2006-2011 Mission
Kearney Foundation of Soil Science: Understanding and Managing Soil-Ecosystem Functions Across Spatial and Temporal Scales
July 1, 2010-December 31, 2010

Soil Development and Fertility in an Alluvial Chronosequence, Southwestern Sacramento Valley

Randal J. Southard*[1], Stewart S. Winters[1]

Project Objectives

Many soil properties change as a soil becomes progressively older - especially with regard to mineral weathering – which can have a profound effect on soil fertility. The general trend for soils as they weather is to become decreasingly fertile with regard to nutrient availability. Soils are constantly being subjected to a variety of soil forming processes, but a process common to most soils is the desilication of primary minerals. As this occurs ions become available for plant uptake, but as weathering progresses leaching of nutrients also occurs, resulting in fewer nutrients remaining in the plant rooting zone. This project aims to understand some of the dynamics at play as soils weather, including changes in mineralogy, soil texture, cation exchange capacity, and nutrient abundance. Monitoring one soil over the course of its "life" is not feasible due to the time scale over which weathering occurs. This research substitutes space for time and investigates a chronosequence of soils derived from Putah Creek alluvium, wherein the age of the landscape at different locations is presumed to be the dominant soil's forming factor affecting soil processes and resulting soil properties.

Approach and Procedures

Three soils were sampled in the chronosequence. The youngest soil is represented by the Yolo soil series, which is no more than 2,000 years old. The intermediate age soil is the Hillgate series, which is probably between 75-192 thousand years old. The oldest soil in the chronosequence is the 200-400-thousand-year-old Corning series. Estimated soil ages were developed by Unruh et. al., 1993. Each soil was described in the field and sampled by morphological horizon to a depth of about 60 cm to represent the average rooting depth of most crops. Soil samples were oven dried before analysis to determine air dry water content. The organic matter from each sample was oxidized to aid in dispersion for particle size analysis as well as to determine organic matter (OM). The amount of weight lost through Clorox oxidation of organic matter was used to estimate the amount of OM content of each sample. Particle size analysis, following a pipette method similar to that of Jackson (1975) was conducted to determine soil texture for every horizon and to isolate the different particle size fractions from each other. Sands were separated by wet-sieving through a 300 mesh sieve; clay content was determined by extraction of an aliquot (based on Stokes' Law) from silt/clay suspension, and silt content was determined by difference. For fractionation, silt and clay were separated by centrifugation (based on Stokes' Law). Oriented mounts of clay fractions on glass slides were prepared for X-ray diffraction (XRD) analysis. Clays were treated with KCl, $MgCl_2$, and $MgCl_2$ along with a 1:1 mixture of glycerol and water. The slides were then analyzed by XRD to

[1] Department of Land, Air, and Water Resources, University of California, Davis, CA, 95616
*Mentor

determine the mineralogy of the samples. Following XRD analysis of the KCl slides, the K samples were then heated to 350° C and 550° C to narrow down the possible mineralogical possibilities by seeing how the crystal structure of the minerals responded to heat treatment. Each soil was also tested to determine the cation exchange capacity of each horizon. The method used was mechanical vacuum extraction by NH_4Oac (method similar to Soil Survey Staff, 2004). During this process samples were flooded with NH_4^+ so as to replace exchangeable bases. Excess NH_4^+ was washed from the samples with ethanol. Sorbed NH_4^+ was displaced with Na, and the displaced ammonium was measured colorimetrically. The NH_4Oac extracts were also analyzed by atomic absorption and flame photometry to determine extractable Ca^{2+}, Mg^{2+}, Na^+, and K^+. Knowing the amount of each nutrient on the exchange complex allows for the calculation of $cmol_c$ for each nutrient as well as base saturation.

Results and Discussion

Many of the soil characteristics conform to the trends expected in this chronosequence (Table 1). From the Yolo to the Corning soils there is a distinct reddening of color. The increase in red coloration from 2.5 Y to 7.5YR is due to the loss of soil constituents through leaching resulting in progressive accumulation of Fe-oxides, which contributes to the reddening. Clay content and distribution within pedons follow patterns related to the stage of development of each soil. For instance, there is a decrease in clay with increasing depth in the Yolo series. Because this soil is on a young landscape, much of the clay deposited as alluvium is found in the uppermost horizons. With the Hillgate there begins to be eluviation of clay from the surface horizon toward greater depths. This trend can also recognized in the Corning series and where the increase in clay content is more pronounced. The changes in soil color and clay content are good indicators of how time contributes to the soil forming process. It also shows how slow the process of clay accumulation in the subsoil is.

The physical properties of a soil can reveal a lot of useful information, but in order to further understand how this chronosequence evolves over time, especially with regard to fertility, it was necessary for the project to quantify many chemical characteristics as well. Table 2 highlights the important chemical properties determined from this research. In the younger soils, Yolo and Hillgate, there are relatively neutral pH values. The Hillgate series has been limited by the soil pH and the amount of Ca within the samples. The Corning soil is only slightly acidic even despite its age and the degree of weathering that it has been subjected to. This pH range is where phosphate dissociates from constituents thereby making P more available to plants than in either highly alkaline or highly acidic soils. The acidity of the Corning soil makes it more likely to be deficient in other plant nutrients like K, Ca, or Mg compared to the other two soils. A larger amount of clay could help the retention of these nutrients in these soils but they all exhibit relatively low clay contents (Singer and Munns, 2006). Soil nutrients like N and S are more dependent on the amount of organic matter (OM) in the system, as well as temperature and soil water. There is little OM to play a role in the release of N and S (Singer and Munns, 2006). The uppermost horizon of each soil is where the most OM was found. Although these soils contain relatively little OM, it is likely that this low level still contributes to the increased acidity of the upper horizons relative to horizons deeper in the profile. This low level of OM also contributes little to the CEC values observed. The trend expected as a soil is increasingly weathered is that there is a loss of CEC due to the desilication of clay minerals, which become less capable of exchanging ions due to the change in structure. This trend is evident in the data shown in Table

2. With the decreasing CEC observed on older landscapes, there is also a general decrease in abundance of each nutrient on the exchange complex. These measured quantities follow what was expected of the chronosequence.

Possibly the most interesting dynamic occurring in this chronosequence is the clay mineralogy. Not only is mineralogy critical in contributing to the CEC of most soils, it also relates to the amount of surface area a clay particle may have. Surface area is crucial in the allowance of space available for organic matter, nutrients, microorganisms, and water to be held by the soil. Figures 1-6 display the XRD results from the two uppermost horizons for each of the three soils in the chronosequence and include every treatment that was conducted on each horizon. Within the Yolo series (Figs. 1 and 2), the dominant minerals present include: smectite, vermiculite, kaolinite, quartz, and mica. In the intermediately aged Hillgate series, the mineralogy is similar to that of the Yolo soil. Though similar, the Hillgate (Figs. 3 and 4) soil does indicate the presence of some feldspar in addition to the previously mentioned minerals. There was also a weakening of the collapse response of smectite to the heat treatments at 350° and 550° C. In the Corning XRD results, (Figs. 5 and 6) the incomplete collapse of the smectite peak is even more evident. The mica present in both the Yolo and Hillgate soils is all but absent in the Corning sample. The explanation for the incomplete collapse of smectite in the Hillgate and Corning soils is one of mineralogical evolution. As the silicate minerals are acted upon by soil forming factors, weathering begins to alter the crystalline structure of the minerals. Hydrated aluminum in soil solution has one or more water molecules dissociate from the molecule, which results in one hydroxy-Al binding to another through two oxygen bonds causing what is known as Al-polymerization (Dixon and Weed, 1989). Deposition of these Al-polymers in the interlayer spacing is another mechanism for creating hydroxy-Al interlayered mica (HIM). This polymerization creates a ‘superlattice effect,’ which causes some interlayers to expand while some remain unaffected. The expansion is due to hydroxy-Al, which begin to fill the the interlayer space in the 2:1 minerals. It is these HIMs that is replacing much of the smectite crystallinity and is the reason for incomplete collapse of the smectite peaks in both the Hillgate and Corning samples. This process is a positive feedback, which facilitates further genesis of HIM as time progresses. Moderately acidic conditions (like that of the Corning series) are the optimal environmental conditions for pedogenic hydroxyl-Al formation (Dixon and Weed, 1989). This hydroxy interlayering can cause a decrease in the base saturation due to its occupancy around exchange sites as well as an increase in acidity as time progresses. This is a likely contributor to the lower acidity of the oldest soil sample. The hydroxy-Al interlayers create zones where there is collapse of interlayer spacing in some areas and ‘pockets’ where ions like K become trapped. This “wedge zone” causes selectivity in the exchange complex that can particularly affect K’s role in CEC in a type of “K-fixation” or entrapment in the interlayer (Dixon and Weed, 1989). Though this process is interesting, it does not facilitate increased fertility in soils as they age, and can be considered one of the main factors contributing to the decreased fertility of the soils in this chronosequence as a function of age.

Some factors that contributed to difficulties or uncertainty in the research were present. One of these was the use of water as a solvent (rather than NH_4Oac) for the dilution of NH_4OA_C extract standards. The matrix effect here is not entirely known but it is suspected that the effects may be significant. If further research were to be done matrix matching here would prove useful. Another difficulty encountered was the fact that the available centrifuges were out of order for some time. Finally, having an allowance in the Kearney fund for lab materials could prove beneficial. This researcher was lucky in that the materials needed for this project were already present in the laboratory.

Finally, I would like to thank the Kearney Foundation of Soil Science for the opportunity to conduct my own scientific research and give me a real idea of the kind of work that must go into successful experimentation and research. Also, I would like to thank Professor Randy Southard for his patience and guidance in this new experience. Additional thanks must go out to graduate students Valerie Bullard, Hideomi Minoshima, Kevin Muzikar and LAWR staff Tad Doane and Cindy Bergens for imparting their wisdom and experience with regard to laboratory procedures. Without them, there would have been many more mistakes and much of this project’s data would be unusable. So for all of this I am deeply appreciative and grateful.

Table 1- Physical characteristics of soils in the chronosequence by horizon depth.

SOIL	DEPTH	COLOR				TEXTURE	SAND	SILT	CLAY	ROCK	AIR DRY	CONSISTENCE	
			H	V	C		%	%	%	FRAGS	H?O CONTENT	D	W
YOLO	0-20	D	2.5 Y	6	3	loam	37.5	41.9	20.6	-	0.0316	VH	SS
		M	2.5 Y	3	3								SP
	20-43	D	2.5 Y	5	3	loam	38.0	43.6	18.4	-	0.0626	EH	SS
		M	2.5 Y	3	3								SP
	43-60	D	2.5 Y	5	4	loam	41.5	44.0	14.5	-	0.0619	SH	SO
		M	2.5 Y	4	4								SP
HILLGATE	0-9	D	2.5 Y	6	4	loam	51.0	38.6	10.4	-	0.0121	MH	SS
		M	2.5 Y	4	4								MP
	9-26	D	2.5 Y	6	4	loam	50.9	36.2	12.9	-	0.0186	SH	SS
		M	10 YR	4	4								SP
	26-35	D	10 YR	5	4	sandy loam	53.5	35.5	11.0	-	0.0131	HA	VS
		M	10 YR	4	4								MP
	35-67	D	10 YR	5	4	sandy loam	52.6	34.8	12.6	-	0.0216	HA	VS
		M	10 YR	4	4								MP
CORNING	0-33	D	2.5 Y	6	4	sandy loam	64.0	23.9	12.1	50% GR	0.0116	MH	SS
		M	10 YR	4	4								SP
	33-43	D	10 YR	6	4	sandy loam	63.2	19.5	17.3	70% GR	0.029	HA	SS
		M	7.5 YR	4	6								MP
	43-57	D	7.5 YR	4	6	sandy clay loam	63.4	14.2	22.4	66% GR	0.0427	MH	SS
		M	5 YR	4	6								MP

Table 2- Chemical characteristics of soils in the chronosequence by horizon depth.

SOIL	DEPTH (cm)	pH	OM %	CEC	Ca cmol/kg soil	Mg cmol/kg soil	Na cmol/kg soil	K cmol/kg soil	BS
YOLO	0-20	6.87	2.41	12.5	5.43	6.77	0.56	0.60	107
	20-43	7.51	0.65	12.4	4.22	6.21	0.66	0.37	92
	43-60	7.61	0.87	13.7	4.58	7.27	0.93	0.21	95
HILLGATE	0-9	8.2	1.27	6.6	17.94	0.85	0.66	0.25	298
	9-26	8.53	0.79	7.4	3.05	3.88	1.05	0.17	110
	26-35	8.42	0.26	10.7	3.47	5.37	1.54	0.18	99
	35-67	8.34	n.d.*	4.9	2.83	1.89	0.58	0.16	112
CORNING	0-33	6.15	0.96	5.9	2.30	2.23	0.64	0.15	90
	33-43	6.27	n.d.*	8.3	2.68	3.45	0.63	0.15	83
	43-57	6.66	n.d.*	5.0	4.12	1.16	0.91	0.18	128

*n.d. = none detected

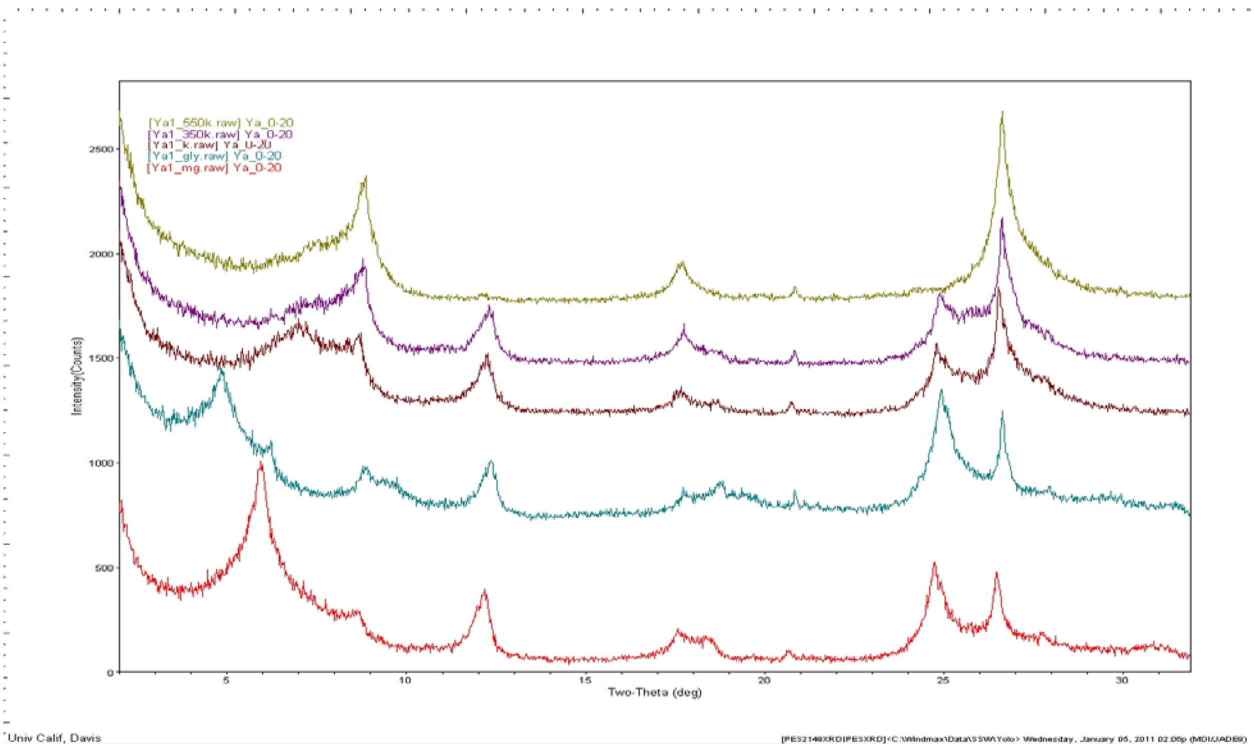

Fig. 1- Yolo Series (0-20 cm) XRD results for each of the five slide treatments.

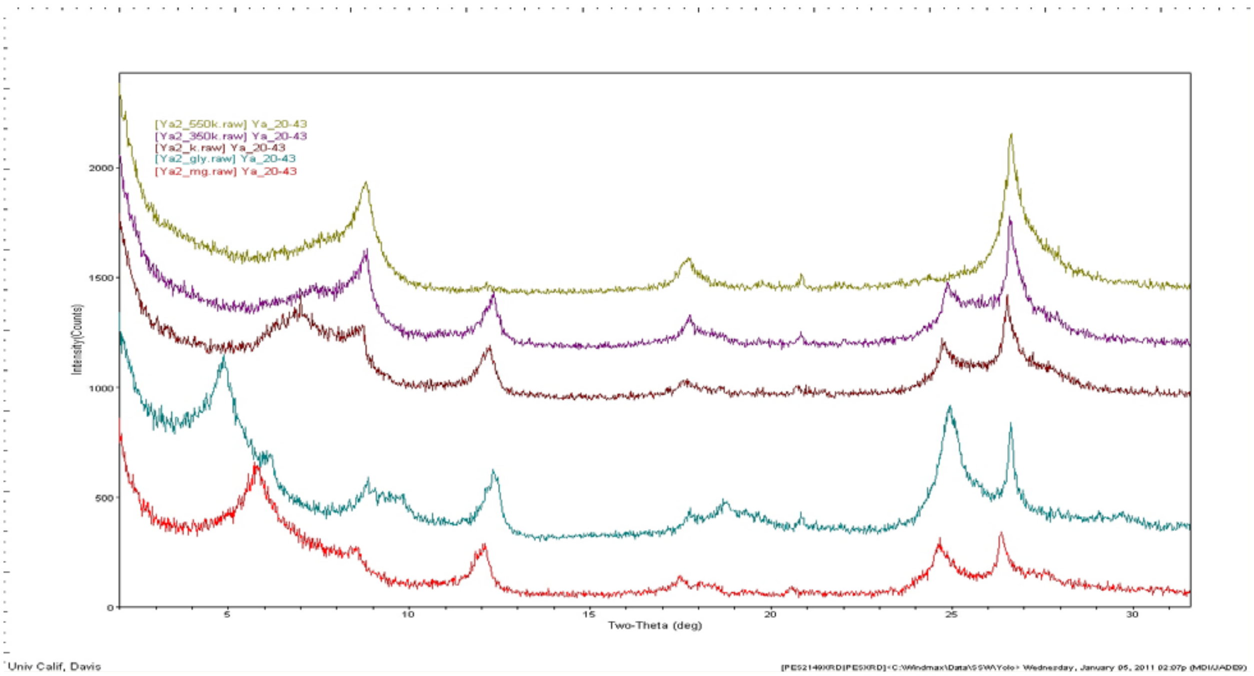

Fig. 2- Yolo Series (20-43 cm) XRD results for each of the five slide treatments.

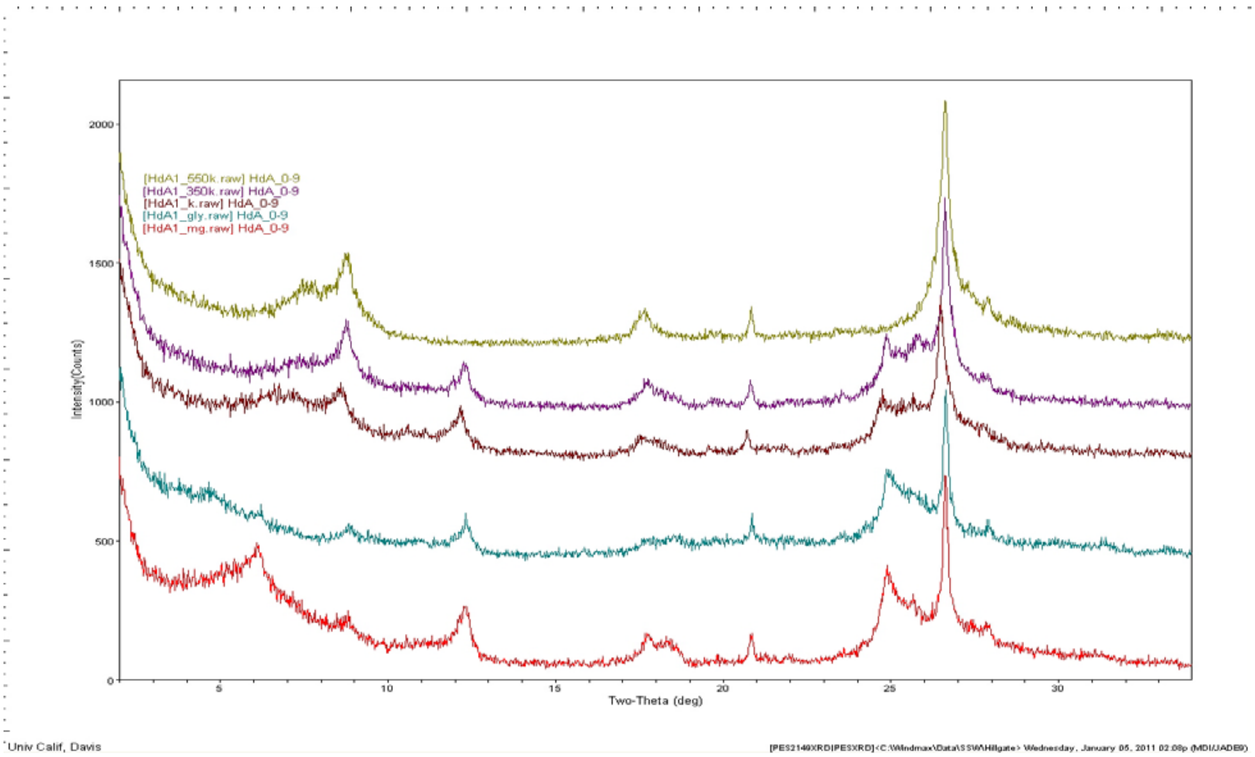

Fig. 3- Hillgate Series (0-9 cm) XRD results for each of the five slide treatments.

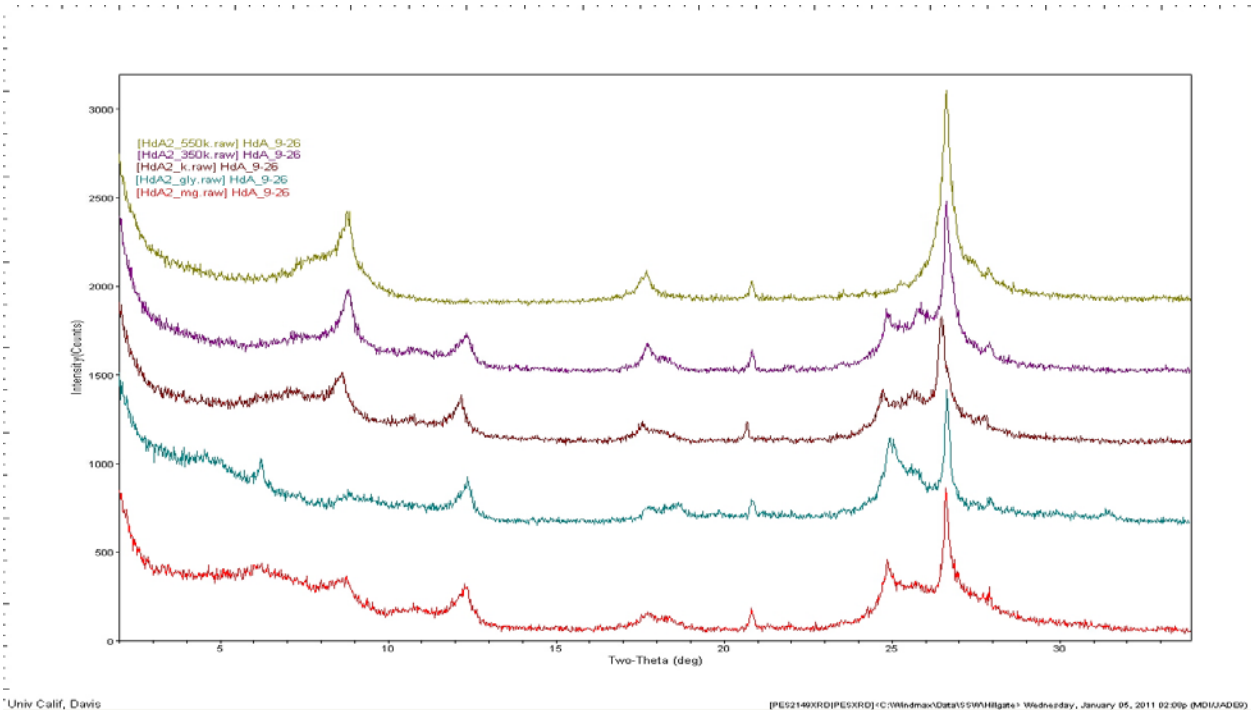

Fig. 4- Hillgate Series (9-26 cm) XRD results for each of the five slide treatments.

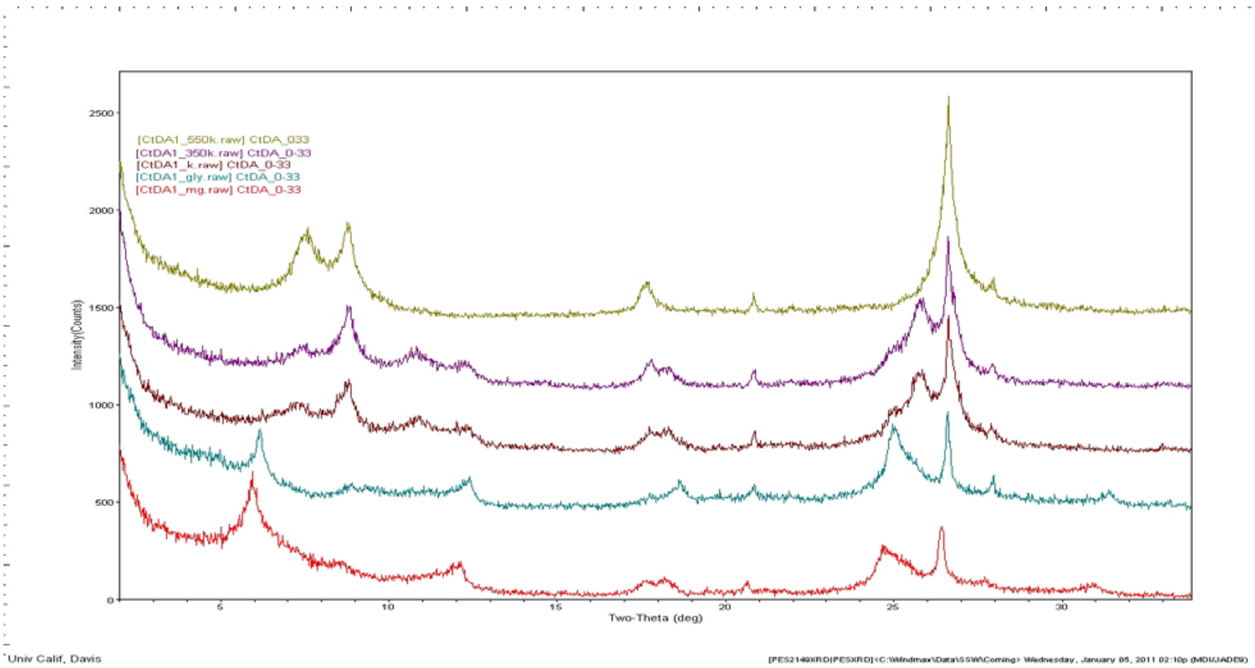

Fig. 5- Corning Series (0-33 cm) XRD results for each of the five slide treatments.

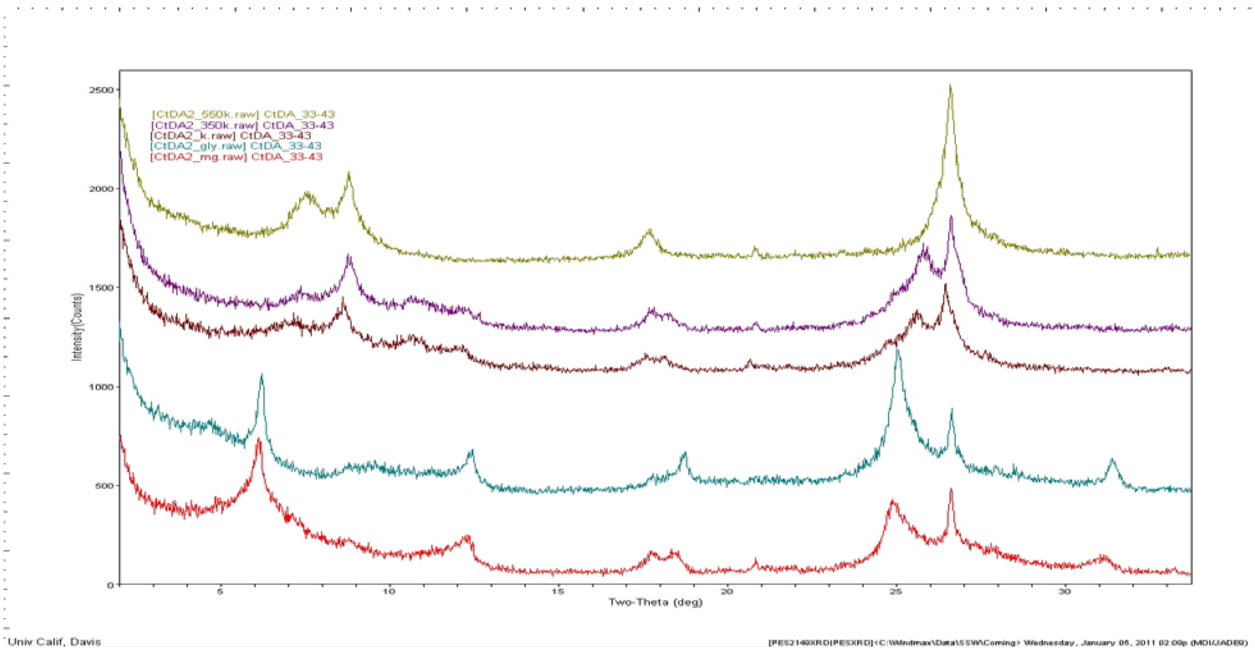

Fig. 6- Corning Series (33-43 cm) XRD results for each of the five slide treatments.

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