600-16	B & W	normal	Teledyne	5/27/31
7	C1600-22	B & W	normal	Teledyne	5/27/31
8	C1600-23	B & W	normal	Teledyne	5/27/31
9	C1600-24	B & W	normal	Teledyne	5/27/31
10	C1600-25	B & W	normal	Teledyne	5/27/31
11	C1600-26	B & W	normal	Teledyne	5/27/31
12	C1600-27	B & W	normal	Teledyne	5/27/31
13	BUT-BUU-289-96	B & W	normal	USAAA	8/2/39
14	BUT-BUU-289-97	B & W	normal	USAAA	8/2/39
15	BUT-BUU-289-98	B & W	normal	USAAA	8/2/39
16	BUT-290-3	B & W	normal	USAAA	8/4/39
17	BUT-290-4	B & W	normal	USAAA	8/4/39
18	BUT-290-5	B & W	normal	USAAA	8/4/39
19	BUT-290-6	B & W	normal	USAAA	8/4/39
20	BUT-290-7	B & W	normal	USAAA	8/4/39
21	BUT-290-8	B & W	normal	USAAA	8/4/39
22	BUT-290-9	B & W	normal	USAAA	8/4/39
23	5-9	B & W	normal	USGS	9/6/46
24	5-10	B & W	normal	USGS	9/6/46
25	5-11	B & W	normal	USGS	9/6/46
26	5-12	B & W	normal	USGS	9/6/46
27	6-11	B & W	normal	USGS	10/28/46
28	6-12	B & W	normal	USGS	10/28/46
29	6-42	B & W	normal	USGS	10/28/46
30	6-43	B & W	normal	USGS	10/28/46
31	AF59-45-717	B & W	normal	USAF	4/3/60
32	AF59-45-718	B & W	normal	USAF	4/3/60
33	AF59-45-742	B & W	normal	USAF	4/3/60
34	AF59-45-743	B & W	normal	USAF	4/3/60
35	8674-7 (CC)	B & W	oblique	CalTrans	2/28/62
36	Not available	B & W	normal	USGS	April, '70
37	Not available	B & W	normal	Not avail.	Sept. '75
38	C6282-3	B & W	oblique	CalTrans	9/20/77
39	C6282-5	B & W	oblique	CalTrans	9/20/77

Aerial Photographs, continued

No.	Agency Code	Color	Angle	Agency	Date
40	SFB-7-3	B & W	normal	COE	12/1/77
41	SFB-7-4	B & W	normal	COE	12/1/77
42	SFB-7-5	B & W	normal	COE	12/1/77
43	SFB-7-6	B & W	normal	COE	12/1/77
44	SFB-7-7	B & W	normal	COE	12/1/77
45	SFB-7-2	B & W	normal	COE	12/14/78
46	SFB-7-6	B & W	normal	COE	12/14/78
47	SFB-7-7	B & W	normal	COE	12/14/78
48	04-Ala-580 8-21	B & W	normal	CalTrans	12/3/78
49	04-Ala-580 8-22	B & W	normal	CalTrans	12/3/78
50	04-Ala-580 8-23	B & W	normal	CalTrans	12/3/78
51	04-Ala-580 8-24	B & W	normal	CalTrans	12/3/78
52	40-CC-80 8-25	B & W	normal	CalTrans	12/7/78
53	04-Ala-580 8-26	B & W	normal	CalTrans	12/3/78
54	04-CC-17.80 8-27	B & W	normal	CalTrans	12/3/78
55	04-CC-17.80 8-28	B & W	normal	CalTrans	12/3/78
56	SFB-7-2	B & W	normal	COE	4/13/79
57	SFB-7-3	B & W	normal	COE	4/13/79
58	SFB-7-4	B & W	normal	COE	4/13/79
59	SFB-7-5	B & W	normal	COE	4/13/79
60	SFB-7-6	B & W	normal	COE	4/13/79
61	SFB-7-7	B & W	normal	COE	4/13/79
62	C7032-20	true color	oblique	CalTrans	9/27/79
63	C7032-21	true color	oblique	CalTrans	9/27/79
64	C7063-1	true color	oblique	CalTrans	9/27/79
65	C7063-2	true color	oblique	CalTrans	9/27/79
66	C7063-3	true color	oblique	CalTrans	9/27/79
67	C7063-4	true color	oblique	CalTrans	9/27/79
68	C7063-5	true color	oblique	CalTrans	9/27/79
69	C7063-6	true color	oblique	CalTrans	9/27/79
70	C7063-7	true color	oblique	CalTrans	9/27/79
71	C7063-8	true color	oblique	CalTrans	9/27/79
72	C7063-9	true color	oblique	CalTrans	9/27/79
73	C7063-11	true color	oblique	CalTrans	9/27/79
74	SFB-7-2	B & W	normal	COE	4/8/80
75	SFB-7-3	B & W	normal	COE	4/8/80
76	SFB-7-4	B & W	normal	COE	4/8/80
77	SFB-32-5	color IR	normal	COE	5/17/80
78	SFB-32-6	color IR	normal	COE	5/17/80
79	SFB-32-7	color IR	normal	COE	5/17/80
80	SFB-32-8	color IR	normal	COE	5/17/80
81	SFB-32-9	color IR	normal	COE	5/17/80
82	SFB-32-10	color IR	normal	COE	5/17/80
83	SFB-32-11	color IR	normal	COE	5/17/80
84	SFB-32-12	color IR	normal	COE	5/17/80
85	SFB-32-13	color IR	normal	COE	5/17/80
86	SFB-38-11	color IR	normal	COE	6/17/80
87	SFB-38-12	color IR	normal	COE	6/17/80
88	SFB-38-13	color IR	normal	COE	6/17/80
89	SFB-38-14	color IR	normal	COE	6/17/80
90	SFB-38-15	color IR	normal	COE	6/17/80
91	SFB-10-1	B & W	normal	COE	9/31/81
92	SFB-10-2	B & W	normal	COE	9/31/81
93	SFB-10-3	B & W	normal	COE	9/31/81

Nautical Charts

No.	Code	Agency	Date of publ.	Last revision
1	5532	USCGS	1903	
2	5532	USCGS	1912	
3	5532	USCGS	1915	
4	5532	USCGS	1927	
5	5532	USCGS	1927	1928
6	5532	USCGS	1937	1940
7	5532	USCGS	1941	1942
8	5532	USCGS	1943	1945
9	5532	USCGS	1947	1950
10	5532	USCGS	1947	1952
11	5532	USCGS	1957	
12	5532	USCGS	1967	
13	5532	USCGS	1968	
14	5532	USCGS	1969	
15	5532	USCGS	1970	
16	5532	NOS	1971	
17	5532	NOS	1972	
18	5532	NOS	1973	
19	5332	NOS	1974	
20	18649	NOS	1975	
21	18649	NOS	1977	
22	18649	NOS	1978	
23	18649	NOS	1979	
24	18649	NOS	1980	
25	18649	NOS	1981	

Abbreviations:

USAAA US Agricultural Adjustment Administration
USGS US Geological Survey
USAF US Air Force
CalTrans California Department of Transportation
COE US Army Corps of Engineers
USCGS US Coast and Geodetic Survey
NOS National Oceanic Survey

APPENDIX B

DEPTH DETERMINATION FROM AERIAL PHOTOGRAPHS

Wavelengths measured on aerial photographs may be converted to water depths according to the following formula:

$$T^2 = \frac{2\pi\lambda}{g} \cot h \frac{2\pi d}{\lambda} \quad \text{(Lundahl, 1948)}$$

where g is the acceleration of gravity, 32.2 ft/sec^2, T is the period of the wave, d is the depth of the water, and λ is the wavelength, measured crest to crest. One depth d_o and corresponding wavelength λ_o must be known in order to calculate the period T, which is constant for a given set of waves. With T and other wavelengths measured, other depths can be calculated using the same formula.

It is necessary to take tide levels into account, since they can change depths by as much as six feet. To do this, the time and day the photograph was taken is determined, and tide levels are obtained from tables. In some cases, especially for older photographs, the time is not available. For these photographs a measurement is taken of the angle of a shadow cast by a tall object across level ground, with reference to some prominent fixed object such as a street. The angle can then be used to determine the time of day according to sun charts (Libby-Owens-Ford, 1975), which unfortunately are not generally available for latitude 37.8^{o}N (Berkeley). They are available for 36^{o}N and 40^{o}N, but the difference introduces an inaccuracy of up to an hour, which is undesirable when determining tide levels. A more accurate method of finding the time is by using the following formula:

$$\left(\cos^2 L \cos^2 \delta - \frac{\cos^2 \delta}{\sin^2 \phi}\right)\cos^2 \omega + \tfrac{1}{2}\sin 2\delta \sin 2L \cos \omega = 1 - \sin^2 L \sin^2 \delta - \frac{\cos^2 \delta}{\sin^2 \phi} \quad *$$

where L is the latitude (37.8^o), ϕ is the angle of the sun (from true south, positive to the east, does not include vertical angle), δ is the declination, determined from the day of the year ($\delta = 23.45\sin[(284 + n)360/365]$, n is the day: Jan 1st = 1, Feb 1st = 32, etc.), and ω is the hour angle. While this equation looks quite difficult, all values are known except ω. Since the equation is a simple quadratic of $\cos^2\omega$, $\cos^2\omega$ can be solved for, ω can be solved for, and the hours before or after solar noon (= PST noon plus 9 minutes in Berkeley) found by dividing ω by 15. The shadow will tell whether these hours should be added to or subtracted from solar noon: if the shadow lies west of true north it is before noon, and the value should be subtracted.

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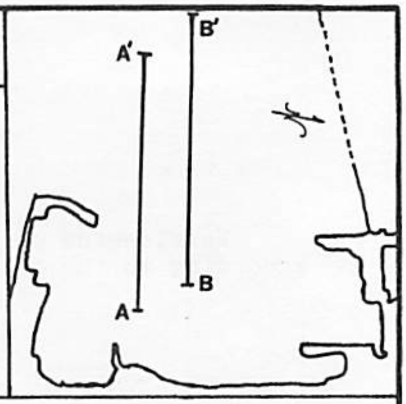
*Derived from $\cos z = \cos L \cos\omega \cos\delta + \sin L \sin\delta$, and $\sin\phi = \cos\delta \sin\omega / \sin z$ (Merriam, 1980, pers. comm.).

Depths in the Berkeley Embayment, 1939

Date: 8/4/39
Time: 4:40pm PST
Tide: +5.5 ft*
λ_o = 54.4 ft.
d_o = 15.5 ft**
T = 11.2 sec. (eq. 1)
d = wavelength in ft.
d = depth in feet
L = distance from Frontage Rd., along AA' or BB' in hundreds of feet.

	λ	d	L		λ	d	L
a	54.4	15.5	103	k	54.4	15.5	109
b	42.5	6.5	90	l	51.0	11.5	99
c	49.4	10	87	m	43.9	7	92
d	47.6	9	78	n	51.0	11.5	90
e	45.3	7.5	70	p	49.6	10	73
f	45.3	7.5	65	q	42.5	6.5	65
g	47.4	9	56	r	45.3	7.5	54
h	45.3	7.5	52	s	47.6	9	43
i	42.5	6.5	39	t	46.2	8	37
j	38.5	5	33				



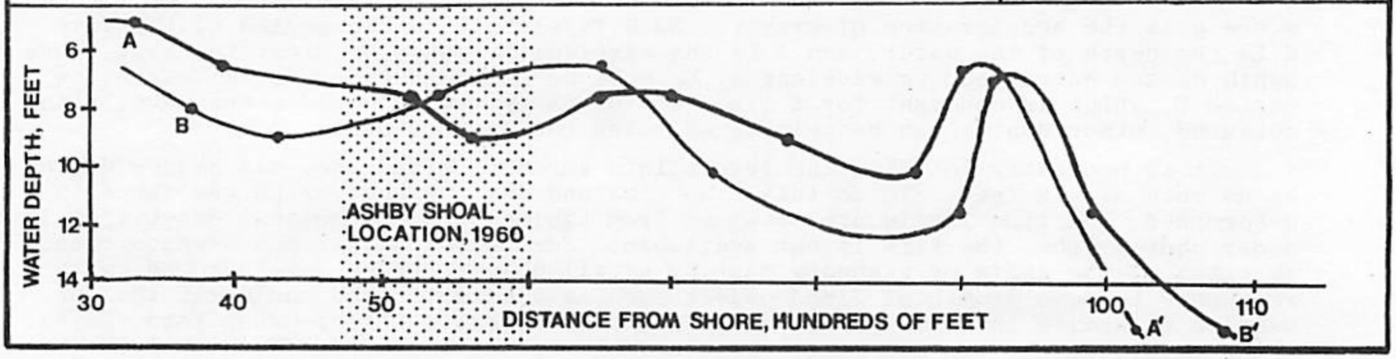


TABLE 1. Wavelength to depth conversion, Berkeley Embayment, 1939. Points a through j are on data line AA' (see insert); points k through t are on BB'. Data plotted above indicate a bar or shoal about 1000 feet west of the present Ashby Shoal, and a second bar well beyond this. The first of these is referred to in the text. Source: Aerial photograph #19.
*S. F. Chronical, 8/4/39; **Nautical chart #6.

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Sources and Methods of Examining Data

Three different resources were used to obtain data: 25 nautical charts (1903 to 1981), 93 aerial photographs (1931 to 1981), and one historical map (1850's; Nichols and Wright, 1971) (Appendix A).