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# Distribution of clay minerals along a soil toposequence

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## Abstract

Recent studies of soil–landscape relationships in Soodejan region identified clay minerals in calcic, argillic and petrocalcic horizons developed on different landforms. The objectives of this study were: i) to evaluate the versatility of clay minerals in the semi-arid soil environment, and ii) to establish the relationship between the soil properties and types of clay minerals on different landforms. Seven representative pedons on different landscapes were selected for mineralogical study. Physiographically, the study area consists of mountain, hill and plateau. Also, there are flood plain, terraces, summit, back slope, foot slope and small parts of low land that located in the toe slope. The profile was dug on all of the land forms. They were classified as Calcixerepts, Haploxerepts, Haploxeralfs and Haploxerolls with xeric and mesic moisture and temperature regimes. The XRD analysis showed that vermiculite and chlorite minerals had the most extensive extent of the particle-size distribution among the secondary phyllosilicates specially in coarse clay particles. Also there are most of the mixed illite and chlorite minerals in comparison to the other minerals. Presence of triviality amounts of kaolinite in different horizons showed that some minerals are formed under bygone moist continent. In the argillic horizons, smectite proved to be the dominant clay mineral in the fine clay particles and increased by the increasing depth. This matter is in each typic sample. Differences in layer charge with landscape position may be due to differences in weathering processes but the drainage condition caused by topography is a critical factor in the transformation and redistribution of clay minerals.

***Key words:*** Landscape, clay minerals, weathering, smectite, argillic horizon.

## Introduction

Consideration of the characteristics of minerals found in soils, and their transformation from one form to another, is essential for understanding the nature of soil properties [1]. The nature of clay minerals in soils is easily affected by soil forming processes. Clay illuviation is also one of the most important pedogenic processes for the selected soils. Soils with argillic horizons cover most of the land area of Soodejan, Iran. In contrast, pedogenic carbonate accumulation primarily occurs in most of soils where the climate is semi-arid. However, in some cases an increase in clay with depth in the profile may be due to the *in-situ* weathering of mica, feldspar, or some other minerals as indicated by many researchers [2]. Illite typically weathers to vermiculite through the release of potassium from the interlayer; the intercalation of Al hydroxyl-polymers often occurs, giving rise to hydroxy interlayered vermiculites (HIV), and to pedogenic chlorites as the end members of the transformation [3]. Detrital chlorite tends to disappear by weathering to vermiculite or smectite and, in both cases, the formation of mixed layer clay minerals between the two end members is common[3]. Kaolinite has been reported as originating from almost all primary minerals [4] but is typically pedogenic only in Oxisols and Ultisols, while in Cryalfs and Udalfs, its distribution is generally uniform with depth, suggesting inheritance from the parent material. Biotite, smectite, chlorite and interstratified chlorite–vermiculite make up the predominant mineralogical association in the clay fraction of the soils, which formed as the result of the transformation of primary biotite under the influence of the hydrothermal activity affecting the formation of the diapir. Bonifacio *et al.* [5] found swelling mixed layer minerals in the surface horizons, where the vegetation cover was favourable to the production of aggressive organic acids, and thus Al may be removed also from the structural sites of phyllosilicates.

Gunal *et al.* [6] reported that in all Harney pedons, X-ray patterns indicate that the parent materials are rich in smectite. Such plain relief is associated with landform stability that favors pedogenesis[7] and the influence of clay minerals on soil physical properties, particularly those associated with soil structural decline and hardsetting [8]. Officer *et al.* [9] found variability of clay minerals in two New Zealand steeplands.

The aim of the study was the recognition of the clay mineral source and formation manner and their relationship with soil properties because the best understanding of the clay minerals exact nature in the soil and these minerals relationship manner with the soil physical and chemical properties is the base to evaluate the soil behavior in agriculture, environment and management field in the future. Several other studies on mineralogy of clays were presented in Iran [4, 10, 11]. We present research on some pedons in central of Iran, with Bt, Bk and Btk horizons that provide a different landscape setting for studying the effects of parent material, climate and topography on soil development and type of clay minerals. As most of central Iran is covered by limestone formations, the parent materials of all soils are strongly calcareous.

## Materials and Methods

***The studied region introducing:*** The studied region (Soodejan) is a county of Shahrekord city near the Zayandeh Rud River with 40 km distance from southwest of Zayandeh Rud dam that has 3000 hectares area. The design geographical boundaries is from 50º21'35" till 50º26'73" eastern lengths and from 32º28'63" till 32º 34'68" northern width on the Zagroos mountain foots in the Iran central plateau. This was used of aerial photograph, topography and geological maps with scale 1:20,000, 1:25,000 and 1:250,000, respectively. This region includes three kinds of landscapes such as mountain, hill and plateau. Also, there are flood plain, terraces, summit, back slope, foot slope and small parts of low land that located in the toe slope, in this region. The profile was dug on all of the land forms.

***Physical and chemical laboratory analysis:*** All analyses were performed on the < 2 mm fraction, which was obtained via sieving. Particle-size distribution was determined after dissolution of $CaCO_3$ with 2 N HCl and decomposition of organic matter with 30% $H_2O_2$. After repeated washing to remove salts, samples were dispersed using sodium hexametaphosphate for determination of sand, silt and clay fractions by the pipette method. Alkaline-earth metal carbonate was measured by acid neutralisation [12]. Organic carbon was measured by wet oxidation with chromic acid and back titration with ferrous ammonium sulphate. Gypsum ($CaSO_4 \cdot 2H_2O$) was determined by precipitation with acetone [12]. Soil pH was measured in a saturation paste, and electrical conductivity (total soluble salts) was determined in a saturation extract. Cation exchange capacity (CEC) was determined using sodium acetate (NaOAc) at pH 8.2 [13].

***Mineralogical analyses:*** Chemical cementing agents were removed and clay fractions separated according to Mehra and Jackson [14], Kittrick and Hope [15] and Jackson [16]. Iron-free samples were centrifuged at 750 rpm for 5.4 min to separate total clay (< 2 µm) and at 2700 rpm for 42 min to separate fine clay (< 0.2 µm)[15]. The fine and coarse-clay fractions were analysed mineralogically by X-ray diffractometry [16]. The same concentration of clay suspensions was used for all samples to give reliable comparisons between relative peak intensities. Two drops of the prepared suspension were used on each glass slide. The (001) reflections were obtained following Mg saturation, ethylene glycol solvation and K saturation. The K-saturated samples were studied both after drying and after being heated at 550°C for 4 h.

## Results and Discussion

***Morphological and physicochemical observations:*** The soils have Munsell colours ranging from 10YR to 2.5Y (Table 1). Coarser rock fragments were present only in pedons on piedmont plains landforms.

Calcite nodules are present in most of soils. Clay pans are present in some soils, specially in the argillic horizons. As shown in Table 2, most of the soils are heavy-textured, ranging from loam and clay loam in the lighter-textured soils to silty clay and clay in the heavy-textured pedons. Some soils are calcareous throughout with an average of >40% $CaCO_3$, increasing with depth.

***Clay mineralogy:*** X-ray diffractograms of the soil clay fraction (<2 µm) are presented in Figs 1-5. Chlorite, illite and vermiculite are the main minerals in the total clay fraction. In the fine clay fraction, smectite is dominant in pedons that placed on footslope landforms. Almost all the soils studied contain illite, vermiculite and chlorite, which forms most of the coarse clay fraction. Kaolinite occurs in small amounts in some pedons.

The XRD analysis of the Ap horizon at the footslope site was selected for detailed clay mineralogical description (Fig. 1). The Mg-saturated sample after glycerol solvation showed no *d*-spacing expansion beyond 1.4 nm, which indicates the absence of smectite. Trace of smectite was formed in fine clay fraction (Fig. 2). After heating the K-saturated samples at 550ºC, the 1.4 nm XRD peak shifted to low *d*-spacing and the intensity of the 1.0 nm peak increased, which indicates the presence of vermiculite. The XRD patterns for the Mg- and K-saturated clays showed an intense 1.0 nm peak, indicating the presence of illite. A tiny XRD peak at 0.46 nm was quartz.

The XRD pattern of the clay fraction from the Bt 1 horizon at the footslope site indicates that the clay mineralogy of the subsoil horizons is different from that at the surface horizons. The main difference between the X-ray patterns of fine clay and that of coarse clay is the predominance of smectite. Smectite was present in the Bt1 horizon (Figs 3 and 4).

The XRD pattern of fine clay particle depicted in Fig. 4 shows that the Bt horizon of the footslope site has well-defined peak in the 14–15 Å (001) region, which expand after being treated with ethylene glycol to16–18 Å, indicating the predominance of smectites. Traces of kaolinite were found in the deepest horizons. Kaolinite was identified from its 0.72 and 0.36 nm reflections. Both XRD peaks collapsed when K-saturated clays were heated to 550ºC.

The distribution of clay minerals in the soil profile at the summit and backslope landforms was uniform with depth. A representative XRD of the these sites is in Fig. 5. Vermiculite, illite and chlorite clays were present. The surface horizon at the backslope site was dominated by illite and vermiculite, with small amounts of smectite and trace of kaolinite.

The smectite existence with vermiculite is the main factor for the high CEC in soil that resulted in the low land soil. The simulation in the mica and smectite sheet structure predicated that smectite can be formed of mica by the potassium desorption. Perhaps the primary stage of this transformation process is vermiculite. This process is very fast and due to this process continue, vermiculite is changed to smectite. In the backslopes and shoulder landforms, vermiculite was seen, but in footslope landforms smectite is demonstrated. The mineral amount increases by increasing of the depth. The available moisture increasing in the soil horizons in the region with more moisture (low land) causes the illite weathering and potassium depletion. This process provides sufficient condition in the region with calcic and highly active Mg and Si till smectite forms by the changing and transformation of illite in the soil surface. Smectite that forms in this condition and with good drainage can go to the subsurface horizons by leaching and illuviates in the horizons. A part of smectite mineral in the control profile of argillic horizons is due to this process. In

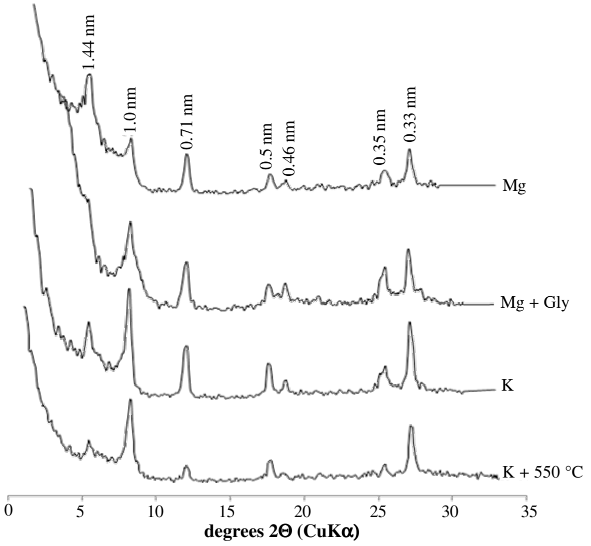


***Figure 1.*** The X – ray diffractograms of coarse clay fraction separated from the Ap horizon of 44 pedon at footslope site.

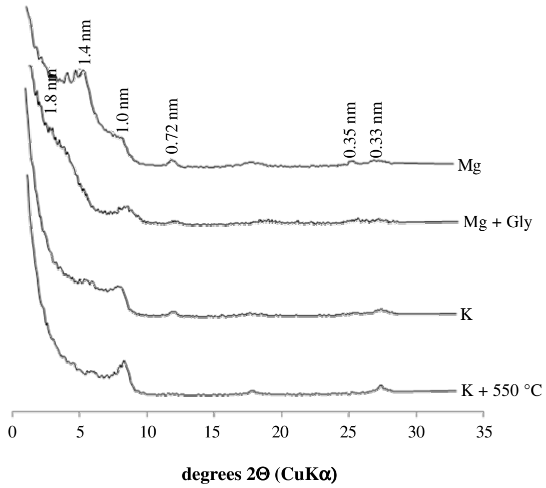


***Figure 2.*** The X – ray diffractograms of fine clay fraction separated from the Ap horizon of 44 pedon at footslope site.

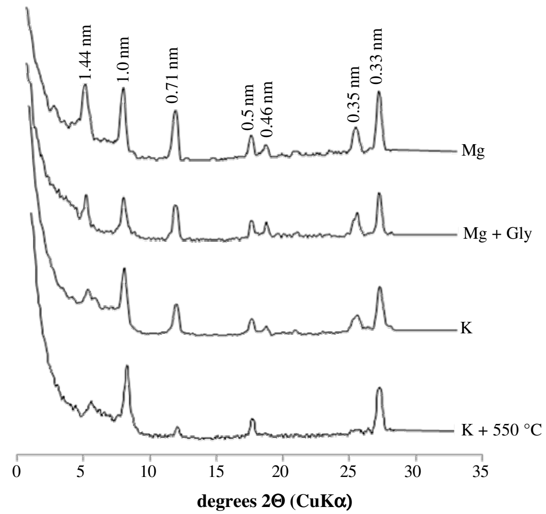


***Figure 3.*** The X – ray diffractograms of coarse clay fraction separated from the Bt horizon of 44 pedon at footslope site.

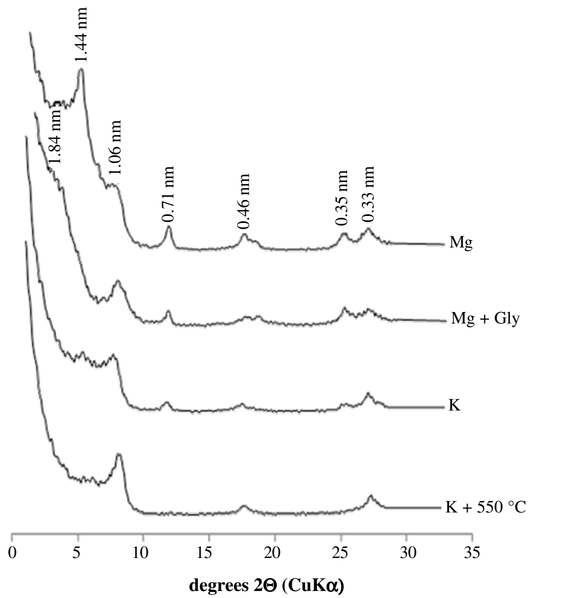


***Figure 4.*** The X – ray diffractograms of fine clay fraction separated from the Bt horizon of 44 pedon at footslope site.

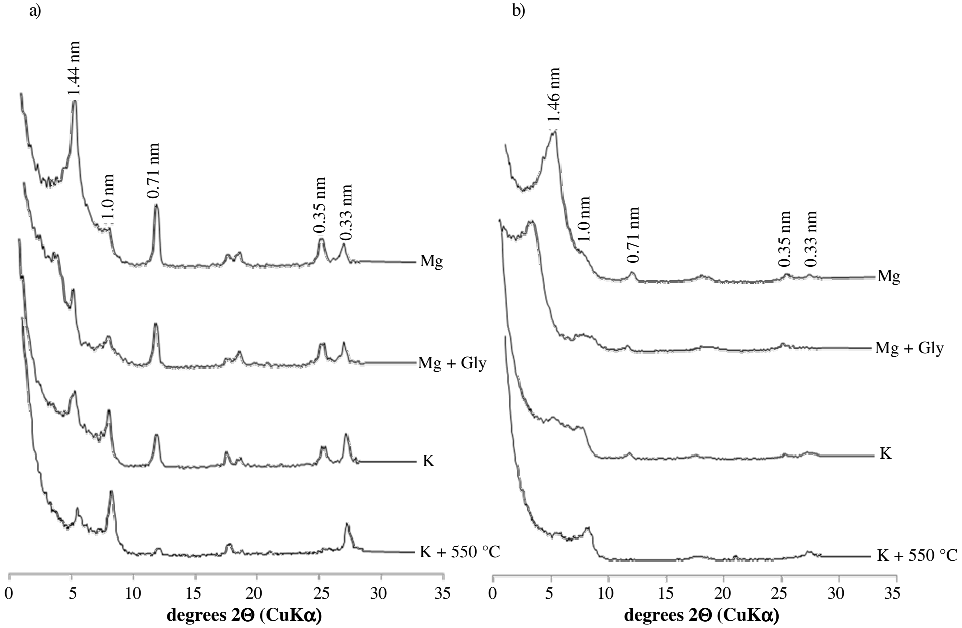


***Figure 5.*** The X – ray diffractograms of clay fraction of selected horizons from 48 pedon at summit site. a) Coarse clay fraction b) Fine clay fraction.

study region, topograghy is perhaps the most diverse of the five factors of soil formation named by Jenny [17].

According to the Jenny [17] view, the soil genesis factors (climate, parent materials, organism, time and topography) cause start and rotation of most of the soil formation inner phenomena due to apparent diagnostic surface and subsurface horizons in the profile. According to this matter, that studied region climate includes very cold winter and hot and dry summer and also the most rainfall is in the cold seasons, so there is enough moisture for soil changing and developing such as leaching phenomenon, and the weathering processes are very active. The climate, rather high rainfall (470 mm) and the heavy and long-term snowing, affects the studied region soil changing and developing, that by water and moisture infiltrating into the soil results in the lime eluviation from the surface horizons and its illuviation into the horizons deeper than 50 cm. Also the clay colloids transferring from surface to the beneath horizons and calcic horizons formation have been studied in most soils of the region. The parent materials have more effects on the formed soil type in the region. The abundant lime existence in most soil profiles of the studied region shows the limny parent materials effects, profoundly.

Mineralogical study of the soil horizons showed little difference in the type of clay minerals among the different locations of the toposequence, but the relative amount of clay minerals differed in weathering conditions probably because of internal drainage. Because of poor drainage, relatively restricted weathering intensity and leaching occurred in this soils.

Clay mineral composition is known to be influenced by physical properties of the soils concerned. Drainage conditions caused by topograghy are a critical factor in the transformation and redistribution of clay minerals in this region.

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**Table 1.** Morphology and classification of the selected pedons.

| Horizon | Depth (cm) | Colour (moist) | Structure | Consistence (moist) | Calcite features | Clay skin | Physiography position |
|---|---|---|---|---|---|---|---|
| **1- Calcic Haploxeralfs** | | | | | | | footslope |
| Ap | 0-25 | 7.5YR3/4 | gr | fr | few | - | (Hill) |
| Bw | 25-50 | 7.5YR3/4 | m1abk±gr | fi | few | v1 | |
| Bt | 50-75 | 7.5YR4/3 | c2abk | fi | common | few | |
| Btk | 75-100 | 5YR4/4 | c3abk | vfi | many | few | |
| Bk | 100-150 | 7.5YR4/3 | f1abk | fi | many | v1 | |
| **5- Typic Haploxerolls** | | | | | | | |
| Ap | 0-25 | 7.5YR3/3 | gr | fr±fi | many | - | |
| Bw | 25-40 | 10YR6/4 | m1abk±gr | Fi | many | - | Alluvial |
| CB | 40-60 | 10YR6/4 | c2abk | Fi | many | - | Fan |
| Cr1 | 60-95 | 2.5Y6/2 | c3abk | - | many | - | |
| Cr2 | 95-150 | 5Y7/2 | f1abk | - | many | - | |
| **18-Typic Calcixerepts** | | | | | | | Alluvial Fan |
| Ap | 0-20 | 10YR4/4 | f1gr | fr | - | - | (mid and |
| Bw1 | 20-40 | 7.5YR4/4 | c2abk | fi | common | - | lower parts) |
| Bw2 | 40-60 | 7.5YR4/4 | c2abk | fi | common | v1 | |
| Bk1 | 60-120 | 7.5YR4/4 | f1abk | fi | many | v1 | |
| Bk2 | $120\text{-}150^{+}$ | 7.5YR4/3.5 | f1abk | fi | many | v1 | |
| Ap | 0-20 | 7.5YR4/6 | f2gr | fi | common | - | |
| Bk1 | 20-40 | 7.5YR4/6 | f2abk | fi | many | - | |
| Bk2 | 40-80 | 7.5YR4/6 | c2abk | vfi | many | v1 | |
| Bk3 | 80-120 | 7.5YR5/8 | m2abk | fi | many | - | |
| Cr | 120-150 | 7.5YR7/8 | m | vfi | many | - | |
| **44- Vertic Haploxeralfs** | | | | | | | |
| Ap | 0-20 | 10YR4/3 | gr | fr | few | - | Footslope |
| Bw | 20-35 | 10YR4/3 | c3abk | fi | few | - | (Hill) |
| Bt1 | 35-60 | 10YR4/4 | f3abk | vfi±fi | common | few | |
| Bt2 | 60-95 | 7.5YR4/4 | f3abk | fi | common | few | |
| Bk | 95-150 | 10YR5/6 | f2abk | fi | many | - | |
| **48- Calcic Haploxeralfs** | | | | | | | Summit |
| Ap | 0-25 | 7.5YR4/4 | gr | fi | common | - | |
| Bw | 25-40 | 7.5YR5/4 | f1abk | fi | common | v1 | |
| Bk | 40-60 | 7.5YR4/3 | F2abk | vfi | many | v1 | |
| Btk1 | 60-110 | 7.5YR5/4 | m2abk | vfi | many | common | |
| Btk2 | 110-150 | 7.5YR4/4 | m2abk | vfi | many | few | |
| Ap | 0-20 | 2.5Y5/4 | f1gr | fr | many | - | (Hill) |
| BW1 | 20-45 | 10YR5/4 | m2abK | fi | many | - | |
| BW2 | 45-65 | 10YR5/4 | f1abk | fi | common | - | |
| 2 Bkb1 | 65-100 | 2.5Y6/2 | f1abk | fi | many | - | |
| 2 Bkb2 | 100-150 | 2.5Y7/2 | m1abk | fi | many | - | |

**Table 2.** Physicochemical properties of the selected pedons.

| Horizon | Depth | Particle size distribution | | | Textural | pH | OC[b] | CCE[c] | SP[d] | Gypsum | CEC[e] | EC[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (cm) | Sand (%) | Silt (%) | Clay (%) | class[a] | paste | (%) | (%) | (%) | (%) | (cmol $kg^{-1}$) | (ds $m^{-1}$) |
| **1 - Calcic Haploxeralfs** | | | | | | | | | | | | |
| Ap | 0-25 | 18 | 40 | 42 | sic-c | 7.7 | 0.7 | 2.5 | 79 | tr | 27.3 | 0.30 |
| Bw | 25-50 | 19 | 38 | 43 | c | 7.7 | 0.7 | 2.0 | 68 | tr | 26.5 | 0.21 |
| Bt | 50-75 | 11 | 36 | 53 | c | 7.7 | 0.5 | 11.8 | 79 | tr | 21.2 | 0.26 |
| Btk | 75-100 | 12 | 34 | 54 | c | 7.8 | 0.4 | 23.2 | 75 | tr | 20.4 | 0.32 |
| Bk | 100-150 | 17 | 38 | 45 | c | 7.9 | 0.2 | 23.6 | 68 | tr | 22.1 | 0.3 |
| **5 - Typic Haploxerolls** | | | | | | | | | | | | |
| Ap | 0-25 | 17.2 | 37.8 | 45 | c | 7.8 | 1.02 | 35 | 49 | tr | 26.2 | 0.34 |
| Bw | 25-40 | 14.6 | 35.4 | 50 | c | 7.8 | 0.81 | 38.4 | 48 | tr | 22.4 | 0.32 |
| CB | 40-60 | 15.6 | 41.1 | 43 | sic | 8 | 0.41 | 35.5 | 45 | tr | 17.6 | 0.30 |
| Cr1 | 60-95 | 20.6 | 39.4 | 40 | c-cl | 7.8 | 0.34 | 31.4 | 46 | tr | 16.2 | 0.29 |
| Cr2 | 95-150 | 9.6 | 59.4 | 31 | sicl | 8.1 | 0.11 | 55.5 | 44 | tr | 10.6 | 0.24 |
| **18 - Typic Calcixerepts** | | | | | | | | | | | | |
| Ap | 0-20 | 10 | 47 | 43 | sic | 7.6 | 0.5 | 7 | 69 | tr | 31.8 | 0.87 |
| Bw1 | 20-40 | 6 | 48 | 46 | sic | 7.6 | 0.5 | 4.5 | 69 | tr | 30.7 | 0.76 |
| Bw2 | 40-60 | 9 | 43 | 48 | sic | 7.5 | 0.4 | 14.5 | 56 | tr | 28.4 | 0.86 |
| Bk1 | 60-120 | 10 | 47 | 43 | sic | 7.4 | 0.3 | 27.5 | 69 | tr | 26.3 | 0.95 |
| Bk2 | 120-150+ | 11 | 47 | 42 | sic | 7.5 | 0.3 | 36.5 | 66 | tr | 24.5 | 1.53 |
| **29 - Typic Calcixerepts** | | | | | | | | | | | | |
| Ap | 0-20 | 12 | 44 | 44 | sic | 7.5 | 0.7 | 16 | 49 | tr | 29.1 | 0.74 |
| Bk1 | 20-40 | 22 | 40 | 38 | cl | 7.5 | 0.4 | 29 | 48 | tr | 26.7 | 0.64 |
| Bk2 | 40-80 | 24 | 38 | 38 | cl | 7.5 | 0.3 | 32 | 39 | tr | 27.0 | 0.46 |
| Bk3 | 80-120 | 37 | 29 | 34 | cl | 7.6 | 0.3 | 47 | 39 | tr | 20.5 | 0.44 |
| Cr1 | 120-150 | 56 | 21 | 23 | scl | 7.5 | 0.2 | 75 | 51 | tr | 11.0 | 2.10 |
| Cr2 | 95-150 | 9.6 | 59.4 | 31 | sicl | 8.1 | 0.11 | 55.5 | 43 | tr | 10.6 | 0.24 |
| **44 - Vertic Haploxeralfs** | | | | | | | | | | | | |
| Ap | 0-20 | 9 | 49 | 42 | sic | 7.7 | 1.04 | 7.0 | 79 | tr | 33.5 | 0.30 |
| Bw | 20-35 | 11 | 45 | 44 | sic | 7.5 | 0.81 | 6.0 | 67 | tr | 34.8 | 0.21 |
| Bt1 | 35-60 | 19 | 35 | 51 | c | 7.6 | 0.66 | 3.5 | 75 | tr | 26.1 | 0.26 |
| Bt2 | 60-95 | 6 | 40 | 54 | c-sic | 7.7 | 0.59 | 10.0 | 78 | tr | 36.0 | 0.32 |
| Bk | 95-150 | 23 | 37 | 40 | c-cl | 7.5 | 0.27 | 39.0 | 70 | tr | 24.6 | 0.3 |
| **48 - Calcic Haploxeralfs** | | | | | | | | | | | | |
| Ap | 0-25 | 11 | 49 | 40 | sic-sicl | 7.6 | 0.57 | 28 | 68 | tr | 27.8 | 0.57 |
| Bw | 25-40 | 12 | 40 | 48 | c-sic | 7.6 | 0.62 | 28.5 | 70 | tr | 30.3 | 0.47 |
| Bk | 40-60 | 11 | 40 | 49 | c-sic | 7.5 | 0.40 | 32.0 | 79 | tr | 30 | 0.63 |
| Btk1 | 60-110 | 12 | 40 | 48 | c-sic | 7.6 | 0.24 | 41.5 | 75 | tr | 31.7 | 0.66 |
| Btk2 | 110-150 | 17 | 39 | 44 | c | 7.5 | 0.15 | 30.0 | 76 | tr | 28.5 | 0.64 |
| **57 - Typic Calcixerepts** | | | | | | | | | | | | |
| Ap | 0-20 | 11 | 40 | 49 | c-sic | 7.3 | 0.7 | 34 | 76 | tr | 33.6 | 0.84 |
| Bw1 | 20-45 | 13 | 38 | 49 | c | 7.5 | 0.68 | 26.5 | 75 | tr | 30.3 | 0.63 |
| Bw2 | 45-65 | 12 | 48 | 40 | sic-sicl | 7.4 | 0.44 | 14 | 76 | tr | 25.2 | 0.59 |
| 2Bkb1 | 65-100 | 10 | 44 | 46 | sic | 7.5 | 0.3 | 52 | 78 | tr | 22.4 | 0.63 |
| 2Bkb2 | 100-150 | 10 | 42 | 48 | sic | 7.6 | 0.13 | 58 | 73 | tr | 16.1 | 0.55 |

tr = trace.
[a] c = clay, si = silty, l = loam, s = sandy.
[b] OC=Organic Carbon (%).
[c] CCE = Calcium Carbonate Equivalent (%).
[d] SP= Saturation Percentage (%).
[e] CEC = Cation Exchange Capacity.
[f] EC = Electrical Conductivity.