LATE QUATERNARY STRATIGRAPHIC AND PALEOECOLOGICAL INVESTIGATIONS IN THE SAN FRANCISCO BAY AREA

Introduction

As part of the broad regional study described in the introdution to this guidebook, we have been mapping the Quaternary deposits of the San Francisco Bay Area (Helley) and establishing a paleoecologic and paleoclimatic record (Adam). The mapping is nearly completed, and the maps described below are soon to be released by the USGS (maps MF-335 for Santa Clara County and MF-429 for Alameda County, and in press). The biostratigraphic work, however, is still in its preliminary stages, and the results described here are incomplete.

Mapping of Quaternary deposits, as participants in this endeavor are doubtless aware, is possessed of problems which can be quite different from mapping of older portions of the geologic record. The recent vintage of these deposits may require uncommon mapping techniques, or approaches to dating, or peculiarities in the very definition of map units. In mapping the Quaternary deposits of the bay area, we have tried to use the sorts of criteria that are used in differentiating older geologic units. The consistency of our results suggests success in this approach, but there remains the problem of fitting these units into a coherent historic framework. Some of our units are dated by marine invertebrate fossils, others by continental vertebrate remains; they may or may not contain organic or volcanic materials susceptible to radiometric dating techniques. Microfloras, soil profiles, and the distribution of the units themselves allow additional but different schemes of dating with reference to climatic fluctuations, episodes of soil formation, or inferred isostatic sea level changes during Pleistocene and Holocene time.

Herein is both a problem and an opportunity. The diverse Quaternary deposits of the bay area can all be more or less dated in diverse ways; in the development of a Quaternary history of the bay region, it may be possible to interrelate these diverse approaches to dating and perhaps answer some long-standing general problems of Quaternary mapping and correlation.

Geologic Mapping: Criteria and Methods

The geologic map units are defined by their physical properties and relative age; they were delineated using differences in texture, degree and type of soil development, surface morphology, and stratigraphic position. In the Pleistocene and Holocene deposits mapped for this study, there is a consistent relationship between the texture of a given deposit, the type of soil profile developed upon it, and its depositional morphology (where still preserved). The relative ages of the various deposits exposed at the surface are indicated by differing development of soil profiles and by the degree of erosion of original surface morphology.

Vertical exposures in natural stream channels, artificial cuts and trenches, and test borings show that the relative ages inferred from surface criteria are consistent with superposition of one deposit on another. Paleontologic evidence and radiometric ages from organic and volcanic materials allow the units to be dated.

Various sources of geologic information were used in making our maps. The distribution of older units--the continental and marine deposits of Pliocene and Pleistocene age--was compiled from previous geologic maps, and is shown largely for engineering and planning purposes in the bay region project. We are still far from a detailed understanding of the depositional and tectonic history recorded by these units. Our efforts have been primarily concerned with the younger deposits that fill the lowlands and canyons of the present topography. The margin of alluvial deposits along San Francisco Bay was taken from Nichols and Wright (1971) and Radbruch (1969). The shoreline as mapped by the U.S. Coast and Geodetic Survey circa 1850 was taken as the maximum extent of San Francisco Bay during the post-Wisconsin marine transgression. We recognize the imperfection in this simplistic model, but used it for lack of a better datum. Local perturbations in this model become readily apparent, especially from the distribution of archeological sites.

Soil series maps of the U.S. Soil Conservation Service were used in conjunction with field investigations and aerial photo interpretation to delineate our map units. The type--or series--of soil which develops in an area is partially controlled in its early stages of development by the texture of the deposit upon which it forms. Soil series were combined and their map contacts modified to establish different textural units or facies of alluvial fan systems. Degrees of soil profile development further allow differentiation of the fan systems in terms of their age. The texture and age of the deposits, as delineated by soil series and field investigations, correlate with their particular surface morphologies. Therefore, where modern soil series mapping is not available, the morphologies have been used in the field and on aerial photographs to map the deposits.

Two groups of geologic units (older and younger alluvial fan systems) are distinguished on the margin of San Francisco Bay by the relative preservation of original depositional morphology. Within each of these two groups the different units are distinguished primarily by morphology and texture, which are functions of the depositional environment.

Summary of Results

Multiple discrete periods of alluviation during late Cenozoic time are indicated by the distribution and ages of units shown on our maps.

The Pliocene and earlier Pleistocene units are composed of alluvial and lacustrine deposits and record a long and complex depositional history. These semiconsolidated deposits are locally deformed by faulting and

folding and lack their original depositional morphology. These characteristics, and the widespread distribution of these deposits throughout the bay region, indicate that they were deposited in basins not directly related to present-day drainage systems. K-Ar dating of volcanic deposits yielded ages from 1-6 million years old. The units of the younger fan systems underlie the broad lowland along the margins of San Francisco Bay as well as the open valleys and narrow canyons not directly connected to the bay. These alluvial, marine, dune(?), and lacustrine deposits record two periods of deposition during which the natural drainage systems and landscape were much as they are today, except for the absence of the bay during the earlier of the two periods.

Streambed deposits and alluvial aprons and fans of the earlier period (Qof) are present throughout the bay area. On the margins of the bay these deposits grade bayward into the Merritt Sand (Qm), which may represent old beach deposits or sand dunes, and older mud deposits (Qom), which are either estuarine or lacustrine in origin.

The youngest fan deposits are superimposed on the older fan systems and grade into the modern muds of San Francisco Bay. The texture and depositional morphology are important in the development of soils on these younger deposits. Three textural units or facies (Qyf, Qyfo, and Qb) can be distinguished by their morphology and the type of immature soils developed upon them.

Biostratigraphic Studies

Several types of late Quaternary deposits containing plant and animal remains have been found in our area. We have recovered bones from alluvial and marsh deposits, and plant remains have been found in sag ponds, marshes formed on old landslides, and in filled-in oxbows associated with former alluvial plains. Archeological middens are useful in studies of Holocene deposits. Some of our results are described below.

The Mountain View Dump

The City of San Francisco has contracted with the City of Mountain View for the use of low land marginal to San Francisco Bay for its garbage dump. Disposal of this export will involve the excavation of as many as eight large pits up to 10 meters deep and several hundred meters on a side, but to date only two pits have been excavated. We have been investigating the larger of these which has yielded a rich fossil flora and fauna of late Pleistocene and Holocene age. Additional pits will extend bayward from the existing excavations and should prove interesting, because facies changes in the units presently exposed have so far been very rapid.

The Homoscene: a "sanitary landfill" operation along the margins of San Francisco Bay in the City of Mountain View. Exposures such as this provide a unique opportunity to study the Quaternary record of the Bay area. The depth of excavation is 8.6 m, when completed this project will have exposed about 3/4 of a square kilometer of fossil-bearing strata.

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Stratigraphy

Alluvial deposits of both generations of fan systems are exposed in the excavation. A section as much as 5 meters thick in the lower part of the pit walls comprises generally fine-grained sediments capped by a well-developed soil profile about 1.5 meters thick (described in Table 1). These sediments (the distal Qof of this report) do not have their base exposed in the dump site, but the log of a nearby well suggests that they are as much as 21 meters thick and that they probably lie on preconsolidated fine-grained sediments correlative with the Pliocene-Pleistocene gravels on the margins of the bay lowland. About 3 meters of deposits above the paleosol are largely assigned to the fine-grained overbank and basinal facies (Qyfo and Qb) of the younger fan system, although some gravel lenses in hollows cut into the Qof paleosol can be properly considered as the channel or levee facies (Qyf). The older unit must have been deposited when sea level was lower, because the ground surface now lies a few centimeters below mean sea level and the younger fan system is very nearly graded to the modern muds of San Francisco Bay. Dikes between the dump and the bay have kept bay water away from the site for many years.

Table 1. Soil Profile Description
(after: U.S. Soil Conservation Service)

Unit	Depth	Description
Ap	0-13 cm	brown (10YR5/3), dark brown (10YR4/3) moist, massive; slightly hard, very friable, non-sticky and nonplastic, very-fine roots and root tubes; pH 6.0, with clear smooth boundary 8 cm thick.
A_{12}	13-25 cm	pale brown (10YR6/3), dark brown (10YR4/3) moist, massive, slightly hard, nonsticky, nonplastic with abundant roots and root tubes; pH 6.1, gradual wavy boundary 10-15 cm thick.
B_1	25-50 cm	brown (YR5/3), dark brown (10YR4/3 moist, subangular blocky structure, hard, friable, slightly sticky, plastic, few roots, many pores, few thin clay films in pores and on red surfaces; pH 6.5, gradual smooth boundary 25-50 cm thick.
B_{2t}	50-80 cm	brown (10YR5/3), dark brown (10YR4/3) moist, medium subangular blocky structure, hard, slightly sticky and plastic, few roots; abundant pores, many clay films on ped surfaces; pH 6.5, gradual smooth boundary 25-50 cm thick.

Table 1. Soil Profile Description (cont'd)

Unit	Depth	Description
B_3	80-100 cm	yellowish brown (10YR5/4), dark yellowish brown (10YR4/4) moist, weak medium subangular blocky structure, hard, friable, nonsticky and nonplastic, few fine roots, very fine tubes and pores; abundant clay films on peds and bridging individual mineral grains; pH 6.5, clear smooth boundary 20-25 cm thick.
IIc	100-150 cm	brown (10YR5/3) becoming very gravelly dark brown (10YR3/3) moist, massive hard, very friable nonplastic and nonsticky; pH 6.5.

Bayward these soils grade to dark gray clay (N/4), (N/3) moist, with dry mottles; still maintain their blocky structure but become harder, stocky and plastic and slightly calcareous, pH 8.0, at depths up to 100 cm they become distinctly olive (5Y5/3) and have calcareous nodules and are moderately alkaline.

At several points around the periphery of the pit, a drainage ditch exposes gray clay "plugs" up to 1 meter in thickness in the lower unit which are inferred to be filled-in oxbow lakes. This clay has provided a reducing environment since deposition and has yielded abundant well-preserved seeds, leaves, wood fragments and whole logs, and faunal remains. Radiocarbon dates of 20,820±320, 21,960±520, and 23,000±500 years B.P. have been obtained from wood at elevations of -6.1, -6.3, and -7.0 meters below present mean sea level. Comparison with the best estimates of the timing of eustatic sea level fluctuations indicates that the lower unit records terrestrial deposition during the lowering sea level in "classical" Wisconsin time. The soil profile on this unit would have thus been formed during an interval of non-deposition when the shoreline was far to the west beyond the Golden Gate. Deposition of the younger sediments is believed to have begun about 5,000 years B.P., when the rising base level once again allowed aggradation on the bay margins.

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1. Late Quaternary section exposed along west wall of pit 2B, "sanitary landfill" operation in the City of Mountain View. The base of the section shown in this photo is about 23,000 radiocarbon years old.

2. Close-up of fragipan exposed in pit 2B as shown above. Note strong ped development.

3. Late Quaternary section exposed along bay margin in the City of Mountain View. Qybm, young bay mud underlain and interfingering with Qyf, young alluvial fan underlain by Qof, older alluvial fan

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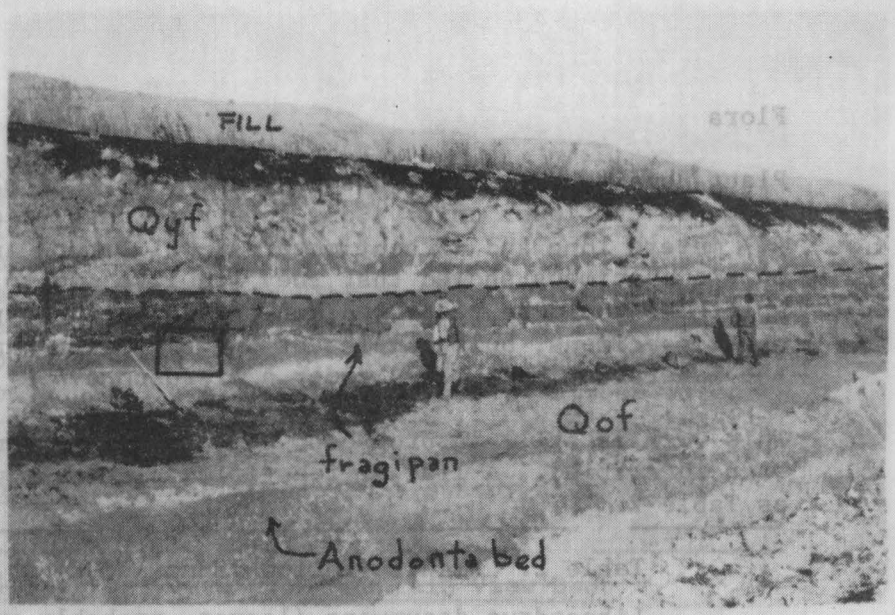
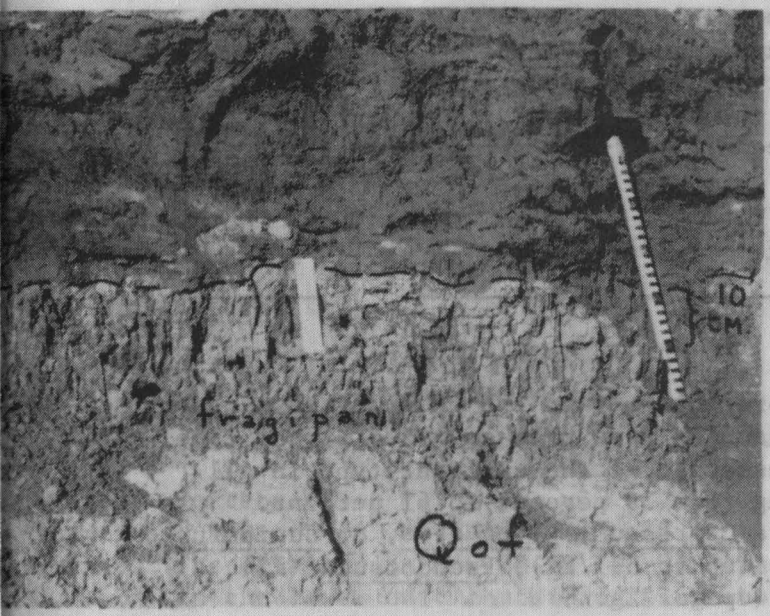
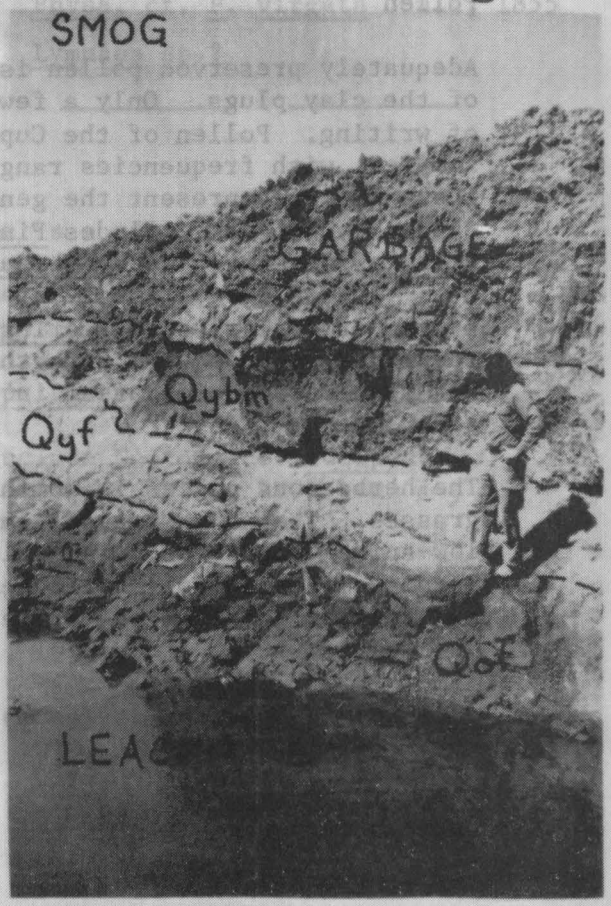
1


FILL
Qyf
Qof
fragipan
Anodonta bed

2


10 CM
fragipan
Qof

3


SMOG
GARBAGE
Qybm
Qyf
Qof
LEA

Flora

Plant remains collected thus far have come entirely from the clay plugs in the lower unit. Some logs have been recovered, including one 2.7 meters long and 25 centimeters in diameter, and tree-ring counts on two specimens showed that they had lived up to 140 years. Wood specimens could be recovered directly from the exposures; for all other specimens, bulk samples of the clay were removed and washed in the laboratory and picked under a microscope.

This work is still in progress, and many plant remains have not yet been identified. A list of identified plants recovered is presented as Table 2.

Table 2. Plants (follows Munz and Keck, 1963)

Libocedrus decurrens (leaves, probably wood)
Cupressus sp (wood, leaves)
Pseudotsuga (needles, possibly wood)
Pinus sp (very few, fragmentary needles)
Juniperus (?) (abundant seeds, possibly foliage)
Zannichellia palustris (abundant seeds)
Elatine californica (seeds)
Potamogeton spp (seeds)
Xanthium strumarium (fruit)
Dichondra cf. D. repens (leaf)

Pollen

Adequately preserved pollen is present only in the reducing environment of the clay plugs. Only a few samples have been analyzed at the time of writing. Pollen of the Cupressaceae is the dominant type in all samples, with frequencies ranging from 39 percent to 61 percent. These grains represent the genera Cupressus, Libocedrus, or Juniperus. Other tree pollen includes Pinus (up to 5-1/2%), Pseudotsuga (1%), Sequoia (one grain) and Quercus (up to 2%).

It is particularly interesting to note the virtual absence of Quercus (oak) and Sequoia from both the pollen and the macrofossil record. Both genera are widespread in the coast range to the west of the site today.

The herbaceous pollen is dominated by Compositae, chenopods, and grasses. The composite pollen is mostly of the high-spine-type, but low-spine Compositae, Liguliflorae, and Artemisia pollen also occur. Total Compositae pollen reaches 30 percent in one sample. Chenopods and grasses are limited to frequencies less than 7 percent.

Mollusca

Abundant mollusk shells from two of the clay plugs have been studied by Allyn Smith of the California Academy of Sciences. The species identified by him are listed in Table 3. He states (written communication, August 7, 1972) that: "The Mountain View Dump shells seem to call for two rather different habitats: (1) a silty-mud, quiet-water situation such as a swamp or sluggish stream for Sphaerium transversum; (2) a perennial lake, river or stream with some water action and a coarser bottom sediment of sand or gravel for Sphaerium kettelmanense and Pisidium compressum (also with associated water plants for Valvata humeralis)--definitely not swampy or stagnant water."

Table 3. Molluscs recovered from Mountain View Dump

(identified by Allyn Smith)

Bulk Sample A	Bulk Sample B
Anodonta sp?	Sphaerium kettelmanense Arnold, 1910
Sphaerium cf. S. transversum Say, 1829	Pisidium cf. P. compressum Prime, 1852
Musculium? sp?	Gyraulus parvus Say, 1817
Gyraulus parvus Say, 1817	Valvata humeralis Say, 1829
Lymnaea sp?	Physa, cf. P. virgata Gould, 1855
Physa cf. P. virgata Gould, 1855	Lymnaea sp.?
Succinea sp?	

Vertebrates

The other major source of faunal remains is a silty and sandy stratum in the lower unit containing large bones. The stratum is about 1-2 meters thick and its top is about 3.5 meters below the paleosol. The bone layer has yielded Equus, Bison, Camelops, Mammuthus and a ground sloth, Mylodon harlani. Most bones occurred singly, but several articulated partial skeletons of Camelops hesternus have been recovered.

Smaller vertebrates from this stratum include Neotoma cf. lucipes, Dipodomys cf. heermani, and Eumeces?. All vertebrates have been identified by C. A. Repenning (oral communication, 1972).

Some fish remains occur in the clay plugs, and these have been identified as Gasterosteus aculeatus (stickleback) by W. Follett of the California Academy of Sciences (oral communication, 1972).

Other remains which have not been studied as yet include anthropods, ostracods, and mosses.

Marsh and pond deposits

In theory, the deposits contained in closed depressions in the study area should supply us with a biologic record of regional climatic fluctuations. Both depressions in landslide blocks and sag ponds created by fault movements may be suited to the purpose, but we have preferred to work with landslide depressions thus far because of the possibility that on-going faulting has disturbed the stratigraphy of sag ponds.

Once a regional climatic sequence has been established, however, we hope to use paleoecological studies of sag ponds to extend the records of earthquake activity back beyond the presently available historical records.

Two marshes atop landslides are currently under study. On the Weeks Creek landslide near the town of La Honda in San Mateo County, a single radiocarbon date from the base of a 2-meter core suggests that the depression is at least 3350 years old in its central portion. However, the toe of the landslide is currently moving, as evidenced both by surface morphology and by the need for frequent repairs of a highway that crosses the toe. The marsh core contains abundant pollen, fresh water mollusca, seeds, and small bones.

The other marsh site is located within 1 km of the Pacific coast in northern Santa Cruz County. We have just obtained a radiocarbon date of 15,080±190 B.P. from the base of a 3-meter core. The site appears to have not been disturbed by man, and it seems likely that we will be able to obtain a climatic record extending back into the period of Wisconsin glaciation.

Archaeology

The distribution of archaeologically and radiometrically dated kitchen middens relative to the "post-Wisconsin" (i.e., 1850 A.D.) shoreline of San Francisco Bay provides yet another datum useful in our studies. In the south bay (south of San Mateo and San Leandro), all middens lie landward of and above the 1850 shoreline. Most sites are on the bay end of natural levee deposits (Qyf), where there was a combination of high ground and easy access to tidal flats and marshes. Northward from San Mateo and San Leandro, particularly on the east side of the bay, the middens often lie bayward of the 1850 shoreline and are as much as 1 meter below sea level. Radiocarbon dating of the bases of these mounds give ages of only 3,000 years.

The relatively young age of the mounds is somewhat troublesome as it suggests that the central bay is subsiding relative to the south bay. Yet the south bay contains the thickest section of post-Pliocene sediments--as much as 600 meters, compared to a local total absence to the north--and radiocarbon dating of submerged peat beds suggests that the south bay has been subsiding rapidly for the last 3,300 years. Historical information shows that the south bay has subsided 0.6-2.4 meters between the years 1920 and 1964, at least in part because of ground water withdrawal.

No boring, trench, or artificial exposure thus far examined around the south bay (including 300-meter borings) has revealed any marine or estuarine fossils. We have found fossils all around the shoreline to be sure, but they are from fresh-water habitats, suggesting that the south bay is as large today as it has ever been. Therefore, we feel that the subsidence of a tectonic sort is probably still going on and will continue in the future, even if subsidence from ground water withdrawal can be stabilized.

No bay area archaeological site, to our knowledge, is older than 4,800 radiocarbon years, although the known history of human habitation in coastal California indicates that older sites should exist, or they have already been destroyed, or they lie buried beneath the water and mud of San Francisco Bay.

We have located four human burials in the banks of a storm drain in one of our local communities. These burials occur in and are capped by deposits of the younger fan system (Qyfo) which correlate with the upper units exposed in the Mountain View dump site. The burial holes "bottom out" about 2.7 meters below land surface on the fragipan soil horizon at the top of the older fan deposits (Qof), and they are covered by as much as 1.8 meters of post-interment sediment. An incipient soil profile on the grave fills and surrounding deposits indicates the land surface at the time of burial. Pre-interment marsh deposits of the young fan system contain a horizon of abundant fresh-water mollusks that yield a C^{14} date of about 10,430 years b.p., thus placing a maximum age on the burials. Attempts to date human bone have so far been unsuccessful.

The regional stratigraphic and climatic sequences which we are defining for the San Francisco Bay area will form the basis for further studies in the environmental geology of this heavily settled area. An understanding of the ages of the young deposits is of particular importance, for only with a proper time perspective can we realistically evaluate the rates at which contemporary geologic processes are acting. If regional planners are to avert or minimize the impacts of future geological disasters, such information soon must be forthcoming for all of the densely populated areas of the country. As the Homoscene exerts an ever-increasing pressure upon the natural environment, we may expect the study of the Quaternary to assume a new relevance and perhaps even a respectability.

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