Report on the Geology and Soils of Lamorinda and Surrounding Regions

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Introduction

This report summarizes the characteristics of the geology and soils of the Lamorinda wine-growing region (Lafayette, Moraga, and Orinda), located in southwest Contra Costa County, California, and compares them to adjacent areas of the Livermore Valley and eastern San Francisco Bay region. This report is based on our interpretation of original geologic mapping by Dibblee in the 1970s (and published in 2005 and 2006) and Graymer (2000), and on reports on the soils prepared for Contra Costa County (Soil Conservation Survey, 1977) and adjacent Alameda County (Soil Conservation Survey, 1961). To this interpretation, we add our own observations made during field visits to the region.

Executive Summary

The main conclusions of this report are the following:

1. The Lamorinda area is underlain by a unique sequence of sedimentary rocks that reflect its distinctive geologic history. In particular, the Orinda conglomerate, which underlies most of the area, is an unusual deposit of coarse sandstone and claystone clasts that were deposited in a terrestrial basin as nearby marine rocks were uplifted and eroded.
2. Areas adjacent to the Lamorinda area are either steep ridges formed from older, more resistant sedimentary and volcanic rocks (Oakland-Berkeley Hills, Mt. Diablo, Sunol area), or basins that remain active centers of deposition. (San Francisco Bay, the Sacramento-San Joaquin Delta, and Livermore basin). The geology and soils of these areas differ considerably from those of the Lamorinda area.
3. The greater Livermore basin, largely contained within the Livermore AVA, is geologically distinct from the Lamorinda area. Except for a thin sequence of marine rocks at its base, the Livermore basin is predominantly non-marine material. The dominant rock type is a conglomerate consisting of sandstone clasts shed from surrounding older marine rocks, and lacking the high proportion of claystone clasts found in the Orinda conglomerate that underlies the Lamorinda region.
4. The primary winegrowing areas of Lamorinda are located on thin, clay-rich soils that are well-drained due to moderate to steep slopes. The modest thickness of these soils restricts their field capacity relative to soils in adjacent valley bottoms. Nearby winegrowing areas in Livermore valley are predominantly in flat regions of recently deposited gravel conglomerate, with poorly-developed gravel-loam soils and low field capacity.
5. There is greater similarity between the soils of Lamorinda and those formed in the foothills of Mt. Diablo, within the northern part of the Livermore basin. Nevertheless there are differences, and they are primarily due to the presence of claystone clasts in the Orinda conglomerate of Lamorinda. This leads to the formation of more clay rich soils with slightly higher water-storage capacity. We note however this part of the Livermore basin does not currently support vineyards.

Background

The geology of the Oakland-Berkeley Hills, including Lamorinda, has been the subject of more than a century of geologic study, due in part to its proximity to the original University of California campus at Berkeley. For this report we rely on two later resources that have synthesized this earlier work. T.W. Dibblee mapped an extensive region of coastal California as an employee of both the California Division of Mines and

Geology, and later the United States Geological Survey. His mapping provided the regional synthesis and correlations that are the foundation for much that is now known about the geologic history of the California Coast Ranges. Dibblee incorporated earlier work into his mapping, and this is reflected in his citations of this work on the various map sheets used in constructing this report (see the Bibliography for a complete listing). Graymer (2000), working for the U.S. Geological Survey, developed regional scale geologic maps for much of the Coast Ranges surrounding the San Francisco Bay. His work differs from that of Dibblee in that there is a greater focus on the role of major faults in juxtaposing distinct geologic terranes. These include the Hayward fault and the Calaveras fault - two major and active strands of the San Andreas fault system - that bound the Lamorinda region. In our own field inspection we paid close attention to the geology adjacent to these faults, confirming that the rock types are different across them.

Soils information was synthesized from county-wide reports prepared by the U.S. Soil Conservation Service. These reports divide soils into named series based on correlation to key sites of detailed study. However many of the distinctions between soils are subtle, and overall the practice of naming soil series has fallen out of favor. We base our analysis instead on the descriptive content of these soils reports, from which we can characterize broadly based soil-formation regimes characteristic of the Lamorinda region and surrounding areas. Soil formation reflects a combination of geologic substrate, climate conditions, and time. Each of these factors plays a role in understanding the distinguishing characteristics of the soils of the Lamorinda region.

Geology

The geologic history of the Lamorinda area mirrors the broader development of the Coast Range Province of California, characterized by two distinctive eras and styles of geologic processes. In the Mesozoic and early Cenozoic (~180 to 20 million years before present), the geologic history of the region was dominated by subduction of oceanic crust beneath the margin of North America. During this time the Lamorinda region was part of a broad, submerged marine basin covered by an apron of debris shed from the adjacent North American continent. Rocks deposited in this era range from fine-grained shales to coarse sandstones and are exposed in the higher topography of the Oakland Hills, as well as in the foothills of Mt. Diablo, to the east. The later geologic history of the Coast Ranges was dominated by motion along strands of the San Andreas fault system. This activity fragmented the formerly broad marine basin into numerous smaller, fault-bounded basins. Marine deposition persists today in some basins (e.g. San Francisco Bay) but most have been filled with a mixture of marine rocks and non-marine detritus shed from surrounding areas. Some, including the Lamorinda area, have transitioned from sites of deposition to areas of folding, uplift, and erosion.

We divide our description of the geologic strata into units found within the Lamorinda region, *versus* units found in surrounding areas. In general we have adopted the simplified stratigraphy mapped by Dibblee. The numerous subdivisions mapped by Graymer (2000) are often unimportant for understanding the overall geology. However in some cases these subdivisions prove critical for understanding relationships across major faults, and we note where this is the case. Many of the units present in the Lamorinda region have also been mapped in adjacent areas. In each case we interpret the basis of this correlation and contrast the rock units mapped in each area.

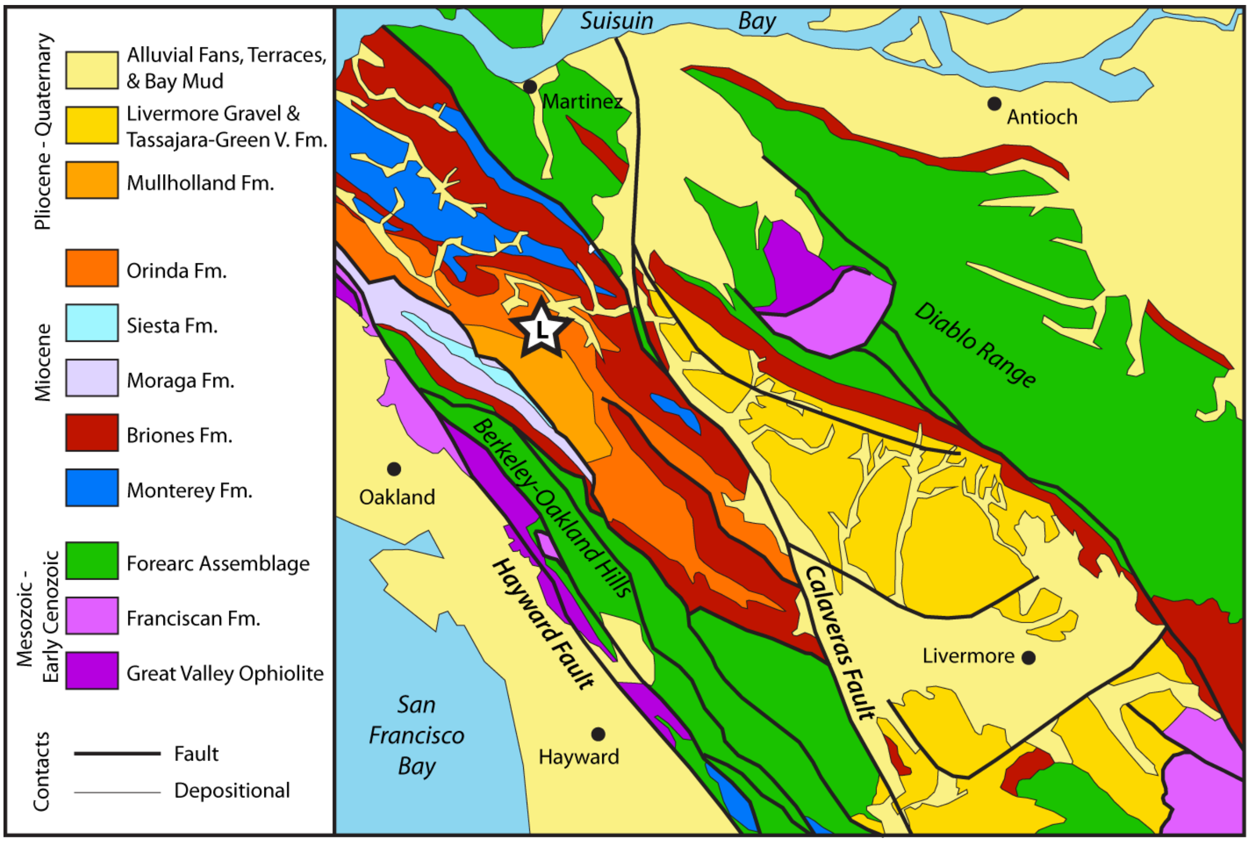

Fig. 1. Simplified Geologic Map of Lamorinda and Adjacent Areas. Star shows center of Lamorinda (Lafayette-Moraga-Orinda) region.

Geologic Strata of the Lamorinda Region

Monterey Formation: This marine unit consists of claystone, shale, and minor sandstone. It is ubiquitous throughout the Miocene-age sedimentary basins of coastal California and has been correlated to as far south as Los Angeles. The Monterey formation was deposited throughout the Miocene (6 to 23 million years ago), typically in restricted, fault-controlled basins. Its thickness varies greatly, from a few feet at its furthest extent to more than a mile thick in the deepest basins. The era of the Monterey Formation was characterized by high marine biologic productivity, leading to deposition of organic-rich shales that comprise the most important petroleum source rock in California. Thick deposits of Monterey claystone and shale are found between Lamorinda and Pinole. Based on much previous work in the area, Graymer subdivides the Monterey formation into up to nine different formations, the names of which we exclude here for the sake of brevity. Sandstone interbeds present in the northern part of Lamorinda, adjacent to Briones Reservoir, pinch out to the north. This relationship indicates shoaling of the marine basin towards the south. A very thin deposit of Monterey formation is also found at the base of the Livermore basin, presently exposed in the foothills of Mt. Diablo, reflecting a very brief eastward invasion of marine waters at the onset of deposition in this basin. Dibblee (2005a) grouped this thin layer of marine rocks into the Briones formation, described below.

Fig. 2. Marine Sediments of the Monterey Formation. (Flash drive – 2 inches long – for scale.)

Briones Formation: This formation is composed of shallow marine, nearshore to littoral (beach) deposits of highly fossiliferous sandstone deposited during the Miocene (6 to 23 million years ago). The Briones formation is everywhere a thin deposit, no more than a few hundred feet thick. It marks the transition from marine deposition of the underlying

Monterey formation to nonmarine deposition above. This distinguishing characteristic has led to correlation of the Briones formation over much of the Coast Ranges in north-central California. In the Lamorinda area, the Briones formation is mapped by Dibblee (2005a) as locally interfingering with the Monterey formation. Sandstone interbeds mapped in the uppermost Monterey formation are very similar to the Briones formation, and overall this package of sandstones represents the periodic advance and retreat of marine waters as the basin filled and sea level fluctuated. A thin deposit of Briones formation at the base of the Livermore basin records a single, broad advance of marine water here, subsequently overlain by monotonous deposits of non-marine conglomerate. Both Dibblee and Graymer have mapped subdivisions of the Briones formation in some areas, but these correlations are inconsistently applied except for the Neroly sandstone, which forms the uppermost layer of the Briones formation.

Fig. 3. Fossiliferous Sandstone of the Briones Formation

Siesta Formation: This distinct gray-green sandy conglomerate is interbedded with basalt flows (Moraga formation). These rocks underlie the westernmost part of Lamorinda, and continue both to the north and south along the eastern side of the Oakland-Berkeley hills. The presence of basalt, as well as the distinctive color and abundant serpentinite clasts within the conglomerate, distinguish this unit from the contemporaneously deposited Orinda formation, described below. Note that Dibblee (2005c) incorrectly grouped these rocks with the Orinda formation - an interpretation later rejected by Graymer (2000).

Fig. 4. Conglomerate of the Siesta Formation

Orinda Formation: This non-marine conglomerate was deposited in the latest Miocene and Pliocene (3 to 6 million years ago) by streams eroding nearby uplifted marine strata. This unusual conglomerate deposit, comprised of a mixture of sandstone and claystone clasts, underlies most of the Lamorinda region. Naming conventions and correlation of the Orinda formation vary between Dibblee (2005c, 2005d, 2005e, 2006a), who correlated the unit to adjacent areas, and Graymer (2000), who rejected these correlations, as well as the name 'Orinda formation' and instead mapped these as 'unnamed conglomerates.' In this report we agree with Graymer's skepticism of the extent of this conglomerate, but we retain the term 'Orinda formation' to describe the unique conglomerate mapped in the Lamorinda region. West of Lamorinda, Dibblee (2005c) mapped the Orinda conglomerate interbedded with the Moraga basalt of the Oakland-Berkeley Hills. Graymer maps a strand of the Hayward fault system separating these rocks from the Orinda conglomerate. Based on our fieldwork, we concur with Graymer's designation of a distinct rock unit.

Dibblee (2005d, 2005e, 2006a) also mapped the Orinda formation in the southern foothills of Mt. Diablo, within the lower portion of the Livermore basin. However in his mapping, he notes that these conglomerates are dominated by sandstone clasts reworked from older marine strata ('Franciscan detritus') and lack the presence of the claystone clasts that we find characteristic of the Orinda formation. The Mt. Diablo foothills are separated from Lamorinda by the Calaveras fault, which brought these rocks, which were deposited within separate basins, into close proximity. Thus we reject Dibblee's correlation of the Orinda formation here, and adopt the composite name of 'Tassajara-Green Valley formation' for these units, based on the original mapping by Conduit (1938) and adopted by Graymer (2000).

Fig. 5. Conglomerate of the Orinda Formation. Note the presence of claystone clasts of the Monterey Formation.

Mullholland Formation: This unit of Pliocene (3 to 5 million years ago) lacustrine shale and sandstone is mapped by Graymer (2000) as deposited above the Orinda formation ('unnamed sedimentary rocks'). Dibblee (2005d) groups these rocks within the Orinda formation. Because these rocks are lithologically distinctive from the Orinda conglomerate we adopt Graymer's subdivision of these into a separate unit. The Mullholland formation represents deposition within a lake near the axis of the basin filled by conglomerates of the Orinda formation. It is the last deposit preserved in this basin before folding and uplift transformed the Lamorinda region into the hilly, eroded terrain present today.

Fig. 6. Lacustrine Shales of the Mullholland Formation

Geologic Strata of Surrounding Regions

Great Valley Ophiolite: Ophiolite is a general term describing oceanic crust trapped within a continent. The Great Valley Ophiolite underlies the Coast Ranges east of the San Andreas fault, as well as much of the Great Valley to the east. To a great extent, these ophiolitic rocks have been altered to a distinctive green rock known as serpentinite. Less altered basalt and gabbro are also present. This assemblage of rocks is exposed where faulting has caused sufficient uplift to expose it from beneath the sedimentary cover. A several square-mile window of these rocks is exposed in the core of the Mt. Diablo uplift. A larger belt of these rocks is exposed in fault-bounded slivers along the Hayward fault, in the western slopes of the Oakland-Berkeley Hills.

Franciscan Formation: This is a catch-all formation name for moderately to intensely deformed, mildly to strongly metamorphosed sedimentary rocks that were deposited in a trench-slope setting offshore of California during the Jurassic, Cretaceous, and early Tertiary (broadly between 180 and 50 million years ago). These rocks were progressively attached to the margin of North America and are found in fault contact with the Great Valley Ophiolite. Occurrences are widespread between Pt. Conception to the south and the northernmost coastal regions of California. Low-grade Franciscan rocks may appear similar to forearc strata (see below) deposited on the continental shelf, especially when reworked into younger sedimentary conglomerates. Locally, Franciscan rocks crop out in the Mt Diablo uplift, and on the western slope of the Oakland-Berkeley Hills, along the Hayward fault.

Forearc assemblage: Multiple named and unnamed rock formations together comprise a thick blanket of sedimentary rocks deposited on the continental shelf of North America from late Jurassic-Cretaceous, through the early Cenozoic (approximately 170 to 40 million years ago). These rocks are almost entirely of marine origin, fluctuating between some shale and more abundant sandstone, with occasional conglomerates that were deposited by submarine fan systems. Dibblee designated the local forearc strata of Cretaceous age as the Panoche formation, and mapped it widely to the south of Lamorinda and the Livermore basin. Graymer maps strata of the same age, but generally as unnamed units. Outcrops of Jurasic-Cretaceous forearc strata also occur along the crest of the Berkeley-Oakland Hills, and within the Mt Diablo uplift. Slightly younger, Paleocene-Eocene forearc strata, mapped as the Martinez, Meganos, and Domengene formations by Dibblee (2005e) occur on the lower slopes of the Mt Diablo uplift and as small fault-bounded slivers within the Berkeley-Oakland Hills.

Monterey / Briones Formations: As described in greater detail above, these rocks were deposited in restricted, fault-bounded basins as the San Andreas fault system began to segment and offset portions of the Coast Ranges. This activity disrupted the formerly extensive forearc continental shelf. Some areas became emergent, shedding clastic detritus into adjacent basins as marine shales, claystones, and sandstones (Monterey formation). As basins filled, the fossiliferous Briones sandstone was deposited at the shoreline, followed by nonmarine conglomerate deposits reflecting local sediment source areas (e.g., the Orinda, Siesta, and Tassajara-Green Valley formations described above, and the Livermore gravels described below).

Livermore Gravels: The Livermore gravels are a Plio-Pleistocene (less than 5 million years old) deposit of valley fill in the Livermore basin that has been subsequently folded and uplifted by active faults. The gravel is compositionally identical to the underlying Tassajara-Green Valley formation, a conglomerate consisting primarily of sandstone detritus, and represents a continuation of the progressive infilling of the Livermore basin that endures to the present.

Stream Terraces: stream terraces are widespread in valley bottoms along larger stream courses, and also form stepwise flights of benches in southern areas of the Livermore Valley. These are relatively young remnants of active stream and alluvial fan systems and typically are underlain by coarse stream gravel deposits. Dibblee (2006b) maps two generations of stream terraces in the southern Livermore valley. These terraces are abandoned parts of alluvial fans that had their source in mountainous areas to the south. The terraces exist due to uplift above active thrust faults that fringe the basin (Unruh, 1997).

Alluvial Fans: Alluvial fans are areas of active deposition. These are formed as streams make the transition from eroding, higher-gradient source areas to low gradient basins, causing the streams to lose the energy that is necessary to transport their coarse bed load. With sufficient burial and cementation, alluvial fan deposits become the conglomerates and course sandstones that are typical of nonmarine deposits in the Coast Ranges. Alluvial fans are absent from the Lamorinda region because it is an area presently undergoing erosion, feeding stream systems and deposition elsewhere. Alluvial fans cover the flat floor of the Livermore basin - a site of active deposition. Alluvial fans also mantle the western slope of the Berkeley-Oakland Hills, depositing their coarse sediment (prior to urbanization) and transporting finer sediments to the San Francisco Bay.

Bay mud: This unit is represented by fine-grained mud and silt deposited in the San Francisco Bay, San Pablo-Suisun Bay, and the Sacramento and San Joaquin Delta. This material is deposited from suspended sediment transported by tides and river floods, and it forms the substrate of marshlands reclaimed for agriculture in the Delta. It differs considerably in texture from the course-grained detritus deposited by locally sourced alluvial fan systems.

Soil-Forming Processes of the Coast Ranges

Grassland soils of coastal California are generally calcic and rich in clay minerals formed through weathering of the underlying rocks and sequestration of atmospheric dust. These soils are classified as mollisols with the soil column forming recognizable horizons of topsoil and subsoil. Where clay content is higher the soils may undergo slow mixing due to shrink-swell processes. These soils, classified as vertisols, are recognizable by a lack of formation of soil horizons and the presence of slickenside surfaces formed when peds (soil clumps) slide slowly past one another.

Where differences in the clay content of soils arise, these may be due to the parent material or to time. Rocks richer in clays will lead to more clay-rich soils. Volcanic rocks and serpentinite both tend to form clay-rich soils with unusual clay chemistry. Time influences the soil-forming process in two ways. Where recent sedimentary deposits form a stable surface, soil-formation will progressively increase the clay (and in drier areas, soil carbonate) content. Weakly developed soils developed on young surfaces are classified as inceptisols. With time and soil development, these soils will tend to become mollisols.

Time also enters in a more subtle way where soils form on slowly eroding substrates, such as the hilly topography which is common in the Lamorinda region. Here soil is constantly being produced by weathering, organic activity, and atmospheric inputs, and removed by erosion. The resulting balance defines a lifetime for soil formation. This lifetime controls the soil maturity, and the combination of soil lifetime and the rate of soil production controls the soil thickness. Soil lifetime may be the same everywhere or increase downhill if there is net deposition of soil in the valleys. In this situation, soils will tend to be thinnest on steep slopes and on hilltops, and thicker on gentle slopes and adjacent valley bottoms.

Soils of the Lamorinda Region

Soils of the Lamorinda region are a patchwork of well-developed mollisols and vertisols, reflecting the balance of primary clay input to the soil from underlying strata. Soils are generally of modest thickness (around two feet) due to their formation on moderate to steep slopes, in balance with slow erosion of the readily fragmented sedimentary rocks that make up the region.

Hillslope soils that are spatially dominant across Lamorinda fall mostly into five mapped soil series: Two mollisols: Los Osos clay-loam and Lodo clay-loam; and three vertisols: Alo clay, Sehorn clay, and Altamont-Fontana complex (also a clay soil). Note that the mollisols are also clay-loam soils. This term indicates a clay-rich mix of soil particle sizes, whereas the vertisols are clay soils, an indication of higher clay content that leads to their characteristic shrink-swell behavior. All five of these soils reflect the relatively high clay content of the strata underlying the Lamorinda region. In particular, the weathering of claystone clasts within the Orinda conglomerate appears to lead to higher clay content in the overlying soils than would otherwise be expected from a conglomeratic substrate. This gives rise to an overall clay-rich (but importantly, not exclusively clay) suite of soils with good drainage, due to steep slopes, and moderate field capacity, due to high clay content offset by limited soil thickness. These hillslope soils are favorable for viticulture, and the vineyards of Lamorinda are located primarily on these soils.

Fig. 7. Thin Clay-loam Soil of the Lamorinda Area (Note: the original soil has been modified for viticultural purposes.)

Other soils of the Lamorinda region reflect their substrate or position within the landscape. Soils tend to thicken down slope, indicative of net soil deposition in the valley floors. This process concentrates clays, reflected in thick clay vertisols in valley bottoms: Clear Lake clay, and Cropley clay. These soils have much higher field capacity than those on surrounding hillslopes, and are thus not as well suited for growing wine grapes. Some hilltop areas are characterized by rocky, thin soils with low field capacity, mapped as Millsholm loam. Basalt present in the Moraga area is capped by Gilroy clay loam, a somewhat acid (low pH) soil characteristically developed atop such rocks. Diablo clay and Dibble clay loam are also mapped on these rocks, but this may be an error from photo interpretation used to construct the soils map, as these soils are more characteristic of sandy sedimentary rock substrates rather than volcanic rock.

Soils of Surrounding Regions

Diverse geology and climate conditions of areas surrounding Lamorinda give rise to a variety of soils. Here we review some of the more important soil characteristics of nearby areas, with greatest attention to the soils of the Livermore valley and surrounding uplands. Areas fringing the bays of San Francisco, San Pablo, and Suisun typically consist of fine-grained bay mud, with coarser alluvial fan deposits rising towards flanking hills. Very clay-rich, poorly drained 'muck' soils are found upon bay mud deposits. Nearby, gentle alluvial fan gradients and somewhat moister climate host thick (>6 ft), fertile soils such as Danville silty clay-loam. Surrounding steep upland regions (e.g., the Berkeley Hills) are mostly sedimentary rocks with thin soil cover. Many of these soils are rocky clay-loam or loam formed on sandstone substrates, such as Linne clay-loam, Dibble clay-loam, or Millsholm loam. A somewhat unusual soil, the excessively drained Briones loamy sand, is found on poorly consolidated sandstone lenses within the Monterey formation, but curiously not on the Briones formation itself, which is a well cemented sandstone that tends to form clay-loam soils. In our field visit we observed thin, very clay-rich soils mainly on outcrops of Monterey formation shale and claystone. The thinnest of these soils are mapped as rock outcrops, rather than a particular soil series.

Fig. 8. Very Thin Soil Developed on the Monterey Formation

Livermore valley and surrounding uplands host soils that are generally coarser textured (clay-loam, loam, and gravelly loam) than the soils of Lamorinda (clay and clay-loam). The central, flat area of the Livermore basin is dominated by deposits of recently transported sand and gravel mobilized from surrounding uplands. Due to their youthfulness and the arid climate, soils are not well developed on these materials, forming inceptisols (Livermore gravelly coarse sandy loam). Higher, older alluvial terraces have been subject to soil formation for a sufficient period to develop greater clay-fractions, forming soils more closely resembling mollisols (Pleasanton gravelly loam, Positas gravelly loam). These gravelly soils, especially the Livermore series, comprise the primary grape-growing land in Livermore Valley (Soil Conservation Service, 1961; Livermore Valley Winegrowers Association, 2012). The hilly uplands surrounding the Livermore basin are primarily underlain by gravelly conglomerate deposits (Livermore gravels) and Tassajara-Green Valley formation. Importantly, these conglomerates lack claystone clasts derived from erosion of the Monterey formation. Thus the soils formed upon the conglomerates are generally lower in clay than in similar settings at Lamorinda, and tend to be loam (Millsholn series) or clay-loam (Lodo, Los Osos, or Linne series) mollisols rather than clayey vertisols. Alluvial fans in eastern Livermore valley tap some shale detritus eroded from older forearc strata. The soils formed on these fans tend to be somewhat finer grained than elsewhere on the Livermore Valley floor: Rincon series loam and clay-loam (mollisols), and Pescadero clay (vertisol).

Analysis of the Geology and Soils of the Lamorinda Region and Adjacent Areas

The Lamorinda area is underlain by a unique sequence of sedimentary rocks that reflect its distinctive geologic history. That history began about six million years ago with the formation of a restricted basin similar to but narrower than the southern half of today's San Francisco Bay. Compression of the adjacent Berkeley Hills caused older (10-30 million year old) fine-grained marine claystones to be uplifted, eroded, and recycled into the basin. This “geologic processing” of originally marine material imparted a non-marine character to the material coming into the basin. The result was formation of a distinctive, terrestrial sedimentary unit, known as the Orinda formation. The Orinda formation is a conglomerate, consisting of a mixture of sandstone and claystone clasts. It is the dominant rock type underlying the Lamorinda area. Eventually the restricted basin became completely separated from the sea. The deposition that took place in the resulting shallow lake environment produced the sandstones and shales of the Mulllholland formation.

Subsequent faulting along strands of the San Andreas fault system produced the hilly terrain that dominates the Lamorinda region today. The soils that formed in this terrain are clay-rich vertisols but with enough sand to limit the degree of soil mixing. Steep slopes limit the resulting soil thickness, but not so much as to exclude soil retention altogether. Thus the Lamorinda area is characterized by clay-rich soils of modest thickness with good drainage. The steep slopes and thinness of the soils limits the field capacity and creates conditions favorable for growing wine grapes.

Fig. 9. Wine Grapes Growing on Steep Slopes of the Lamorinda Area

In contrast, the areas adjacent to the Lamorinda area are either steep ridges formed from older, more resistant sedimentary and volcanic rocks (Oakland-Berkeley Hills, Mt. Diablo, Sunol area), or basins that remain active centers of deposition. (San Francisco Bay, the Sacramento-San Joaquin Delta, and Livermore basin). The geology and soils of these areas differ considerably from those of the Lamorinda area in part because the geologic imprint of terrestrial recycling of marine sandstones and claystones together is missing. The importance of this recycling to soil character is evident from the soils formed on purely marine Monterey claystone, which are very thin, if present at all.

The greater Livermore basin, largely contained within the Livermore AVA, is also geologically distinct from the Lamorinda area. Except for a thin sequence of marine rocks at its base, the Livermore basin is predominantly non-marine material. However, the dominant rock type is a conglomerate consisting of sandstone clasts shed from surrounding older marine rocks, and lacking the high proportion of claystone clasts from the Monterey formation found in the Orinda conglomerate that underlies the Lamorinda region. Thus, both the mineralogy and the physical characteristics of soils of the Livermore basin are quite different than those of the Lamorinda area.

Because of these differences, most of the grape-growing in the Livermore basin takes place on or near the valley floor on recently deposited gravel conglomerate, with less well-developed gravel-loam soils, whereas the grape-growing of the Lamorinda area takes place on steep slopes with thin, clay-rich soils. Both areas exhibit low to modest field capacity, but for very different reasons: high porosity and rapid subsurface drainage in the flat Livermore basin, versus thin soils and rapid overland drainage in the Lamorinda region.

The soils of Lamorinda are somewhat similar to those formed in the foothills of Mt. Diablo, within the northern part of the Livermore basin. However there are important differences that arise because of movement across the Calaveras and other faults of the San Andreas fault system that separate the Lamorinda area from the Mt. Diablo area. The geologic units that are now in proximity across these faults originated many tens of kilometers apart in basins with different geologic properties. In particular, the soils of the Mt. Diablo area have only a minor contribution from claystone clasts from the Monterey formation. In the Lamorinda area, the presence of these clasts in the Orinda conglomerate leads to the formation of more clay rich soils with moderately higher field capacity. We note that the foothills of Mt. Diablo are not currently an area of viticulture.

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