Soil Chemistry and Mineralogy of the Santa Cruz Coastal Terraces

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1.0 Introduction

Marine terraces in the central coast of California provide an opportunity to study a soil chronosequence in which similar materials (beach deposits) have been weathered under similar slope, climatic, and vegetation conditions during the Quaternary. The terraces between Santa Cruz and An_o Nuevo, California have been studied for decades and are thought to be one of the best example of marine terraces in California {Lawson (1893), Wilson (1907); Branner and others (1909), Rode (1930) Page and Holmes (1945), Alexander (1953), Bradley (1956, 1957, 1958, and 1965), Bradley and Addicott (1968), Clark (1966 and 1970), Jahns and Hamilton (1971), Lajoie and others (1972), Bradley and Griggs (1976). Hanks and others (1986), Aniku (1986), Fine and others (1988), Anderson (1990 and 1994), and Rosenbloom and Anderson (1994).} Here we report morphological, chemical, physical and mineralogical data for the soils that were formed in deposits on the Santa Cruz marine terraces in order to examine soil characteristics as a function of increasing terrace age.

2.0 Geologic setting

The main characteristics of terrace formation include (1) deposition of sediment while the platform is still submerged (2) platforms, formed by wave energy, are cut into bedrock during sea-level high stands (3) as sea level drops beach sediment, colluvium, and local stream alluvium are deposited onto the newly exposed bedrock platform and (4) terraces are tectonically uplifted, deformed, eroded and incised (Bradley and Griggs 1976). In general, the terraces slope seaward at low angles and with a slight concavity. Although processes that form and deform the terraces are well understood, the time of deposition and stabilization of the terrace surface, and the exact rates of the tectonic uplift, are less well known (Bradley and Griggs 1976, Hanks and others 1986, Perg and others 1999). In general, however, terraces increase in age from the lowest terrace that forms the current ocean blufftop to the highest terrace that occurs ~4 km inland and ~500 m in elevation.

There are five discernable terraces between Santa Cruz and An_o Nuevo, California defined by Bradley and Griggs (1976), in order from oldest to youngest, as Quarry, Blackrock, Wilder, Western and Highway 1. Only the Highway 1 terrace is
spatially continuous. Regional uplift rates appear to be more rapid toward the south, as a result, identification and correlation of specific terraces is problematic especially where fewer than five terraces are present (Anderson, 1990, 1994). Although we refer to our sites using the nomenclature of Bradley and Griggs, we caution that absolute ages and even the assignment of terrace names are tenuous until more dating information becomes available. Our identification of the top two terraces, Quarry terrace and Black Rock (Table 1) are particularly suspect. The two sites could conceivably be front and back edges of one terrace (Quarry) or indeed are two separate terraces.

The present climate is Mediterranean with cool, wet winters (9 to 10°C) and warm dry summers (16 to 17°C) with the influence of fog. The climate of the late Pleistocene, when the marine terraces were cut, was similar to present day with only moderately cooler, wetter conditions during glacial periods (Gorsline et al. 1976, Johnson, 1977, Sims et al., 1981). The vegetation at present, on the terraces is composed of annual grasses and oak with redwood trees found in the stream channels.

There are numerous faults traversing these terraces from the North American-Pacific plate boundary (Anderson, 1990, 1994). Tectonics associated with these faults is one of the major components in forming marine terraces. The uplift rates along the coast according to Bradley and Griggs (1976) vary from 0.16 to 0.48 m kyr\(^{-1}\), but may be as fast as 1.15 m kyr\(^{-1}\) (Perg and others, 1999). Understanding rates of uplift aid in dating the terraces and soil profiles.

Underlying the terraces is Tertiary Santa Cruz mudstone and Santa Margarita sandstone. These are easily eroded by waves and streams, but remain intact in interfluves (Clark, 1981: Bradley and Griggs, 1976). The Santa Cruz Mudstone is a thin to medium-bedded, brown and gray to light-gray, buff, and light-yellow siliceous mudstone with nonsiliceous mudstone and siltstone and minor amounts of sandstone. The siliceous nature implies organic deposition in a quiescent, deep-water environment. The Santa Margarita sandstone is a thin, bioturbated light-gray to grayish-orange to white, friable, very fine-to very coarse-grained arkosic sandstone. Fine-grained sandstone commonly contains glauconite. A quartz and feldspar pebble conglomerate crops out locally at the base of the section. The Santa Margarita Sandstone represents a shallow marine deposit (Barnes and others 2000).
3.0 Field and laboratory procedures

Conventional methods were used to describe, sample and analyze soils from the Santa Cruz terraces. Briefly, soil profiles were sampled by genetic horizons from backhoe pits and drill cores. Physical, extractive chemical, and total chemical analyses are reported in appendices following the conventions of Harden and others (1986), USGS Bulletin series 1590. A detailed explanation of our field and analytical methods is included in Singer and Janitzky (1986). Methods for iron and clay mineralogy are described in J.R. Aniku (1986).

4.0 Data set descriptions

4.1 Table 1 Locations of Sample Sites
List UTM coordinates and elevation for all terrace sample sites.

4.2 Table 2 Field descriptions
Table 2a, Field description abbreviation explanations: This table describes the abbreviations used in the following table. This includes explanations for soil structure, texture, consistence, horizon boundaries, roots and pores, and clay films.
Table 2b, Field description: A “--” indicates that property was not described. This table list the properties described in the field for all soil horizons and consist of:
- No.—A numeric sequence to quickly cross compare data from table to table
- Sample—Descriptor of pit
- Horizon—General description of the sampled horizon according to conventions of the Soil Survey Staff (1998)
- Depth—Depth of upper and lower boundaries, in cm, of the horizon
- Lower Boundary—Description of contact with lower boundary according to conventions of the Soil Survey Staff (1998)
- Munsell Color—Moist and dry color according to the Munsell color chart.
- Texture—Soil texture class following conventions of Soil Survey Staff (1998), a + indicates more clay
Structure—Soil structure strength, size and type according to conventions of Soil Survey Staff (1998)
Consistence—Consistence according to conventions of Soil Survey Staff (1998), described for dry, moist and wet consistence
Roots—Root abundance and size according to conventions of Soil Survey Staff, (1998)
Pores—Pore abundance and size according to conventions of Soil Survey Staff, (1998)
Clay films—Clay frequency, thickness and morphology according to conventions of Soil Survey Staff (1998)
pH—The pH of the sample as determined in the field

4.3 Table 3 Physical properties
This table yields data from particle size analysis delineated according to classification of Soil Survey Staff, (1998). The first three columns are the same as the Table 2. The other columns are as follows:
Basal depth—Lower depth of sample horizon in cm
Bulk Density—Grams soil per cubic centimeter on an oven-dry basis
Texture—Texture according to the particle size distribution and as defined by Soil Survey Staff (1998)

4.4 Table 4 Extractive chemical analyses
The first three columns are the same as the Table 2. Analyses performed on selected samples, <2 mm fraction, quantifying, organic carbon, cation exchange capacity, Fe, Al, pH, exchangeable Na, K, Ca, Mg, and N.

4.5 Table 5 Mineralogy
Analyses performed selected samples to determined presence of Kaolinite, Mica, Chlorite-Vermiculite, Gibbsite, expanding clays, Quartz and Feldspar.

4.6 Table 6 Total chemical analyses of the fine (<47 µm) fraction by X-ray fluorescence.
The first three columns are the same as the Table 2. Analyzed for Quartz (SiO₂), Aluminum Oxide (Al₂O₃), Iron Oxide (Fe₂O₃), Magnesium Oxide (MgO), Calcium Oxide (CaO), Sodium Oxide (Na₂O), Potassium Oxide (K₂O), Titanium Dioxide
(TiO₂), Phosphorus Pentoxide (P₂O₅), Manganous Oxide (MnO), Zirconium Dioxide (ZrO₂).

4.7 Table 7 Total chemical analyses of the <2mm fraction by X-ray fluorescence.
The first three columns are the same as the Table 2. Analyzed for Quartz (SiO₂), Aluminum Oxide (Al₂O₃), Iron Oxide (Fe₂O₃), Magnesium Oxide (MgO), Calcium Oxide (CaO), Sodium Oxide (Na₂O), Potassium Oxide (K₂O), Titanium Dioxide (TiO₂), Phosphorus Pentoxide (P₂O₅), Manganous Oxide (MnO), Zirconium Dioxide (ZrO₂).

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Washington D.C.
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6.0 Acknowledgements

In memory of Denis Marchand, who died suddenly just months before this field excursion. Denny was leader and mentor for the USGS project on soil chronosequences of the Western U.S. We thank our field party Mike Machette, Marith Reheis, Alan Busacca, Emily Taylor, Bill Bradley, Sam Schaler, and Bob Curry for their generous help and support. We also thank Peter Janitzky and USGS analysts (A.J. Bartel, K. Stewart, J. Taggart, R. Johnson, K. Dennen under J.R. Lindsay) for their standard of excellence in laboratory procedures.
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<th>Sample Site</th>
<th>UTM Coordinates</th>
<th>Elevation</th>
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<tr>
<td><strong>Highway 1 (Davenport) Terrace</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site SC2</td>
<td>10s 0586434e</td>
<td>14m</td>
</tr>
<tr>
<td></td>
<td>4090149n</td>
<td></td>
</tr>
<tr>
<td><strong>Western Terrace</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not Sampled</td>
<td>Not Sampled</td>
</tr>
<tr>
<td><strong>Wilder Terrace</strong></td>
<td></td>
<td></td>
</tr>
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<td>Site SC3 (upper site)</td>
<td>10s 0584467e</td>
<td>126m</td>
</tr>
<tr>
<td></td>
<td>4093212n</td>
<td>116m</td>
</tr>
<tr>
<td>Site SC4 (lower site)</td>
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<td>116m</td>
</tr>
<tr>
<td></td>
<td>4092971n</td>
<td></td>
</tr>
<tr>
<td>Site SC5 (lower site)</td>
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<td>116m</td>
</tr>
<tr>
<td></td>
<td>4092971n</td>
<td></td>
</tr>
<tr>
<td><strong>Black Rock Terrace</strong></td>
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<td></td>
</tr>
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<td>Site SC1</td>
<td>10s 0583143e</td>
<td>138m</td>
</tr>
<tr>
<td></td>
<td>4093268n</td>
<td>138m</td>
</tr>
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<td>Site SC7</td>
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<td>4093268n</td>
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</tr>
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<td>Site SC9</td>
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<td><strong>Quarry/ Black Rock Terrace</strong></td>
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### Field description abbreviation explanations

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<th>Table 2</th>
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#### SOIL STRUCTURE

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<tr>
<th>Grade</th>
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<th>Type</th>
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<tr>
<td>m; massive</td>
<td>vf; very fine (v thin)</td>
<td>gr; granular</td>
</tr>
<tr>
<td>sg; single grained</td>
<td>f; fine (thin)</td>
<td>pl; platey</td>
</tr>
<tr>
<td>1; week</td>
<td>m; medium</td>
<td>pr; prismatic</td>
</tr>
<tr>
<td>2; moderate</td>
<td>c; course (thick)</td>
<td>cpr; columnar</td>
</tr>
<tr>
<td>3; strong</td>
<td>vc; very coarse (v thick)</td>
<td>abk; angular blocky</td>
</tr>
<tr>
<td>sbk; subangular blocky</td>
<td></td>
<td></td>
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</table>

*If two structures-listed as primary and secondary

#### SOIL TEXTURE

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<tr>
<th>Size</th>
<th>Texture</th>
<th>Texture</th>
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</thead>
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<tr>
<td>co; coarse</td>
<td>S; sand</td>
<td>SCL; sandy-clay loam</td>
</tr>
<tr>
<td>f; fine</td>
<td>LS; loamy sand</td>
<td>CL; clay loam</td>
</tr>
<tr>
<td>vf; very fine</td>
<td>SL; sandy loam</td>
<td>SiCL; silty-clay loam</td>
</tr>
<tr>
<td>L; Loam</td>
<td>SC; sandy clay</td>
<td>SiL; silt loam</td>
</tr>
<tr>
<td>Si; silt</td>
<td>C; clay</td>
<td>SiC; silty clay</td>
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#### SOIL CONSISTENCE

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<tr>
<td>lo; loose</td>
<td>lo; loose</td>
<td>so; nonsticky</td>
<td>po; nonplastic</td>
</tr>
<tr>
<td>so; soft</td>
<td>vfr; very friable</td>
<td>ss; slightly sticky</td>
<td>ps; slightly plastic</td>
</tr>
<tr>
<td>sh; slightly hard</td>
<td>fr; friable</td>
<td>s; sticky</td>
<td>p; plastic</td>
</tr>
<tr>
<td>h; hard</td>
<td>fi; firm</td>
<td>vs; very sticky</td>
<td>vp; very plastic</td>
</tr>
<tr>
<td>vh; very hard</td>
<td>vf; very firm</td>
<td>ef; extremely firm</td>
<td></td>
</tr>
<tr>
<td>eh; extremely hard</td>
<td></td>
<td></td>
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#### HORIZON BOUNDARIES

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<th>Distinctness</th>
<th>Topography</th>
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<tr>
<td>va; very abrupt</td>
<td>s; smooth</td>
</tr>
<tr>
<td>a; abrupt</td>
<td>w; wavy</td>
</tr>
<tr>
<td>c; clear</td>
<td>i; irregular</td>
</tr>
<tr>
<td>g; gradual</td>
<td>b; broken</td>
</tr>
<tr>
<td>d; diffuse</td>
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#### ROOTS AND PORES

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<tr>
<th>Size</th>
<th>Abundance</th>
<th>Pore Shape</th>
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<tr>
<td>vf; very</td>
<td>1; few</td>
<td>tub; tubular</td>
</tr>
<tr>
<td>f; fine</td>
<td>2; common</td>
<td>ir; irregular</td>
</tr>
<tr>
<td>m; medium</td>
<td>3; many</td>
<td>v; vesicular</td>
</tr>
<tr>
<td>co; coarse</td>
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#### CLAY FILMS

<table>
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<tr>
<th>Frequency</th>
<th>Thickness</th>
<th>Morphology</th>
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<tr>
<td>v1; very few</td>
<td>n; thin</td>
<td>of; ped face coatings</td>
</tr>
<tr>
<td>1; few</td>
<td>mk; moderately thick</td>
<td>br; bridging grains</td>
</tr>
<tr>
<td>2; common</td>
<td>k; thick</td>
<td>po; pore linings</td>
</tr>
<tr>
<td>3; many</td>
<td>(w; occurs as waves or lamellae)</td>
<td>co; coats on clasts</td>
</tr>
<tr>
<td>4; continuous</td>
<td></td>
<td></td>
</tr>
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---

*Page 1 of 1*
### Table 3

#### Physical properties

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>Horizon</th>
<th>Basal Depth (cm)</th>
<th>Bulk Density (g/cm³)</th>
<th>Texture</th>
<th>Total sand (%)</th>
<th>Very coarse sand (%)</th>
<th>Coarse sand (%)</th>
<th>Medium sand (%)</th>
<th>Fine, very fine sand (%)</th>
<th>Silt &lt;2-mm clay (%)</th>
<th>&lt;1-mm clay (%)</th>
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<tr>
<td>1</td>
<td>SC2</td>
<td>A1</td>
<td>29</td>
<td>1.57</td>
<td>sandy loam</td>
<td>69.03</td>
<td>0.94</td>
<td>3.77</td>
<td>8.80</td>
<td>55.52</td>
<td>21.71</td>
<td>9.26</td>
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<td>2</td>
<td>SC2</td>
<td>A2</td>
<td>50</td>
<td>1.70</td>
<td>sandy loam</td>
<td>70.08</td>
<td>0.10</td>
<td>2.48</td>
<td>6.83</td>
<td>60.66</td>
<td>20.26</td>
<td>9.66</td>
</tr>
<tr>
<td>3</td>
<td>SC2</td>
<td>B1</td>
<td>90</td>
<td>1.76</td>
<td>sandy clay loam</td>
<td>68.33</td>
<td>0.62</td>
<td>3.85</td>
<td>8.84</td>
<td>55.02</td>
<td>17.05</td>
<td>14.62</td>
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<tr>
<td>4</td>
<td>SC2</td>
<td>B2</td>
<td>106</td>
<td>1.96</td>
<td>sandy clay loam</td>
<td>66.80</td>
<td>0.10</td>
<td>2.47</td>
<td>7.73</td>
<td>56.49</td>
<td>16.30</td>
<td>16.90</td>
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<tr>
<td>5</td>
<td>SC2</td>
<td>B3</td>
<td>170</td>
<td>1.65</td>
<td>sandy clay loam</td>
<td>83.67</td>
<td>0.00</td>
<td>1.12</td>
<td>12.30</td>
<td>70.25</td>
<td>3.02</td>
<td>13.31</td>
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<tr>
<td>6</td>
<td>SC2</td>
<td>C1ox</td>
<td>200</td>
<td>1.66</td>
<td>sand</td>
<td>96.36</td>
<td>0.00</td>
<td>3.13</td>
<td>20.61</td>
<td>72.62</td>
<td>1.74</td>
<td>1.90</td>
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<tr>
<td>7</td>
<td>SC2</td>
<td>IIC2</td>
<td>457</td>
<td>--</td>
<td>sand</td>
<td>97.47</td>
<td>0.20</td>
<td>0.91</td>
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<td>IICn</td>
<td>518</td>
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<td>0.00</td>
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<td>SC3</td>
<td>A11</td>
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<td>1.32</td>
<td>clay loam</td>
<td>45.10</td>
<td>1.13</td>
<td>8.76</td>
<td>11.68</td>
<td>23.54</td>
<td>32.90</td>
<td>22.00</td>
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**Alluvium of Black Rock terrace**

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**Alluvium of quarry terrace**

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### Table 5

**Mineralogy**

*Analysts: Jacob Aniku, University of California, Davis*

+++ = dominant; ++ = moderate; + = trace; 0 = not detected; -- = not analyzed; XX = dominant; X = present.

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Table 6

Total chemical analyses of the fine (<47µm) fraction by X-ray fluorescence

Analysts: A.J. Bartel, K.Stewart, and J. Taggart and R. Johnson and K. Dennen under J.R. Lindsay

All analyses in weight percent

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## Table 7

Total chemical analyses of <2 mm fraction by X-ray fluorescence

Analysts: A.J. Bartel, K. Stewart, and J. Taggart and R. Johnson and K. Dennen under J.R. Lindsay

All analyses in weight percent

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