Geomorphic and Soil Stratigraphic Evaluation of a Faulted Alluvial Sequence, Eastern Coachella Valley, California

STEPHEN G. WELLS and SEAN CONNELL, *Dept. of Earth Sciences, University of California, Riveride CA 92521*
JAY J. MARTIN *CHJ Inc., 1355 E. Cooley Drive, Colton CA 92324*

INTRODUCTION

A major problem facing geologists working in tectonically active settings is the ability to determine the history of fault activity in areas where conventional dating techniques, such as radiocarbon dating, are unabailable. The careful use of soil chronosequences can provide age constraints for fault activity provided the rupture history can be bracketed by geomorphic surfaces with distinctive soil characteristics. Soil stratigraphic studies conducted in the Indio Hills (Keller and others, 1982) and the Eastern Mojave-Silver Lake area (Wells and others, 1987) can provide age constraints on the basis of soil development.

This paper presents results from a study conducted by Gary S. Rasmussen and Associates (1992) for a proposed low-level sanitary landfill extension in the Coachella Valley, Riverside County, California. The proposed landfill site, termed here as the Coachella Landfill Extension (CLE), is north of the town of Indio and is underlain by a faulted alluvial fan and pediment complex of the Little San Bernardino Mountains piedmont. The primary goal of this paper is to present the soil stratigraphic, geomorphic, and neotectonic setting of this part of the Little San Bernardino Mountains piedmont.

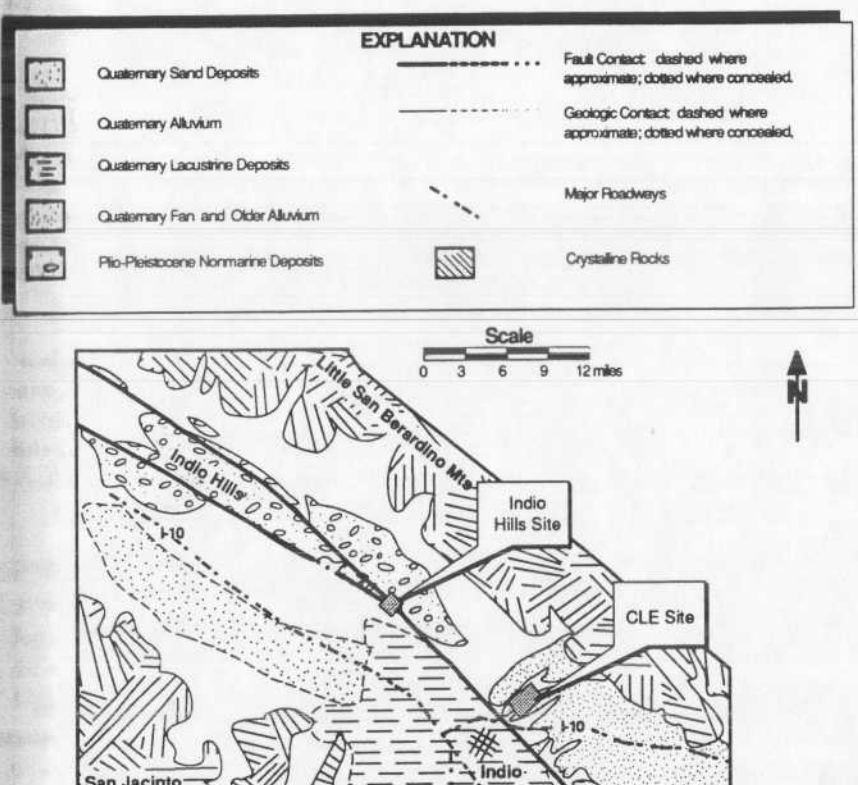


Figure 1. Generalized geologic location map of the Coachella Valley area, southern California, depicting locations of the Coachella Landfill Extension (CLE; see Fig.2) and the Indio Hills site (Fig.3).

The CLE site (Figs. 1 & 2) is south of the Indio Hills and north of the Mecca Hills. The Indio Hills are composed of a series of northwest-trending hills deformed by the Mission Creek and Banning fault segments of the San Andreas fault zone. The southern Indio Hills and the CLE study area are underlain by the Ocotillo and Palm Spring(?) formations, which consist of deformed sandstone and fanglomerate (Dibblee, 1954; Popenoe, 1959).

The climate is very arid with hot summers and moderate to cool winters, a mean annual temperature of approximately 21°C (72°F) and a mean annual precipitation of approximately 10 cm (Knecht, 1980).

GEOLOGY AND GEOMORPHOLOGY

The study area is on the northeastern piedmont of the Coachella Valley between the Little San Bernardino Mountains, to the east, and the San Jacinto and Santa Rosa Mountains, to the west. The Coachella Valley is structurally dominated by the San Andreas fault which is located less than 520 m (1700 ft) southwest of the site (Dibblee, 1954; Crowell, 1975; Sylvester and Smith, 1976; Rymer, 1991). The CLE site is between the Indio and Mecca hills, where the strike of the San Andreas fault is approximately N43°W and parallel to the prevailing plate motion vector (Sylvester, 1991). The Indio Hills lie to the north of the study area and consist of uplifted Plio-Pleistocene sedimentary rocks of the Palm Spring and Ocotillo formations as well as younger Quaternary alluvium (Fig. 3). The Indio and Mecca Hills represent structural culminations, or uplifted segments, that developed in response to compression along restraining bends in the San Andreas fault, where the

Table 1. Soil profile descriptions for Coachella landfill extension site. Soil descriptions from field measurements. Colors based on Munsell notation. Profile terminology follows that of Soil Survey Staff (1951 and 1975) with revisions in Birkeland (1984).

Alluvial Unit	Pedon Number	Profile Horizon Designation	Carbonate Morphology
Qf5	2	Avk-Bk1-Bk2-2Bk-3Bk-4Bwkb	disseminated to weak Stage I
Qf3a	4	A-AvBwk-Bwk1-Bwk2-Bk1-Bk2-Cox-2Btkb	disseminated to weak Stage I
Qf2	3	Ak-AvBwk-Bwk1-Bwk2-Bwk3-Bwk4-Bk-C-2Ck-3Bwkb1-3Bwkb2-4Kb-4Bkb-4Btkb	Stage I
Qf1	1	Ak-AvBwk-Btkl-Btk2-Avkb-Btkb-2Avkb-2Btkb	Stage I+ to II

fault strike is typically about N48°W (Sylvester, 1991). The piedmont along the western flank of the Little San Bernardino Mountains is disrupted by the Indio Hills, which deflect most drainages. However, major drainages, such as Pushwalla and Thousand Palms canyons, have been able to transect the Indio Hills.

The CLE site is underlain by an areally extensive pediment-alluvial fan complex, mapped as Qf1 (Fig. 2). This pediment is cut into sandstone and conglomerate of the Ocotillo and Palm Spring(?) formations and is part of an alluvial fan associated with several drainages heading in the Little San Bernardino Mountains. An poorly-exposed ash along the southern portion of the study area may be the 0.74 Ma Bishop ash which has been found to occur within the upper part of the Palm Spring Formation in the Mecca Hills (Rymer, 1991). At least six distinct late Holocene to late Pleistocene alluvial fan deposits have been differentiated on the site. These alluvial units represent geomorphic surfaces that have developed due to base level lowering in response to stresses along the San Andreas fault (Clark, 1984).

Mapping of geomorphic surfaces was performed on the basis of geomorphic position and surface alteration. Surface alternation was evaluated on the basis of stone pavement development, degradation of exposed clasts, presence of rock varnish and depositional topography (e.g., presence of depositional bars and swales). Several trenches were excavated in order to evaluate the subsurface character of faulting and to establish geomorphic and stratigraphic control of late Quaternary fault activity. The primary focus of this paper is on soil stratigraphic relationships. The nature and style of faulting at the site will only be briefly discussed.

An extensive trenching program for the Coachella Landfill Extension (Figs. 2, 4, & 5) has resulted in the delineation of several northwest- to northeast-trending faults that cut a pediment surface and alluvial fan deposits. Ages of alluvial an deposits were made on the basis of correlations between soil chronosequences established at Silver Lake (Wells and others, 1987), approximately 195 km (120 miles) north of the site, and ages determined on an offset pediment-alluvial fan complex (Keller and others, 1982) in the Indio Hills (Fig. 3).

Determination of geomorphic surface ages was made foll analyses of terrace stratigraphy, geomorphology and detailec geomorphic-surface mapping by Gary S. Rasmussen and As: Descriptions of soil morphology, characterization of a soil chronosequence and correlation with other soil sequences v then made.

SOIL MORPHOLOGY DESCRIPTION

Studies of soil morphology and soil-profile development used to aid in the subdivision and correlation of unconsolid surficial sediments and to aid in providing age estimates for sediments. Four pedons (profile descriptions) were establish described in four trenches, designated at pedons 1, 2, 3 and 2, Tables 4, 5, 6, & 7) which expose late Quaternary alluvi deposits and continental sedimentary rocks of the Quaterna Ocotillo formation. At each pedon location, field descriptio soil morphology and landscape conditions were used to esta detailed soil stratigraphic relations. Soil stratigraphic relatio in turn, used to interpret and assign age estimates for geom surfaces and soil stratigraphic units.

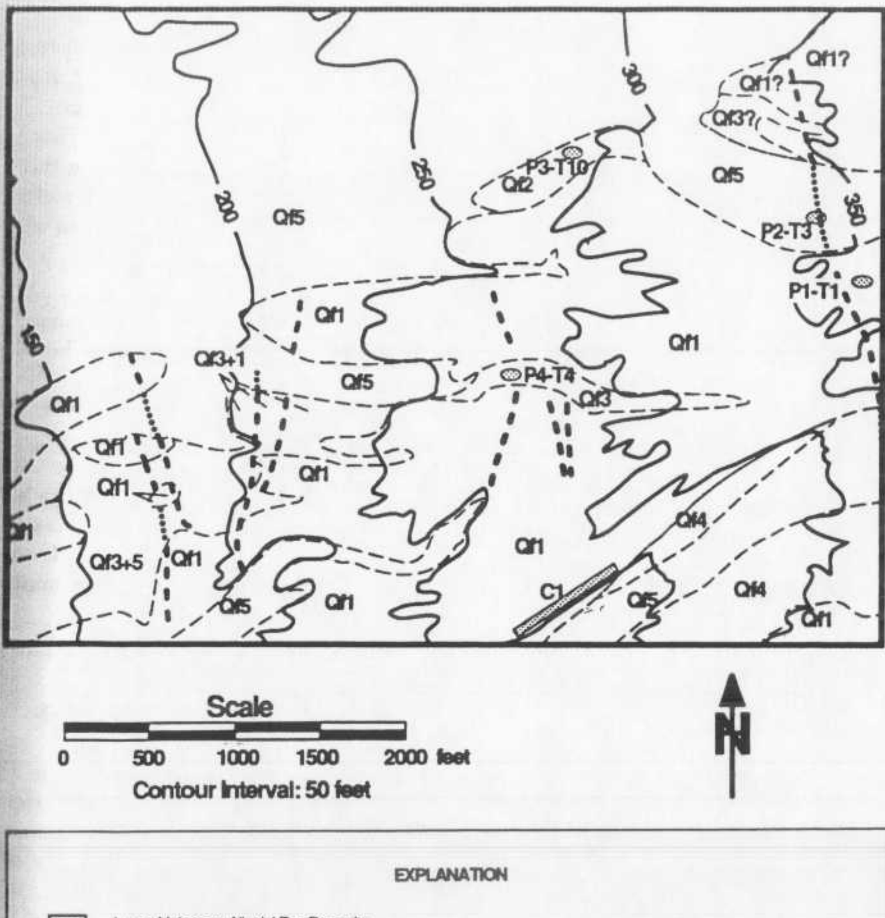
Soil profiles were described at sites which reflect the mo landscapes (i.e., surfaces which display minimum erosion or deposition) in order to assess the maximum degree of soil development for a given landform. The soil profiles were desc using the field terminology of the U.S. Soil Conservation Sta and 1975) with 1981 revisions (see Birkeland, 1984). Approx twelve soil properties were recorded at each site, including ho designation, depth, thickness, dry and moist color, texture, str dry and moist consistency, clay film development, stone conte and pore development, pedogenic carbonate development, ca morphology and lower boundary characteristics. The vertical arrangement of the soil horizons and associated properties are described from the land surface down to the parent material c of trench. In addition, properties such depositional topograph pavement development and clast weathering observations of a fan surfaces near each trench and profile site were recorded; s surface morphology data are summarized in Table 3. Tables 1 and 7 summarize soil profile data from the trenches at selecte locations on alluvial fan surfaces.

The similarity in parent materials (eg., coarse-grained plut metamorphic clasts and reworked Ocotillo formation and sedi

Table II. Age estimates based on soils morphology and regional correlat

Comparison of the Coachella soil chronosequence and surface morphological parameters with dated chronosequences and surface properties described by Wells et al.(*1987) and Keller et al.(+1982)

Coachella Landfill Extension	Eastern Mojave Silver Lake	Indio Hills	Age Estimate	Nu Esti
Qf5	Qf5	unit Qal	latest Holocene	>1(
Qf3a	Qf3 or Qf4	unit Qf1	middle to late Holocene	>1(<8(
Qf2	Qf2	unit Qf1	early Holocene	>8(<11
Qf1	Qf1	unit Qf2	late Pleistocene	>22 <5(



and slight splitting. The lack of weathering and alteration of surface clasts suggest a very young age for this unit.

The soil profile of unit Qf5 is characterized by a thin Avk horizon overlying several thin Bk horizons (Tables 1 & 4). The Avk horizon is greater than 2.5 cm in thickness and is composed of a vesicular sandy loam with 2.5Y hues, platy structure, and disseminated, as well as reworked, pedogenic calcium carbonate. The Avk horizon is underlain by four Bk horizons with a total thickness of approximately 76 cm (30 in). The morphology of these horizons is dominated by translocated (pedogenic) calcium carbonate which resulted in the Bk horizon designation, as opposed to the commonly but erroneously used Ck horizon. The morphology of the sand-textured Bk horizons are typified by single grain structure (loose, non-sticky, and non-plastic consistency) and disseminated to weak stage I calcium carbonate. This profile rests above a buried soil developed in older Quaternary deposits. This buried profile was not described. The thin nature (81 cm; 32 in.) of unit Qf5 demonstrates the "strath-like" character of this young fan deposit.

Unit Qf3a

The surface of alluvial fan unit QF3a is characterized by well-developed bar and swale depositional topography with weakly developed stone pavements in swale areas (Table 3). Th

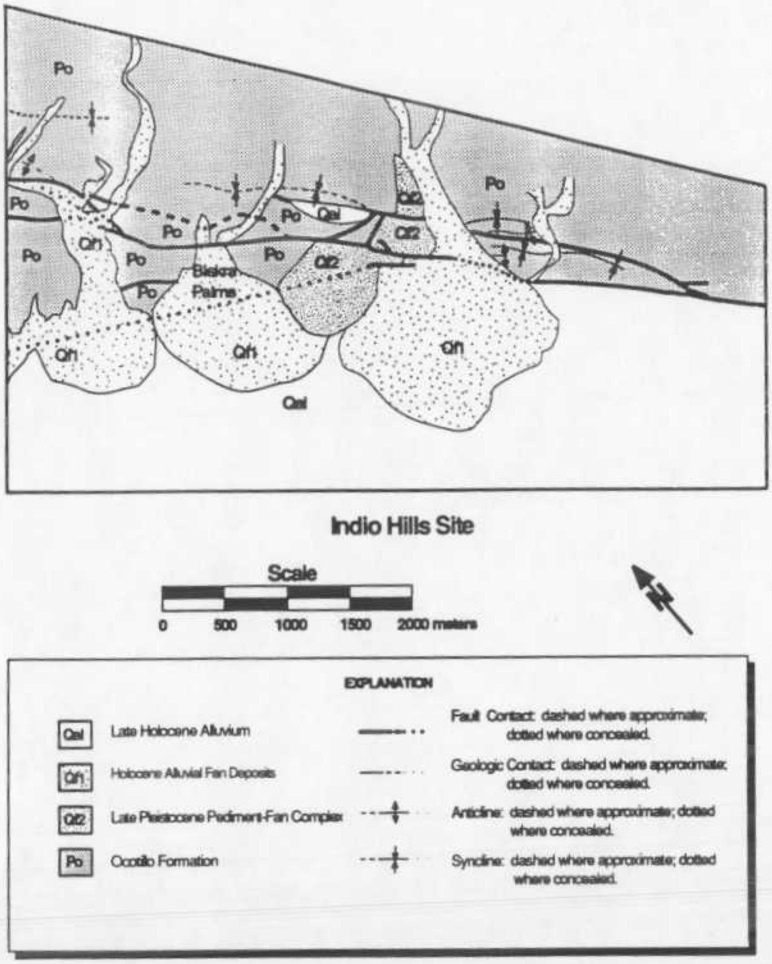


Figure 3. Generalized geologic map of the Indio Hills site illustrating major mapped units and faults. Modified from Keller et al. (1982).

Unit Qf2

The surface of alluvial fan unit Qf2 has been modified sufficiently such that only faint bar and swale topography exists (Table 3). Moderately developed stone pavement with interlocking clasts occurs on swales and bars. Relief on the surface is produced by individual clasts and not by clast aggregates. Clasts of coarse-grained plutonic rocks exposed at the surface are significantly more fractured than the clasts of units Qf5 and Qf3a and also show significant amounts of disintegration whereby clasts are eroded down to the level of the stone pavements. Rock varnish coatings are thin due to the increased weathering of surface clasts. Rubefication on surface clast undersides varies from weak to strong with hues ranging from 2.5Y to 7.5YR.

The soil horizons of this unit are moderately thick (Table 6). The AvBwk shows advanced development of morphological properties in unit Qf2 compared to unit Qf3a, such as a more platy structure and the presence of clay films on ped faces. The Bwk horizons have a total thickness of approximately 56 cm (22 in) with 8.5YR hues on ped faces and sandy loam textures. Colloidal stains and bridges dominate over clay film development in the Bwk. Carbonate stage morphology has a weak stage I development. The hues shift to 10YR and 2.5Y in the underlying Bk and C horizons. Unit Qf2 overlies a buried soil consisting of Bwkb horizons and a K horizon (stage III+ calcium carbonate morphology), indicating that the buried soil is very well developed and truncated.

Unit Qf1

The surface of unit Qf1 is widespread and displays very w developed pavements with no traces of depositional relief. R varnish coatings on clasts is less well developed on Qf1 as compared to varnish coatings present on Qf2 and Qf3a. This reflects an increase in clast splitting and disintegration on thi older surface. Numerous clasts of coarse-grained plutonic rock are eroded to the level of the ground surface. Rubeficiation o clast undersides have hues to 2.5YR (Table 7).

This soil profile exhibits the most advanced stages of pedogenesis as compared to the other surfaces. It also displays cumulic features such as the burial of AvBwk horizons. Thin Ak and AvBwk horizons are underlain by two thin Btk horizons with 7.5YR hues, thin to thick clay films and weak stage I carbonate morphology. Below these horizons lie two buried Avk and Btk horizons with properties similar to the surface AvBwk horizon. Weak stage I carbonate morphology i typical of these horizons. Five 2Bkb horizons decrease in hue with depth (over 46 cm) with a carbonate morphology of I+ and II. These morphological parameters demonstrate that unit Qf1 is significantly older than the other fan surface units.

AGE ESTIMATES, REGIONAL CORRELATIONS AND LANDSCAPE-STRATIGRAPHIC RELATIONS

Soil age estimates are based on correlation with the well-dated Eastern Mojave-Silver Lake soil chronosequence described by Wells and others (1987). The oldest fan unit is correlated on the basis of soil development with an offset fan-pediment complex described by Keller and others (1982) near the intersection of the Mission Creek and Banning segments of the San Andreas fault zone in the southern Indio Hills (Fig. 3) Comparison of the CLE site soil chronosequence and surface morphological parameters with soils described by Keller and others (1982) and Wells and others (1987) allow the tentative correlations and age estimates to be made (Table 2).

The piedmont in the study area is predominantly mantled late Quaternary unit Qf1 (Fig. 2). Unit Qf1 is variable in thickness and apparently rests unconformably to conformably on the underlying Ocotillo and Palm Spring(?) formations. We tentatively correlate unit Qf1 of the Coachella area with the late Pleistocene Qf1 of the Eastern Mojave-Silver Lake area which has a minimum age constraint of approximately 22 Ka derived from radiocarbon dates and lacustrine sedimentation rates and an upper age limit of approximately 40 to 50 Ka based on experimental surface-exposure ages. Such age estimates are compatible with those of Keller and others (1982) for a similar alluvial unit in the Indio Hills (Table 2). Inset below the Qf1 surfaces are units Qf2 through Qf5 which are inferred to range in age from early to late Holocene based upon the degree of soil development.

CONCLUSIONS

Tectonic deformation within the Coachella landfill extension (CLE) site is dominated by dip-slip faults that strike between N20°W and N20°E. This site is between the Indio and Mecca hills, immediately east of the main trace of the San Andreas fault zone. Faults mapped at the CLE site do not exhibit significant lateral offset. In contrast, the offset pediment-fan complex (Keller and others, 1982) in the Indio Hills exhibits significant right-lateral oblique slip and folding that has occurred since the late Pleistocene.

The Indio Hills and Coachella landfill extension site exhibit significant differences in along-strike tectonic style over relatively short distances. The style of faulting along the San Andreas fault in

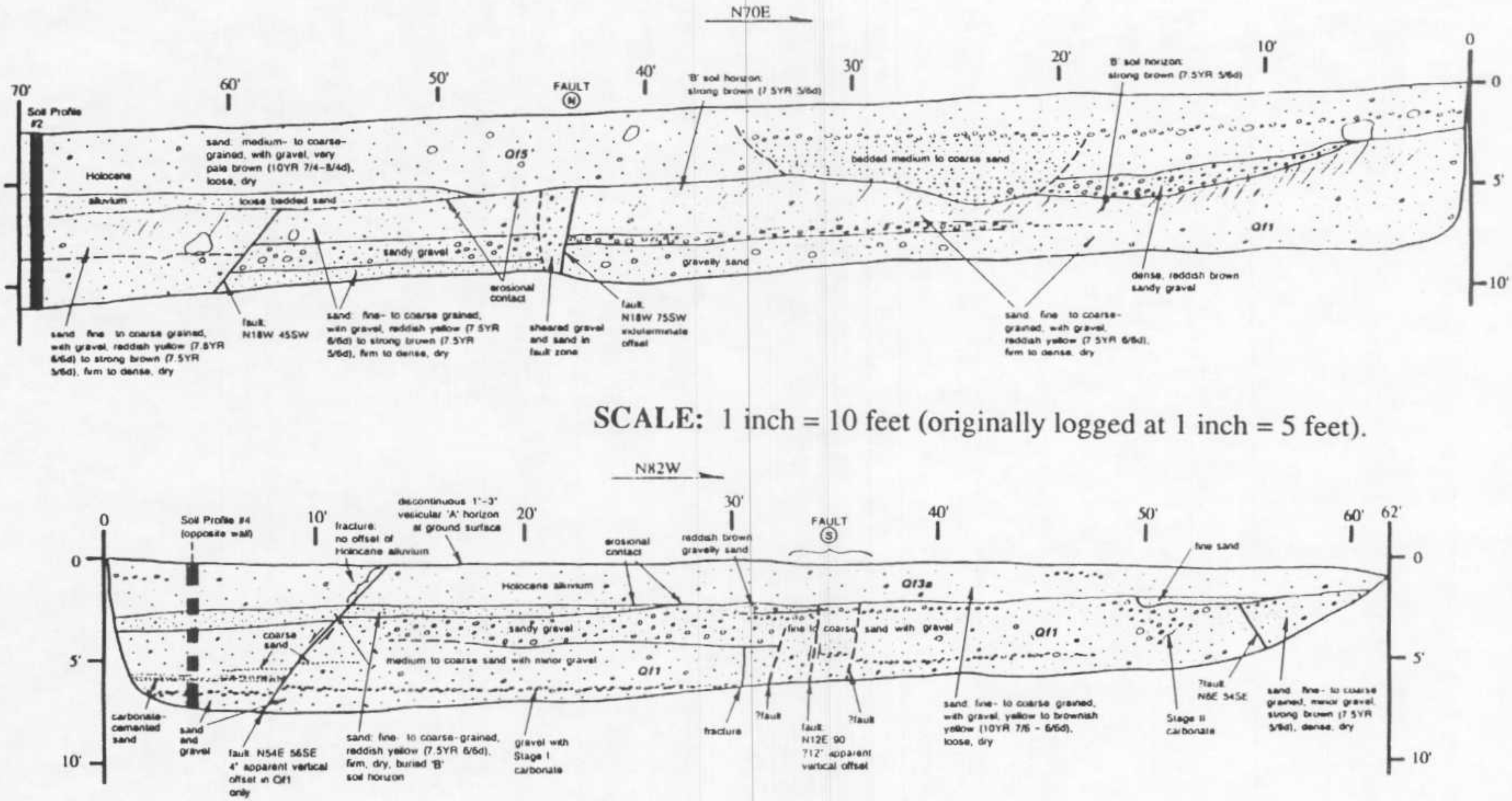
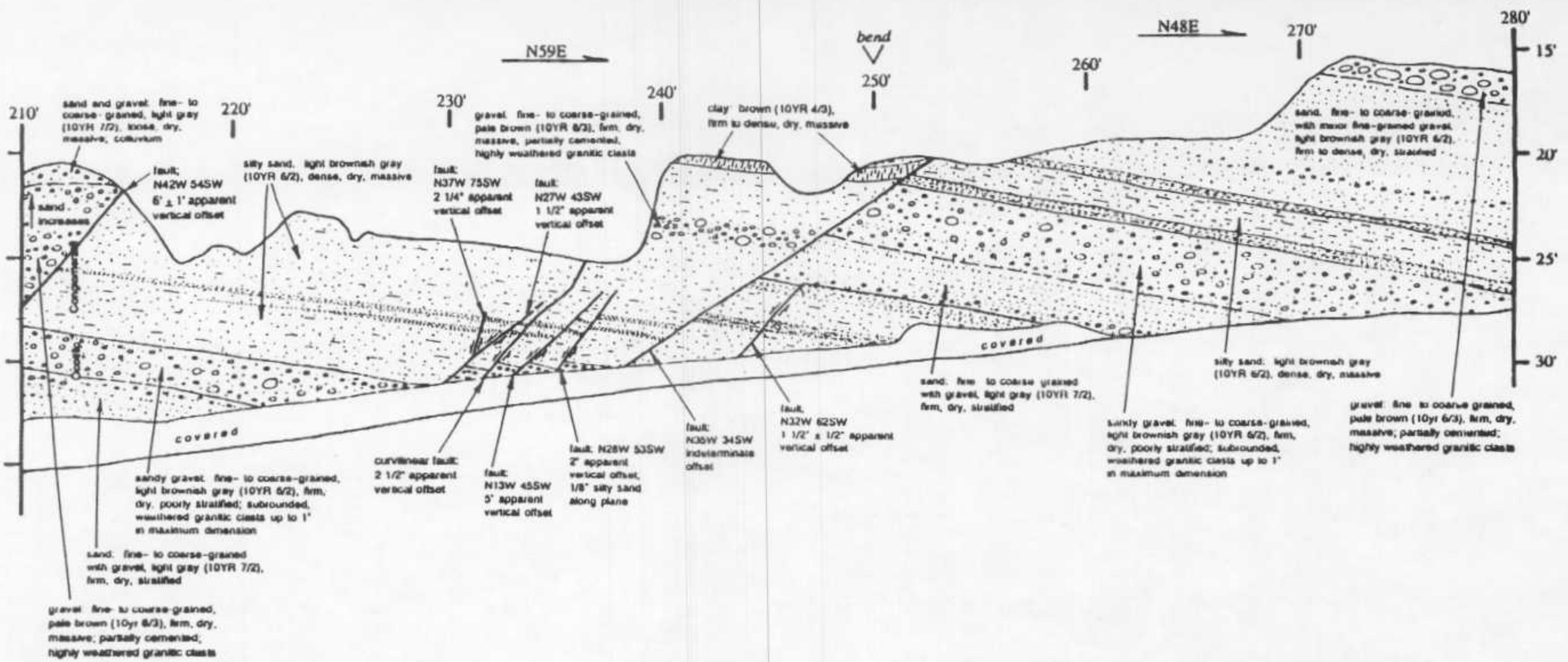


Figure 4. Geologic Logs of backhoe excavations in the Coachella Landfill Extension Site. Trench 3, pedon 2 (top) exhibits undeformed latest Holocene (Qf5) fan deposits. Trench 4, pedon 4 (bottom) exhibits undeformed early to middle Holocene alluvial fan deposits (Qf3) (From Rassmussen, 1991).



SCALE: 1 inch = 10 feet (originally logged at 1 inch = 5 feet).

Figure 5. Geologic Log of bulldozer excavation in the Coachella Landfill Extension Site. This cut (Cut 1) exhibits deformed Ocotillo Formation (From Rassmussen, 1991).

Table III. Surface morphology and stone pavements of alluvial fan deposits, CLE.

Alluvial Unit	Depositional Bar Relief	Reddening on Clast Undersides* Cover (a)	Reddening on Clast Undersides* Max. Color (b)	Clast Varnish+ Color (c)	Clast Varnish+ Cover/Thickness (d)
Qf5	> 1 ft strong bar & swale	n.m.	n.m.	[very weak to no varnish]	
Qf3a	< 3/4 ft strong bar & swale	weak	5YR 5/8	5YR 2.5/1	75-100%/T
		weak	7.5YR 5/6	5YR 3/2	50%/T
		n.o.	n.m.	5YR 3/2	50%/T
		weak	7.5YR 6/8	10YR 2/2	<25%/T
		weak	7.5YR 5/8	5YR 2.5/1	75-100%/T
		moderate	7.5YR 5/8	5YR 2.5/1	50%/T
		weak	7.5YR 6/8	5YR 3/1	75%/T
		weak	5YR 4/6	7.5YR 2/0	75-100%/T
		weak	7.5YR 5/6	5YR 2.5/1	50%/T
Qf2	single clast faint bar & swale	weak	2.5YR 5/8	5YR 2.5/1	75%/T
		weak	5YR 5/8	5YR 3/2	50-75%/T
		weak	7.5YR 6/8	5YR 2.5/2	75-100%/T
		moderalte	5YR 5/8	5YR 3/1	25-50%/T
		weak	5YR 5/8	10YR 2/2	25%/T
		weak	5YR 5/8	10YR 2.5/1	25%/T
		strong	5YR 5/8	5YR 3/2	50-75%/T
		moderate	5YR 5/6	7.5YR 3/2	25-50%/T
		n.o.	n.m.	5YR 2/5/1	50%/T
		weak	7.5YR 5/6	7.5YR 3/2	50-75%/T
Qf1	single clast no bar & swale	moderate	5YR 6/8	5YR 3/2	50-75%/T
		strong	2.5YR 4/6-8	5YR 3/2	50-75%/T
		weak	5YR 3/2	2.5YR 2.5/0	25-50%/T
		weak	7.5YR 5/8	10YR 4/1	25-50%/T
		moderate	5YR 5/8	5YR 3/2	25-75%/T
		moderate	5YR 5/8	5YR 2.5/2	75%/M
		moderate	5YR 5/4	5YR 2.5/1	<25%/T
		weak	5YR 6/8	5YR 3/2	<25%/T
		moderate	2.5YR 5/8	5YR 3/2	25-50%/T
		weak	7.5YR 2.5/1	5YR 2.5/1	25-50%/T

Surface descriptions are from field measurements. Colors are measured dry and are based on Munsell notation.
***Reddening on Clast Undersides**
(a) Maximum color observed is given
(b) Cover and thickness estimates:
weak = clast lithology clearly visible and <30% of underside reddened
moderate = clast lithology faintly visible and 30-60% of underside reddened
strong = clast lithology obscured and >60% of underside reddened
+Clast Varnish
(c) Darkest color observed
(d) Cover and thickness estimated:
classes = 0%, 0-25%, 25%, 25-50%, 50%, 50-75%, 75%, 75-100%, 100%
T = thin, mineralogy observable; M = moderate, mineralogy partially obscured; Th = thick, mineralogy completely obscured

the eastern Coachella Valley is geomorphically manifested by the development of linear hills where compression along restraining bends result in local uplift with subsequent dissection and exposure of subsurface structure. This tectonic style is contrasted by the adjoining southern fault-zone segment in the CLE area, which has an orientation parallel to the prevailing plate motion vector of approximately N43°W (Sylvester, 1991). The style of faulting along this segment is manifested by smaller magnitude dip-slip faulting and basinward lowering of base-level. This results in partial burial of Quaternary deposits towards the valley floor, rather than compression, uplift and the formation of hills to the north and south of the CLE.

Stresses generated along the restraining bend in the San Andreas fault zone, north of the CLE site, are taken up by folding and uplift, which results in the formation of structural culminations, such as the Indio Hills. Smaller magnitude slip and deformation at the CLE site results in a geomorphic expression of an uplifted pediment and fan complex. The differences in geomorphology between these two areas are probably the result of changes in the stress field near the

Table IV. Soil profile description of Pedon Number 2, Alluvial Fan Unit Qf5, CLE, Riverside Co.

Pedon description conducted by S.G. Wells & S. Connell on 8/27/92. Soil descriptions from field measurements. Colors based on Munsell notation for dry (d) or moist (m) colors. Profile terminology follows that of Soil Survey Staff (1951 and 1976) with revisions in Birkeland (1984).

SURFICIAL SETTING

Landform: alluvial fan and terrace with well-developed bar & swale topography

Parent Material: alluvium reworked from Ocotillo fm and sediment from Little San Bernardino Mts

Vegetation: creosote bush *(Larrea tridentata)*, mormon tea *(Ephedra)*, pencil cholla *(Opuntia ramosissima)*, paloverde *(Parkinsonia* spp), four-wing saltbush *(Atriplex canescens)(?)* **Aspect/slope**: southwest/<4 degrees **Elevation**: ~345 ft

PROFILE DESCRIPTION

Horizon	Depth (in)	Description
Avk	0 - 1.5	2.5Y 6/3 light yellowish brown on ped face (d), 2.5Y 4/2 grayish-brown (m), 2.5Y 6/3 light yellowish brown (crushed); sandy loam; moderate coarse platy; slightly hard (d), slightly sticky non-plastic (md); few thin colloidal stains on larger grains; 50% gravel; few very fine roots; fine common vesicles coated with siltans; strongly effervescent, disseminated pedogenic $CaCO_3$; clasts appear to have reworked stage I $CaCO_3$ larger clasts; abrupt smooth
Bk1 [Ck1]*	1.5 - 7.5	2.5Y 7/3 pale yellow (d), 2.5Y 5/2 grayish brown (m); sand; single grain; loose (d), non-sticky, non-plastic (md); very few thin colloidal stains; 40-50% gravel; common very fine to fine roots; many medium pores; strongly effervescent, disseminated to very weak stage I $CaCO_3$; large wide void spaces under large clasts which have sand caps; clear smooth
Bk2 [Ck2]*	7.5 - 13.5	2.5Y 6/3 light yellowish brown (d), 2.5Y 5/2 grayish brown; sand; single grain; loose (d), non-sticky, non-plastic; 25% gravel; common very fine to fine roots; common medium pores; strongly effervescent, very weak stage I $CaCO_3$; clear wavy
2Bk [2Ck]*	13.5 - 24	2.5Y pale yellow (d); 2.5Y 5/2 grayish brown (m); sand; single grain; loose (d), non-sticky, non-plastic (m); very few thin colloidal stains on larger clasts; 5% gravel; few very fine roots; strongly effervescent, disseminated $CaCO_3$; clear wavy
3Bk [3Ck]*	24 - 32	2.5Y 6/3 light yellowish brown (d); 2.5Y 5/2-3 grayish brown to light olive brown (m); sand; single grain; loose (d), non-sticky, non-plastic (m); very few thin colloidal stains on larger grains and clasts; 50% gravel; very slightly effervescent, disseminated to weak stage I $CaCO_3$; sand caps on clast tops; abrupt smooth
4Bwkb	32 +	buried soil (not described)

*Horizon designation of Ck is not considered proper by the Soil Staff Manual if pedogenic calcium carbonate has been translocated in profile; however, the Ck horizon designation is commonly used rather than the proper horizon designation of Bk. Both horizon designations are given for clarification.

intersection of the Mission Creek and Banning faults.

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Table V. Soil profile description of Pedon Number 4, Alluvial Fan Unit Qf3a, CLE.

Pedon description conducted by S.G. Wells & S. Connell on 8/28/92. Soil descriptions from field measurements. Colors based on Munsell notation for dry (d) or moist (m) colors. Profile terminology follows that of Soil Survey Staff (1951 and 1976) with revisions in Birkeland (1984).

Surficial Setting

Landform: thin alluvial fan with well-developed bar & swale topography which overlies Ocotillo fm (?)
Parent Material: alluvium reworked from Ocotillo fm and sediment from Little San Bernardino Mts
Vegetation: creosote bush *(Larrea tridentata)* **Aspect/slope**: southwest/4 degrees **Elevation**: ~284 ft

Profile Description

Horizon	Depth (in)	Description
A	0 - 0.25	2.5Y 6/3 light yellowish brown (d), 2.5Y 6/2 light brownish-gray (m); loamy sand; single grain; loose (d), non-sticky, non-plastic (m); 0% gravel; strongly effervescent, disseminated $CaCO_3$; very abrupt smooth
AvBwk	0.25 - 1.25	2.5Y 6/2 light brownish gray on ped face, 10YR 7/3 very pale brown on ped interiors, crushed (d); 10YR 4/3 brown (m); sandy clay loam; moderate medium to coarse subangular blocky; slightly hard (d), sticky, very slightly plastic; few thin discontinuous colloid stains and bridges; 30% gravel; few very fine roots; many fine vesicles and tubular pores; violently effervescent, disseminated to stage I $CaCO_3$; very abrupt smooth
Bwk1	1.25 - 5.25	10YR 7/2-3 light gray to very pale brown (d), 10YR t/3 brown (m); loamy sand; weak fine to medium subangular blocky; weakly coherent (d); very slightly sticky, non-plastic (m); few thin colloid stains and bridges on large grains and clasts; 5-10% gravel; common very fine roots; few fine pores in krotovina; strongly effervescent, disseminated to very weak stage I $CaCO_3$; clear wavy
Bwk2	5.25 - 5.25	10YR 7/3 very pale brown (d), 10YR 6/3-4 pale brown to light yellowish brown (m); sand; single grains to weak medium granular; loose (d); non-sticky, non-plastic (m); few very thin colloid stains and bridges on larger grains and clasts, bridges on larger grains; 15-20% gravel; few very fine roots, few fine pores; strongly effervescent, weak stage I $CaCO_3$; abrupt smooth
Bk1	5.25 - 11.25	2.5Y 7/3 pale yellow (d), 2.5Y 6-5/3 light yellowish brown to light olive brown (m); sand; single grain to weak medium subangular blocky; loose to slightly hard (d), non-sticky, non-plastic (m); few thin colloid stains on large grains; 15% gravel; few very fine roots; few fine pores; strongly effervescent, disseminated to very weak atage I $CaCO_3$; abrupt smooth
Bk2	11.25 - 17.25	2.5Y 7/4 to 10YR 7/4 pale yellow to very pale brown (d), 2.5Y 6-5/3 light yellowish brown to light olive brown (m); sand; single grain to weak medium to coarse granular; loose to weakly coherent (d), non-sticky, non-plastic (m); few thin colloid stains; 10-15% gravel; common very fine roots; few fine pores; strongly effervescent, disseminated $CaCO_3$; abrupt wavy
Cox	17.25 - 20.25	10YR 6/4-6 light yellowish brown to brownish yellow (d), 10YR 6/4-6 light yellowish brown to brownish yellow (m); sand; single grain; loose (d), non-sticky, non-plastic (m); few thin colloid stains, bridges on large grains; 5% gravel; no effervescence; abrupt smooth
2Btkb	20.25 - 72.5	buried soil (not described)

Table 6. Soil profile description of Pedon Number 3, Alluvial Fan Unit Qf2, CLE.

Pedon description conducted by S.G. Wells & S. Connell on 8/28/92. Soil descriptions from field measurements. Colors based on Munsell notation for dry (d) or moist (m) colors. Profile terminology follows that of Soil Survey Staff (1951 and 1976) with revisions in Birkeland (1984).

SURFICIAL SETTING

Landform: alluvial fan with faint bar & swale topography

Parent Material: alluvium reworked from Ocotillo fm and sediment from Little San Bernardino Mts

Vegetation: creosote bush *(Larrea tridentata)* **Aspect/slope**: southwest/4 degrees **Elevation**: ~292 ft

PROFILE DESCRIPTION

Horizon	Depth (in)	Description
Ak	0 - 0.25	2.5Y 6/3 light yellowish brown (d), 2.5Y 4/2 dark grayish brown (m); sandy loam; single grain; loose (d), very slightly sticky, non-plastic (m); very slightly effervescent, disseminated $CaCO_3$; very abrupt
AvBwk	0.25 - 2.25	2.5Y 6/3 light yellowish brown on ped top, 10YR 6/4 light yellowish brown on ped underside, 10YR 7/4 very pale brown crushed (d), 10YR 4/3 dark brown (m); clay loam; moderate coarse platy and subangular blocky to very coarse subangular blocky; slightly hard (d), sticky moderately plastic (m); few thin colloid stains and bridges with few thin to merately thick films on larger grains; 5% gravel; few very fine roots; many common vesicles; strongly effervescent on ped undersides to slightly effervescent on ped sides, disseminated $CaCO_3$; abrupt smooth
Bwk1	2.25 - 3.75	10YR 6/4 light yellowish brown (d), 10YR 5/6 yellowish brown (m); sandy loam; weak fine subangular blocky; loose to slightly hard (d); sticky to moderately plastic (m); few thin colloid stains and bridges with few thin clay films on larger grains; 5-10% gravel; few very fine roots; few very fine pores; violently effervescent, disseminated to weak stage I $CaCO_3$; abrupt smooth
Bwk2	3.75 - 10.25	8.5YR 6/4 light yellowish brown to light brown on ped, 10YR 6/4 light yellowish brown (crushed) (d), 10YR t/r yellowish brown (m); sandy loan; weak fine subangular blocky; loose to slightly hard (d), slightly sticky, non-plastic (m); common bridges with few thin colloid stains on large clasts, few thin films on clasts with few locally thick films on larger clasts; 15% clasts; common fine and medium roots; few fine pores; slightly effervescent, disseminated to very weak stage I $CaCO_3$; clear smooth
Bwk3	10.25 - 14.25	10YR 6/4-6 light yellowish brown to yellowish brown (d), 10YR 5/8 yellowish brown (m); sandy loam; single grain to weak fine granular; loose to slightly hard (d), slightly sticky non-plastic (m); few thin colloid stains & bridges; 30-40% gravel; few very fine roots; few fine pores; strongly effervescent, disseminated to weak stage I $CaCO_3$; clear smooth
Bwk4	14.25 - 24.25	8.5Y 6/6 reddish yellow to brownish yellow (d), 8.5YR 5/6 yellowish brown to strong brown (m); sandy loam; single grain to weak very fine granular; loose to slightly hard (d), slightly sticky non-plastic (m); few thin colloid stains on grains & few thin colloid, bridges, & films larger grains & clasts; 60% gravel; slightly effervescent, disseminated $CaCO_3$ near horizon top & weak stage I $CaCO_3$ on clasts; clear smooth
Bk	24.25 - 30.25	10YR 6/4 light yellowish brown (d), 10YR 6/3 pale brown (m); sand; single grain; loose (d), non-sticky non-plastic (m); very few thin colloid stains on large grains; 60% gravel; matrix non-effervescent, very weak stage I $CaCO_3$ on clasts; clear smooth
C	30.25 - 36.75	2.5Y 7/4-6 pale yellow to yellow (d), 2.5Y 6/3 light yellowish brown (m); sand; single grain; loose (d), non-sticky non-plastic (m); very few thin colloid stains on large grains and clasts; 40% gravel; matrix non-effervescent with slightly disarticulated $CaCO_3$ rinds & reworked carbonate coatings; clear wavy
2Ck	36.75 - 44.75	2.5Y 6/3 light yellowish brown (d), 2.5YR 5/3 light olive brown (m); sand; weak fine to medium granular to subangular blocky; loose to slightly hard (d), non-sticky non-plastic; few thin colloid stains; <5% gravel; matrix non-effervescent, strongly effervescent on clast undersides; clear wavy
3Bwkb1	44.75 - 50.75	10YR 5/6 yellowish brown (d), 10YR 4/3 brown (m); sandy loam; weak medium to coarse subangular blocky; loose to weakly coherent (d), slightly sticky non-plastic (m); few thin colloid stains on clasts; 5% gravel; few fine pores; matrix non-effervescent, slightly effervescent on clast undersides, few discontinuous coatings on large grains; abrupt wavy
3Bwkb2	50.75 - 54.25	10YR 5/8 yellowish brown (d); 10YR 5/3 brown (m); sandy loam; weak medium to coarse subangular blocky; loose to slightly hard (d), slightly sticky, very slightly plastic (m); few thin colloid stains and bridges on large grains & clasts; <5% gravel; slight effervescent, disseminated to weak stage I; few siltans; abrupt wavy
4kb	54.25 - 61.25	10YR 8/1 white on ped faces, 10YR 8/2 very pale brown crushed (d), 10YR 7/3 very pale brown (m); sandy clay loam; moderate coarse angular blocky; very hard; slightly sticky slightly plastic; very few thin colloid stains on clasts; <3% gravel; violently effervescent, stage III $CaCO_3$, incipient discoutinuous laminar layers; gradual wavy
4Bkb	61.25 - 68.25	10YR 6/3 pale brown (d), 10YR 7/2 light gray (m); loamy sand; weak fine to medium granular; weakly coherent (d), non-sticky non-plastic (m); very few thin colloid stains on clasts; 5-10% gravel; violently effervescent, stage I to stage II+ $CaCO_3$; abrupt irregular
4Btkb	68.25 - 74.5	10YR 6/4 light yellowish brown (d), 10YR 5/3 brown (m); loamy sand; weak medium subangular blocky to granular; slightly hard; slightly sticky, non-plastic; few thin bridges on grains & granules, moderately thick clay films on clasts; 10-15% gravel; common fine pores; strongly effervescent, stage I+ w/local pockets of stage II+ $CaCO_3$

ble 7. Soil profile description of Pedon Number 1, Alluvial Fan Unit Qf1, CLE.

Pedon description conducted by S.G. Wells & S. Connell on 8/27/92. Soil descriptions from field measurements. Colors based on Munsell notation for dry (d) or moist (m) colors. Profile terminology follows that of Soil Survey Staff (1951 and 1976) with revisions in Birkeland (1984).

SURFICIAL SETTING

Landform: alluvial fan with stone pavement and no bay & swale topography

Parent Material: alluvium reworked from Ocotillo fm and sediment from Little San Bernardino Mts

Vegetation: creosote bush *(Larrea tridentata)* & pencil cholla *(Opuntia ramosissima)* **Aspect/slope**: west/5 degrees **Elevation**: ~360 ft

PROFILE DESCRIPTION

Horizon	Depth (in)	Description
Ak	0 - 0.50	10YR 6/4 light yellowish brown (d), 10YR 4/3 dark brown (m); loamy sand; single grain; loose (d), non-sticky, non-plastic (m); very slightly effervescent, disseminated $CaCO_3$; very abrupt smooth
AvBwk	0.50 - 1.50	10YR 7/3 very pale brown on ped tops & sides, 8.5YR 6/6 reddish yellow to brownish yellow on ped undersides, 10YR 6/4 light yellowish brown crushed (d), 10YR 4/4 dark yellowish brown (m); sandy clay loam; strong fine to coarse subangular blocky, slightly hard (d), sticky plastic (m); very few to few thin bridges & colloid stains on clasts; 5-10% gravel; few very fine roots; common fine vesicles; very slightly effervescent on ped tops & violently effervescent on ped undersides, disseminated $CaCO_3$, very abrupt wavy
Btk1	1.50 - 3.50	10YR 6/6 reddish yellow crushed (d), 7.5YR 4/6 strong brown (m); sandy loam; single grain to weak very fine granular; loose (d), slightly sticky, non-plastic (m); few thin colloid stains & few moderately thick bridges; 10% gravel; few very fine roots; very slightly effervescent, disseminated $CaCO_3$; abrupt smooth
Btk2	3.50 - 5.50	7.5YR 6/4 light brown crushed (d), 10YR 4/4 brown (m); sandy loam; single grain; loose (d), slightly sticky, non-plastic (m); few thin colloidal stains & bridges, few thin to moderately thick clay films & bridges on large clasts; 10% gravel; few fine roots; very slightly effervescent, very weak stage I to disseminated $CaCO_3$; abrupt smooth
Avkb	5.50 - 7.0	7.5YR 7/2 pinkish gray on ped faces, 7.5YR 6/4 light brown crushed (d), 7.5YR 4/6 strong brown (m); sandy loam; moderate fine to coarse subangular blocky; hard (d), slightly sticky, non-plastic (m); few thin bridges and colloid stains with few to common thin films on ped face; 5% gravel; few fine roots; common fine vesicles; violently effervescent, weak stage I $CaCO_3$; horion discontinuous, varying from 0-1.5" thickness; very abrupt wavy
Btkb	7.0-8.50	7.5Y 7/6 reddish yellow (d), 7.5YR 4/6 reddish yellow (m); sandy loam; single grain; loose (d), slightly sticky non-plastic (m); few to common thin bridges & colloid stains & few to common thin films on clasts; 5-10% gravel; gravels disintegrate under slight pressure; few fine roots; strongly effervescent, disseminated to very weak stage I $CaCO_3$; very abrupt wavy
2Avkb	8.50 - 10.0	7.5YR 6/3 light brown on ped face, 7.5YR 6/3 light brown crushed, 7.5YR 5/4 brown (m); sandy loam; moderate very coarse subangular blocky; hard (d), slightly sticky, non-plastic (m); common thin bridges & colloid stains, few thin films on clasts & grains; 15% gravel, edges of clasts disintegrate under moderate pressure; few fine roots; common fine vesicles; violently effervescent, stage I to disseminated $CaCO_3$; abrupt wavy
2Btkb	10.0 - 14.0	7.5YR 6/6 reddish yellow (d), 7.5YR 5/6 strong brown (m); loamy sand; single grain to weak fine subangular blocky; loose to slightly hard (d), very slightly sticky, non-plastic (m); few thin colloid stains with few thin films on clasts & grains; 15-20% gravel; few very fine roots; violently effervescent, disseminated with pockets of very weak stage I $CaCO_3$; clear wavy
2Bkb1	14.0 - 18.0	10YR 6/4-6 light yellowish brown to brownish yellow (d), 10YR 5/6 yellowish brown (m); sand; weak fine sub-angular blocky; loose to slightly hard (d), non-sticky, non-plastic; few thin colloid stains & bridges w/ few thin clay films on large clasts; 35% gravel; few very fine roots; very slightly effervescent, stage I $CaCO_3$; clear wavy
2Bkb2	18.0 - 25.50	10YR 6/4-6 light yellowish brown to brownish yellow (d), 10YR 6/4 light yellowish brown (m); sand; single grain; loose, non-sticky, non-plastic; few thin colloid stains, bridges & clay films; 50% gravel; few very fine roots; violently effervescent, stage I $CaCO_3$; siltans 1-1.5 mm thick around larger clasts; clear wavy
2Bkb3	25.50 - 31.50	2.5Y 7/3 pale yellow (d); 2.5Y light yellowish brown (m); sand; weak fine to medium subangular blocky; loose to hard (d), non-sticky, non-plastic (m); very few thin colloid stains on clasts & large grains; >50% stones; common medium pores; slightly to violently effervescent, stage I+ $CaCO_3$; abrupt wavy
2Bkb4	31.50 - 50.0	2.5Y 7/3 pale yellow (d), 2.5Y 6/4 light yellow brown (m); sand; single grain to weak fine to coarse subangular blocky; loose to hard; non-sticky, non-plastic; very few thin colloid stains on clasts and large grains; >50% gravel; common medium pores; slightly to violently effervescent, varies disseminated to stage II $CaCO_3$ near and bottom of horizon; gradual irregular
2Bkb5	50.0 - 71+	2.5 Y 7/3 pale yellow (d), 2.5Y 6/3 light yellowish brown (m); sand; single grain to weak medium to fine subangular blocky; loose to hard (d), non-sticky, non-plastic (m); very few thin colloids on clasts & grains; >50% gravel; violently effervescent, disseminated to stage I $CaCO_3$ base of trench.