WRITTEN TESTIMONY OF KENNETH R LAJOIE

PERSONAL BACKGROUND

My name is Kenmeth Robert Lajoie. I am a retired Quaternary geologist. From 1970 to 2000 I worked as a research geologist with the United States Geological Survey in Menlo Park, California. From 1970 to 1977 I worked with the Branch of Environmental Geology conducting research in the San Francisco Bay region, mainly on coastal and earthquake hazards. This research focussed on Quaternary sea-level fluctuations and vertical crustal movements, both recorded by uplifted marine terraces and by sediments in subsiding basins. From 1977 to 2000 I worked with the Earthquake Hazards Group, conducting similar research along the west coast of the United States, including Alaska. I also conducted research in Japan, New Zealand and Chile. All this work consisted of separating the climatic signal from the tectonic signal in young geomorphic and sedimentary coastal records. While with the Earthquake Group, I conducted a post-earthquake study of the ground ruptures produced by the 1992 seismic event in Landers CA. In that study I traced thousands of ruptures from over four-hundred aerial photographs using a binocular microscope.

Since my retirement in 2000, I have conducted independent research on the long-term history of San Francisco Bay using bore-hole records. I have also mapped the alluvial fans marginal to San Francisco Bay, in Napa Valley and in the Sacramento/Davis area. The map of alluvial fans in Napa Valley was used by the San Francisco Estuary Institute in a state-funded study of water-quality in the Valley. I served on the advisory/review panel for that study.

I have conducted research on the effects of post-glacial sea-level rise on regional depositional processes and human occupation sites of the San Francisco Bay area. A focus of this work was to investigate the factors controlling the formation of marsh deposits and oyster beds through space and time. A critical part of this project was to construct a new sea-level curve for the Bay based on stratigraphic and radiocarbon data from published sources. I used this new curve to generate a sequence of maps showing the flooding of the Bay basin during the last post-glacial rise in sea level over the past fifteen-thousand years. The results of this research are being used by several groups, including environmental historians studying the long-term exploitation of local oyster resources of San Francisco Bay by both indigenous and European cultures. Over the past fifteen years I have lectured extensively on the "The Origin of San Francisco Bay: The Natural and Unnatural History of an Urban Estuary."

In 2001 I mapped the Quaternary geology of the Sacramento area for an archeological consulting firm. The purpose of this geomorphic/stratigraphic study was to determine the age of artifact-bearing river deposits exposed in the foundation excavation at the new city hall in Sacramento. In my report I outlined the recent geologic history of the area, which helped date the river deposits and the artifacts they contained.

In 2003 I served as consulting geologist for a geophysical survey of the Giza Plateau, Egypt. I returned to Egypt in 2005 as a geologic consultant on the Giza Plateau Mapping Project. I conducted a stratigraphic study of the interfingering relationships between the artifact-bearing sediments of a small alluvial fan and the flood deposits of the Nile Delta. I also revised and updated a large set of radiocarbon dates from sites throughout Egypt.

I am presently employed as an independent geologic consultant by Wallace Environmental Consulting, Inc. to study the fluvial geomorphology of the San Joaquin River Delta. The broad focus of this study is to reconstruct the natural, pre-1850, drainage pattern of the lower San Joaquin River, concentrating mainly on secondary and tertiary channels in the area covered by the USGS Holt 7.5' Quadrangle. This study is a natural link between my previous geomorphic/stratigraphic studies in the San Francisco Bay and the Sacramento areas.

DATA SOURCES AND ANALYTICAL TECHNIQUES

Since the mid-1800's, European farming activities have greatly altered the natural drainage pattern of the Sacramento-San Joaquin Delta, and little of the original drainage system survives. Consequently, any attempt to reconstruct the original conditions in the Delta depends mainly on historical maps and written records (late 1800's to early 1900's), and on aerial photographs (mid 1900's to the present).

Most of the aerial photographs, maps and text documents analyzed for this project were supplied as digital files (pdf) by Dante Nomellini of Nomellini, Grilli and McDaniel, Stockton, CA. The most useful documents in this primary data set are high-resolution scans of 1940 aerial photographs (ABD) of western San Joaquin County. Don Moore, GIS and remote-sensing expert from GEOIMAGERY, supplied a composite digital satellite image of the area covered by the Holt 7.5' Quadrangle. This image is based on 2005 NAIP (National Agricultural Imaging Program) air-photo coverage. Don Moore also supplied a stitched mosaic of rectified 1940 areal photographs covering much of the Hot 7.5' Quadrangle. He also supplied a file in which he precisely collated images of the 1913 and 1978 USGS 7.5' Holt Quadrangle. The digital images supplied by Don Moore are valuable as primary data sources, and as a means of evaluating other data sets.

All analysis of digital files was performed on a dual-core Macintosh computer running operating system 10.6.2. I enhanced all the historic maps and aerial photographs in some way using standard image-editing techniques in Adobe Photoshop (CS4). I reduced file sizes, especially of the aerial photographs, to improve computer performance. However, in no case did I degrade the images below the inherent resolution of the original photograph or map. Don Moore provided guidelines to minimize image degradation, and emphasized the need to refer to unaltered images as a means of insuring quality and accuracy when working with enhanced (altered) digital images.

I imported the enhanced Photoshop files (psd) into Adobe Illustrator (CS4) to trace channel features from the historical maps and aerial photographs. The enhancement capabilities of Adobe Photoshop and the magnification capabilities in Adobe Illustrator allow a level of detail and accuracy superior to the limited capabilities of manual procedures used in previous geologic studies in the Delta.

My testimony consists mainly of twenty maps and diagrams illustrating the techniques and results of this study. The expanded captions of these twenty figures appear below.

FIGURE 1: 1894 Stockton Belotta Drainage District map

The purpose of this study is to determine whether two land parcels, 131-170-03 and 131-180-07 T1N, R5E, lie within the riparian zone along Duck Slough. The focus of the study is twofold:

1. Determine the importance of Duck Slough in the natural drainage system of the area between Middle River to the south and the San Joaquin River, including Burns Cutoff, to the north.

2. Determine the relationship of land parcels 131-180-07 and 131-179-03 to the riparian zone along Duck Slough.

Of primary interest is the area covered by the USGS Holt 7.5' Quadrangle, which includes parts of Lower Roberts Island, Middle Roberts Island and Honker Lake Tract.

The drainage system of the of the San Joaquin River Delta consists of three primary channels, Old River, Middle River and the San Joaquin River, including Burns Cutoff, and several secondary channels that connect them, or flow into them. This 1894 map shows Duck Slough as a secondary channel connecting Middle River with Burns Cutoff. Other maps and aerial photographs analyzed in this study show that Duck Slough also connects Middle River with the San Joaquin River via Black Slough.

The names of some waterways differ on various maps analyzed in this study. To avoid confusion, the names shown on this 1894 map are used throughout this report.

FIGURE 2: 1876 San Joaquin County assessor's map T1N, R5E

Parcels 131-170-03 and 131-180-07 lie within sections 22 and 27 T1N, R5E, Mount Diablo base and meridian. San Joaquin County Assessor's maps of T1N, R5E for the following years were analyzed in study for evidence of natural channels: 1876, 1881-82, 1893, 1894, 1895, 1896, 1897 and 1898. The evidence for channels is similar on all eight maps, consequently only three are presented here for illustrative purposes. These are: 1876 (figure 2), 1893 (figure 3) and 1898 (figure 4).

The unlabeled, hand-drawn lines on the 1876 map lie in roughly the same locations as labeled water courses on the 1894 Stockton Belotta Drainage District map (figure 1). It is safe to assume, therefore, that the unlabeled lines on this map represent the labeled water courses on the 1894 map. The names in parentheses are from the 1894 map.

Duck Slough is a secondary channel connecting Middle River and Burns Cutoff. Parcels 131-170-03 and 131-180-07 lie directly east and west, respectively, of Duck Slough in Sections 22 and 27.

FIGURE 3: 1893 San Joaquin County Assessor's map T1N, R5E

This map shows natural water courses (highlighted in blue) on the 1893 San Joaquin County Assessors map T1N, R5E. Channel names in parentheses are from the 1894 Stockton Belotta Drainage District map (figure 1), and those without parentheses are from this 1983 map. Duck Slough is accurately depicted here as a secondary channel connecting Middle River with Burns Cutoff. Parcels 131-170-03 and 131-180-07 lie directly east and west, respectively, of this prominent water course, and are, therefore, riparian to it.

On this and five other assessor's maps of T1N, R5E dating from 1894 to 1898 (figure 4) Whiskey Slough and Duck Slough are drawn as separate distributary channels branching off Middle River. Atwater,1982 (figure 10) erroneously maps Whiskey Slough as a distributary channel branching off Duck Slough, or vice versa, west of Parcel 131-170-03.

FIGURE 4: 1898 San Joaquin County assessor's map of T1N, R5E

Natural water courses are depicted by hand-drawn lines, here highlighted in blue, on the 1898 assessor's map T1N, R5E. Duck Slough, labeled Cross Levee on this map, is drawn as a secondary channel connecting Middle River and Burns Cutoff. Parcels 131-170-03 and 131-180-07 lie adjacent to Duck Slough and are, therefore, riparian to it.

FIGURE 5: Cross section of natural levees and delta pool basins

Natural levees build up along stream and river channels where flood waters deposit clastic sediments, mainly sand and silt. Levee deposits inter-finger with peat deposits along the margins of adjacent delta pool basins. These basins contain surface water year round owing to surface runoff and groundwater recharge. In effect, the groundwater table lies above the ground surface of these basins throughout the year. Ground surfaces in pool basins rise in response to the gradual rise in sea level, about 2m over the past 1,500 years. The upper limit of natural fresh-water tidal marshes in these basins is 2.5 to 3.5 feet above sea level (Atwater, 1982).

Natural levees are expressed on topographic maps as closely spaced contour lines, usually along delineated watercourses (figure 6). On soil maps they are expressed as elongate areas characterized by mineral-rich soils, usually along delineated watercourses (figure 9). Levees and their formative channels are visible as tonal changes on aerial photographs, even where they have been leveled for agricultural purposes (figures 14, 15, 17 and 18).

Mineral-rich soils develop on levees and organic-rich soils develop in peaty basins. Peat oxidation lowers the ground surface in artificially drained basins, locally exposing buried levees and channels. These exhumed features are visible as tonal changes on aerial photographs.

FIGURE 6: 1913 USGS HOLT 7.5' Quadrangle showing channel levees

Five-foot contours on this 1913 topographic map outline the natural levees along prominent secondary watercourses between Middle River and the San Joaquin River, including Burns Cutoff.

The area between the zero contour (00, mean sea level) and the five-foot contour is highlighted in red to accentuate the natural drainage system as expressed by the pattern of its levees. Duck Slough connects Middle River and Burns Cutoff, just off the eastern edge of the map. Two distributary channels branching northward off Duck Slough flow into the San Joaquin River via Black Slough. This well-integrated drainage system suggests its channels are relatively stable and long-lived. The size and complexity of the levees along Duck Slough and its distributaries indicate this is a prominent drainage system connecting Middle River and the San Joaquin River, including Burns Cutoff. See Figure 9 for a similar depiction of this drainage system as expressed in the distribution of mineral-rich soils.

The size of the levees along Duck Slough and its distributaries diminish in size northward, probably reflecting southward inundation by marshlands owing to recent sea-level rise, about 2m in the past 1,500 years (figure 20). If correct, this interpretation indicates considerable age and stability for the Duck Slough drainage system.

Land parcels 131-170-03 and 131-180-07 lie on the east and west natural levees of Duck Slough, respectively. They are, therefore, riparian to Duck Slough.

Note: Prior to 1929, the 00 contour on USDS topographic maps, including this 1913 map, is referenced to mean sea level. After 1929 the 00 contour on USGS topographic maps is referenced to mean high tide (figure 10).

FIGURE 7: 1927 ALICE M WOODS TRUST MAP (1' CONTOURS)

This detailed topographic map outlines the small natural levees (light blue) of distributary channels (red) branching off Duck Slough in the area of land Parcels 131-170-03 and 131-180-07. These minor levees, expressed in the one-foot contours, collectively comprise the broader levees of Duck Slough, itself. Parcels 131-170-03 and 131-180-07 lie on the east and west levees of Duck Slough, respectively, adjacent to its channel. Therefore, these parcels are riparian to Duck Slough. See figure 18 for details of the minor levee system here labeled A.

Note: The datum of this map is arbitrarily set at -20 feet to avoid confusion when dealing with negative contours below sea level. To obtain correct elevations, subtract twenty feet from the elevations shown on each contour. Prior to 1929, sea level was arbitrarily defined as mean sea level. After 1929 it was arbitrarily defined as mean high tide.

FIGURE 8: 1941 Map of lands served by Woods Irrigation Company

This map shows the courses of at least six north-trending natural channels (red) between Middle River and Burns Cutoff. Reaches of all these channels were straightened when converted to irrigation ditches. Four channels, labeled A through D, appear to be tributary to Duck Slough. Duck Slough, the dominant secondary drainage channel in this area, connects Middle River and Burns Cutoff. Parcels 131-170-03 and 131-180-07 lie along Duck Slough and are, therefore, riparian to it. See Figure 9 for further discussion of these channels.

FIGURE 9: 1952 San Joaquin County soil map; Sheets 22 and 27

This figure shows the pattern of natural stream levees as expressed on the 1952 soil map of San Joaquin County. The areas highlighted in red are underlain by soils characterized by high-mineral and low-organic content, which form on levees of the natural drainage system (figure 5). Intervening peaty areas are underlain by soils with low-mineral and high-organic content, which form in low flood basins.

The highlighted areas reveal the pattern of the natural drainage system. This well-integrated pattern suggests the drainage system is stable and of considerable age.

The blue lines are irrigation channels from the 1941 Map of Lands Served by the Woods Irrigation Company (figure 8). Channels A through D are tributary to Duck Slough. Channels A through C drain the basin to its east and, therefore, have no levees; basins are not sources of clastic debris. The short levees at the north ends of channels B and C suggest there is some back flow from Duck Slough, probably during rising tides. Indeed, all the channels in this system lie close to sea level and, therefore, experience bidirectional tidal flow.

The larger sinuous levees labeled G through J occur along distributary channels branching northward from Duck Slough. See figures 15 and 17 for details of all these labeled sloughs. Obviously, Duck Slough is an abundant source of sediment in this part of the Delta.

Flood waters from Duck Slough flow northward directly into the San Joaquin River via Black Slough. Clearly, Duck Slough, with its own tributary and distributary, channels, and with the largest levee system of all secondary channels in this area, is the dominant natural watercourse between Middle River and Burns Cutoff, and the San Joaquin River, itself.

Land parcels 131-170-03 and 131-180-70 lie on the levees of Duck Slough adjacent to its channel and are, therefore, riparian to it.

Channels D through F are distributary channels flowing northward from Middle River. They built prominent levees because Middle River is an abundant source of clastic sediment.

FIGURE 10: 1982 Quaternary geology of USGS Holt 7.5' Quadrangle; M o d i fi e d from Atwater, 1982, Sheet 16 of 21

Atwater (1982) mapped the Quaternary geology of the Delta on twenty-one USGS 7.5' Quadrangles. He traced natural watercourses from 1970 USGS black-and-white orthophoto maps (1:24,000), and from post-1965 black-and-white aerial photographs. His 1982 publication is a starting point for all subsequent detailed geologic mapping in the Delta.

Atwater's Sheet 16 shows the natural watercourses (red) on the Holt 7.5' Quadrangle. The short arrows show flow directions of minor distributary channels, mainly levee breaches.The dashed blue line is the estimated landward margin of natural tidal wetlands, about 2.5- to 3.5-feet above sea level (mean high-tide datum).

A focus of the present study is to evaluate Atwater's data on the Holt Quadrangle (Sheet 16) by comparing it with detailed data generated in the present study, especially in the Duck Slough area (figures 15 and 17). Except where Atwater shows Whiskey Slough branching off Duck Slough, the two data sets agree, lending credence to both. This agreement is significant, because the two data sets are derived from different primary sources.

The main conclusion drawn from Atwater's map is that Duck Slough is a prominent secondary channel connecting Middle River and Burns Cutoff. Also, Duck Slough's two largest distributary channels are actually the uppermost reaches of Black Slough, which drains northward into the San Joaquin River.

Parcels 131-170-03 and 131-180-07 lie along Duck Slough and are, therefore, riparian to it. The landward margin of natural tidal wetlands (dashed blue line) runs through both parcels, indicating they are riparian to adjacent delta pool basins (see figure 5).

FIGURE 11: 2005 composite NAIP color photograph Holt Quadrangle

Don Moore of GEOIMAGERY produced this stitched composite of high-resolution, rectified, NAIP color aerial photographs of the area covered by the Holt Quadrangle. In the Adobe Photoshop file he produced, he included the following rectified and collated imagery on separate layers: 1913 7.5' USGS Holt Quadrangle map, composite of six 1940 ABD aerial photographs including 333-66 and 333-68, and the 1978 7.5' USGS Holt Quadrangle map.

This multilayered file is used in the present study as a confirming reference for all channel-tracing work on other maps and aerial photographs. It also provides a convenient and precise means of evaluating the channels mapped by Atwater (figures 10 and 12). At the same time it provides a means of assessing ground changes over the intervening twenty-five years.

The composite 1970 orthophoto quad used by Atwater (1982) was black and white, while this image is colored. The potential for detecting subtle channel features in this area is far greater with this high-quality digital image than with the low-quality, black-and-white paper image used by Atwater. Also, digital enlargement and color-enhancement techniques used in the present study maximize the possibility of detecting channel features. Figure 12 compares the channel features mapped in this study with those mapped by Atwater.

Note the location of Parcels 131-170-03 and 131-180-07 in the lower-right quadrant of this colored image.

FIGURE 12: Holt Quadrangle, 1982 and 2005 channel features compared

This map compares natural channel features mapped in 1982 by Atwater (red lines) and those mapped in the present study (black lines). Atwater's primary sources were a 1970 black-and-white orthophoto quadrangle map (paper copy) and post-1965 black-and-white aerial photographs (paper copies). A primary source for the present study is a digital image of 2005 color aerial photographs (figure 11).

There is excellent agreement between the two data sets presented here, especially along courses of all primary and secondary channels. This agreement lends credence to both data sets. The 2005 data set reveals numerous channel features that do not appear in the 1970 data set, especially in drained basins. The superior analytical techniques used in the present study might explain this discrepancy, particularly along prominent water courses. However, the additional channel features in basins might reflect land-surface subsidence over the twenty-five years separating the primary data sources. In effect, it is likely that buried channel features are being exhumed in drained basins as overlying peat oxidizes (figure 5).

Most of the short arrows in the Atwater data set are channels associated with levee breaches. These features, and many more. were recognized but not delineated in the recent mapping project. The size and complexity of the Duck Slough and its numerous distributary and tributary channels, as revealed in both data sets, indicate this is the primary drainage system between Middle River and the San Joaquin River. Duck Slough drains into Burns Cutoff, and at least three of its distributary channels are the southernmost reaches of Black Slough, which drains northward into the San Joaquin River. All the channels in this well-integrated drainage system lie close to sea level and, therefore, experience bidirectional tidal flow.

Parcels 131-170-03 and 131-180-07 lie along Duck Slough, the main channel of this complex drainage system, and are, therefore, riparian to it.

Atwater shows Whiskey Slough as a distributary channel branching off Duck Slough just west of Parcel 131-170-03. However, early assessor's maps (figures 3 and 4) clearly show these two waterways as separate channels branching off Middle River.

FIGURE 13: 1940 ABD-68 aerial photograph, color enhanced

To augment and check the channel features mapped on the 2005 color aerial photographs (figure 12), we have also mapped channel features on larger-scale 1940 black-and-white aerial photographs (figures 15 and 17). The narrow tonal range of the 1940 photographs hinders interpretation, especially without stereoscopic coverage. Consequently, digital copies of the 1940 photographs have been color enhanced to increase contrast and thus facilitate channel mapping on a computer monitor. Two separate digital copies of the original grayscale image were enhanced using color gradients in Adobe Photoshop; these techniques, which are similar to those used by NASA, are broadly used in all fields of science for image-enhancing purposes. Don Moore established technical guidelines for the procedures used in the present study to insure image fidelity. The three images shown here are stacked as separate layers in Adobe Illustrator for tracing purposes. Switching among the three images greatly increased the speed and accuracy of channel mapping. In all phases of the analysis an unaltered copy of the original digital image is frequently referenced as a quality check. Figure 14 is a digital enlargement of the square area near the center of the grayscale image.

FIGURE 14: 1940 ABD 333-68 aerial photograph, enlarged color enhanced

This image is an enlargement of the small, square area near the center of aerial photograph ABD 333-68 (figure 13). The subtle channel features barely visible in the grayscale image are much more evident in the color enhancement. A 10x enlargement on a computer monitor greatly facilitates tracing of small, complex channel features such as these.

A curved drainage channel and its levees are clearly visible in the eastern part of the colored image. A small levee-breach cuts the western levee of this channel.

FIGURE 15: 1940 aerial photograph ABD 333-68, channel features

This map shows the location of Parcels 131-170-03 and 131-180-07 relative to natural drainage channels in the southern Duck Slough area. Black lines are channel features traced from aerial photograph ABD 333-68 in the present study. Solid red lines are channel features shown on map-sheet 16 of Atwater, 1982 (figure 10). Blue lines are channel features traced from the 1941 Map of Lands Served by Woods Irrigation Co (figure 8).

All three data sets show Duck Slough as a prominent channel branching northward off Middle River. Parcels 131-170-03 and 131-180-07 lie adjacent to Duck Slough, and are, therefore, riparian to it.

Channel features traced from the 1940 photograph show a tight meander of Duck Slough penetrating completely through Parcel 131-180-07 from the northwest. This meander, like all tight meanders in the Delta, has been artificially straightened.

Green circles mark the sites of pre-1940 farmsteads. Those along straight roads (dashed circles) likely post-date road construction. Those along the abandoned courses of meandering channels (solid circles) were likely first occupied when access to the interior of the Delta was limited to navigable waterways (figure 16). Indeed, the presence of old farmsteads along an abandoned natural channel is evidence it was originally a navigable waterway. Many farmsteads in the Delta lie along the outside of meanders, probably for close access to deep water when first occupied. Three pre-1940 farmsteads lie along Duck Slough in this area.

The dashed red line is the estimated upper limit of pre-1850 tidal marshes, 2.5' to 3.5' above sea level (mean high tide; Atwater, 1982). This line runs through Parcels 131-170-03 and 131-180-07, indicating their lower parts were tidally inundated, even during the dry season. Consequently, both parcels are riparian to perennial fresh-water basins adjacent to Duck Slough.

See figure 9 for a detailed analysis of channels A through E, and G and H.

FIGURE 16: Sketch of Chinese farmers in the Delta

This sketch depicts the predominant transportation system in the Delta prior to construction of roads and bridges in the late 1800's and early 1900's. Many present farmsteads along former water courses probably occupy sites that were first settled when access to the interior of the Delta was limited to navigable waterways. The presence of historic farmsteads along abandoned channels is evidence they were originally prominent waterways.

FIGURE 17: Map showing channel features traced from 1940 aerial photograph ABD 333-66

This map shows the location of Parcels 131-170-03 and 131-180-07 relative to natural, pre-1850 drainage channels in the southern Duck Slough area. Black lines are channel features traced from ABD 333-66. Solid red lines are channel features from map-sheet 16 of Atwater, 1982 (figure 10). Blue lines are channel features from the 1941 Map of Lands Served by Woods Irrigation Co (figure 8). All three data sets show Duck Slough as a prominent channel branching northward off Middle River.

Parcels 131-170-03 and 131-180-07 lie adjacent to Duck Slough, and are, therefore, riparian to it.

Green circles are the sites of pre-1940 farmsteads. Those along straight roads (dashed circles) likely post-date road construction. Those along meandering channels (solid circles) were likely first occupied when access to the interior of the Delta was limited to navigable waterways (figure 16). The presence of historic farmsteads along an abandoned natural channel, but not also along a straight road, is evidence the channel was originally a navigable waterway.

Many farmsteads in the Delta lie along the outside of meanders, possibly for close access to deep water when first occupied. Three pre-1940 farmsteads lie along Duck Slough and several lie along its distributary channels to the north, which flow the San Joaquin River via Black Slough. All these farmsteads are strong evidence that Duck Slough and some of its major distributary channels were navigable waterways when the Delta was first settled.

The dashed red line is the estimated upper limit of pre-1850 tidal marshes, 2.5' to 3.5' above sea level (mean high tide; Atwater, 1982). This line runs through Parcels 131-170-03 and 131-180-07, indicating their lower parts were tidally inundated, even during the dry season. Consequently, both parcels are riparian to the perennial fresh-water basins adjacent to Duck Slough (figure 5).

See figure 9 for a detailed analysis of the channels labeled A through E, and G through J.

FIGURE 18: 1940 Aerial photograph ABD 333-66 levee breach

Light-colored flood deposits are clearly visible in a dark, tilled field northwest of Duck Slough in the vicinity of Parcel 131-180-07 (A). These deposits form a small levee system along a flood channel branching off Duck Slough. This minor channel and the topographic expression of its levees appear on the 1927 detailed contour map of this area (B; figure 7). One-foot contours on the map reveal three feet of relief (20' to 23') on this levee system. Numerous minor levees of this sort collectively comprise the broader levees of Duck Slough, and of all primary and secondary channels in the Delta.

This minor flood channel and its deposits appear to represent a single levee breach from Duck Slough. This breach predates 1927, but its exact age is unknown. Consequently, the breach might have occurred along the natural levee of Duck Slough prior to 1850, or along an artificial levee after 1850. Either way, Duck Slough is clearly a significant conduit for transporting clastic sediment deep into the interior of the Delta from Middle River.

The base map for B is an inverted image of A with a color gradient applied for enhancement. The channel on the 1927 map almost perfectly matches the channel on the enhanced photograph.

Parcel 131-180-07 lies entirely on the west levee of Duck Slough adjacent to its channel, and is, therefore, riparian to it.

FIGURE 19: 1879 channel data

In 2008 Robin Grossinger of the San Francisco Estuary Institute (SFEI) presented an illustrated talk at a CALFED Conference on the Delta. Grossinger's slides are posted on the SFEI web site. This figure is slide 11 from his talk.

In 1879 the US government surveyed township/range boundaries in the Delta. Excerpts from the 1879 field notes of surveyor W. F. Benson are plotted along two orthogonal section lines (red dots with leaders). Seven of the eleven notes refer to channels eight- to thirteen-meters wide that do not appear on the early 1900's USGS topographic base map. Obviously, there were many more natural channels in the Delta than appeare on any published map. The point of this illustration is that the numerous channel features mapped in the present study (figures 12, 15 and 17) and in previous studies (figure 10) most likely represent a small fraction of waterways that actually existed in the Delta prior to 1850.

FIGURE 20: Late Holocene sea-level rise San Francisco Bay

The elevations and ages of radiocarbon-dated samples (red) from sites marginal to San Francisco Bay set an upper limit on sea level over the past 6,000 years. The resultant rate of sea-level rise over that period of time is roughly one-and-a-half meters per thousand years (1.5m/ka).

This gradual rise in sea level raises the base level of local streams and rivers, and causes the landward encroachment of tidal marshes (figure 6).

CONCLUSIONS

The focus of this study is twofold:

1. Determine the importance of Duck Slough in the natural drainage system of the area between Middle River and the San Joaquin River (including Burns Cutoff).

   The size and complexity of the Duck Slough and its numerous distributary and tributary channels, as shown on historical maps and aerial photographs, indicate it is the primary drainage system between Middle River in the south and the San Joaquin River (including Duck Slough) in the north. Duck Slough directly connects Middle River and Burns Cutoff, and at least three of its distributary channels are the southernmost reaches of Black Slough, which drains into the San Joaquin River.

   The size of the levee system built up by Duck Slough and its numerous distributary and tributary channels indicates this prominent waterway is an abundant source of clastic sediment in this area.

   Many present farmsteads along former water courses likely occupy sites that were first settled when access to the interior of the Delta was limited to navigable waterways. The presence of historic farmsteads along abandoned channels is evidence they were originally prominent waterways. Several farmsteads occur along the original meandering course of Duck Slough and its distributary channels, indicating they were navigable waterways in historic times.

2. Determine the relationship of parcels 131-170-03 and 131-180-08 to the riparian zone along Duck Slough.

   Parcels 131-170-03 and 131-180-08 lie directly on natural levees of Duck Slough, east and west of the drainage channel, respectively. These parcels are, therefore riparian to Duck Slough.

   These parcels also straddle the line delineating the upper limit of fresh-water tidal marshes (2.5' to 3.5' above sea level) and, therefore are also riparian to the delta pool basins adjacent to Duck Slough.

FIGURES