

**Investigation of Alluvial Terrace Soils in the Vicinity of  
First Fort Archaeological Site, Walnut Canyon National Park**

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### **Introduction**

Soil investigations, in conjunction with palynological and alluvial-stratigraphic studies, were conducted on alluvial terraces of Walnut Creek to better understand prehistoric environments and land-use strategies of the Sinaugua occupants of Walnut Canyon. Two main purposes for investigating the alluvial terrace soils near the First Fort site are: 1) soil - geomorphic analysis, and 2) soil fertility. Soil - geomorphic analysis improves our understanding of the relation between observed soil properties and various soil forming factors such as landscape position, age, climate, parent material, and biological factors (Jenny, 1941). This, in turn, helps to interpret soils on the landscape and their potential use for chronologic investigations and stratigraphic correlation. As part of the soil stratigraphic analysis, a relative-age assignment was made using geomorphic position and soil development indices (Harden, 1982). Analysis of soil fertility helps determine the agricultural potential of the soils, which in this case may be used for understanding land-use and prehistoric agricultural conditions. For example, soils analyzed for various nutrient characteristics may aid in determining potential for crop growth and influences on prehistoric inhabitants. This report presents soil - geomorphic and fertility data to aid our understanding of prehistoric land use.

### **Description of the Project Area**

The project area is located in R9E ,T21N NW1/4 Sec. 28 of the USGS Winona 7.5' quadrangle map. Soil investigation were conducted in alluvial deposits of Walnut Creek, where two distinct terraces can be found in a broad meander of Walnut Canyon. From the topographic map, the elevation is estimated to be 1896 m (6220 feet) near the valley bottom and 1951 m (6400 feet) on the canyon rim. Kaibab Formation limestone comprises the bedrock geology of this reach of Walnut Canyon. Alluvial parent material in which soils are developing is dominated by limestone and sandstone, though minor amounts of basalt and cinders are also present. Vegetation along the rim includes ponderosa and pinon pine, juniper, and oak whereas the vegetation on the valley-fill alluvium consists of ponderosa pine, walnut, juniper, rabbitbrush, and various grasses. Soils of the alluvial terraces within the canyon bottom are

classified as Mollisols and Inceptisols, including Cumulic Haplustolls and Pachic Argiustolls; soils on the canyon rim are Alfisols and Inceptisols, including Typic Haplustalfs, Lithic Ustochrepts, and Calcic Ustochrepts; and soils on the canyon side-slopes are Mollisols and Inceptisols, including Lithic Calciustolls, Lithic Ustochrepts, and Calcic Ustochrepts (Miller et al., 1992). No attempt was made to reclassify the soils.

### Methods

Two alluvial terraces occur in the First Fort reach of Walnut Creek; a younger terrace designated Ty, and an older terrace, To. Locations for the soil investigations were chosen to best represent the natural undisturbed soils away from roads, railroad beds, and prehistoric occupation sites. Soil descriptions were completed for 7 soil profiles, five of which were from hand dug pits excavated into the terrace deposits, and two from hand excavated trenches into the exposed terrace edges. The following discussion relates to Ty soils, Profiles 1 (Figure 1) and 5, and To soils, Profiles 2 (Figure 2), 3, and 4 (Figure 3). Soils were described using specifications of the Soil Survey Manual (1993) and Birkeland (1999). For references to soil science terms, see SSSA (1996). Profile development indices for the assignment of relative ages were determined for the described soils using Harden (1982) and Birkeland (1999).

Samples were collected from 44 soil horizons, with 14 horizons being tested for the following laboratory analyses. Particle-size analysis (PSA) was conducted using a Coulter laser particle size analyzer at the Quaternary Soil and Sediment Laboratory, Bilby Research Center, Northern Arizona University. Soils were pretreated to remove binding agents such as organic matter, calcium carbonate, and salts. Other analysis described below were conducted by Laboratory Consultants, Ltd. Tempe, Arizona. Organic matter (OM) was determined using the Walkley-Black Method (Nelson, 1982). Percent calcium carbonate was measured by the titration method (Soil Survey Laboratory, 1996). Exchangeable cations of potassium ( $K^+$ ), sodium ( $Na^+$ ), magnesium ( $Mg^{2+}$ ), and calcium ( $Ca^{2+}$ ) were pretreated using ammonium acetate extractant and analyzed by atomic absorption. The pH of the soil was determined using a 1:1 soil:water paste and electrical conductivity was determined using a conductivity meter (Rhoades, 1982: procedure 10-3.3). Phosphorous (P) was measured by the bicarbonate extraction method (Olsen and Sommers, 1982: procedure 24-5.4) and nitrate nitrogen was measured using an ion specific electrode (Keeney and Nelson, 1982: procedure 33-6.1).



Figure 1. Photograph of Profile 1 soil stratigraphy. Note knife for scale approximately 7 cm in view. Also note gravel throughout the profile. Photograph is from an oblique angle, hence apparent dip to soil horizons.

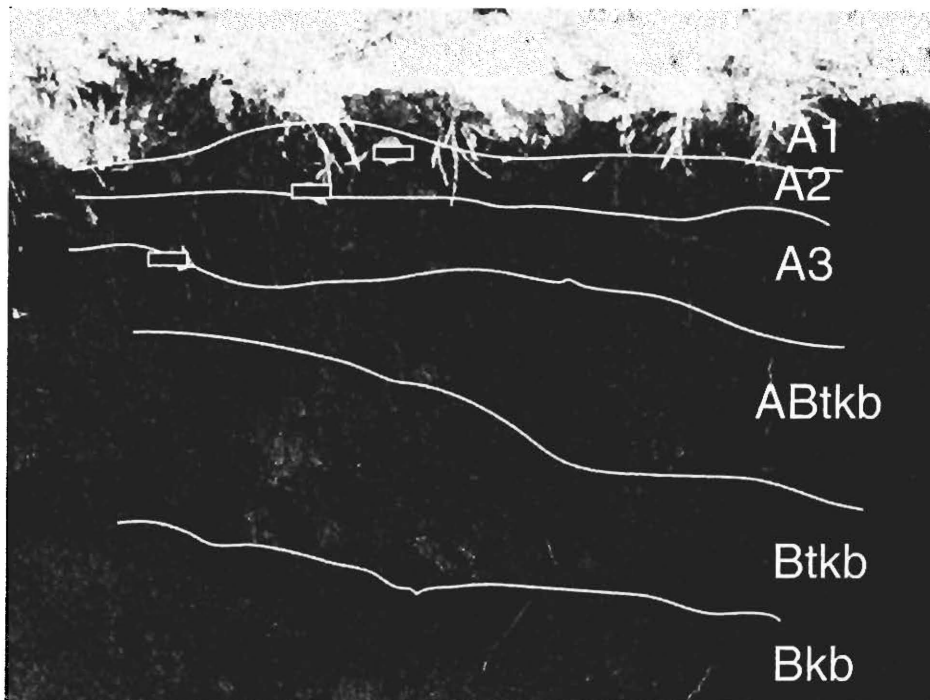


Figure 2. Photograph of Profile 2 soil stratigraphy. Rectangles are horizontally oriented sherds, the lower two of which are found along horizon boundaries.

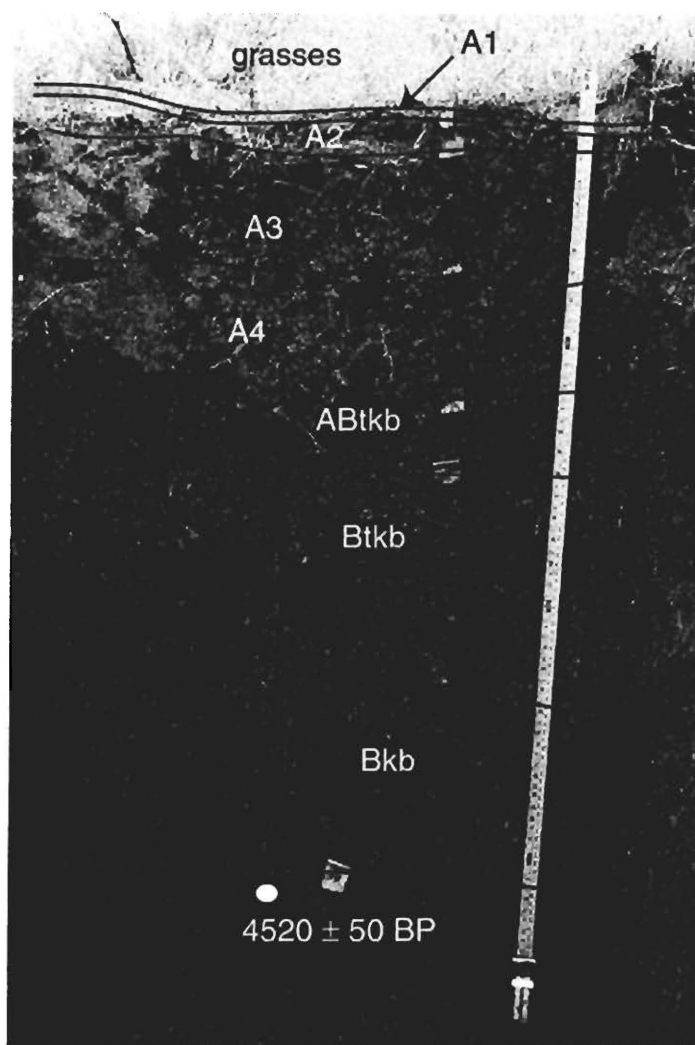


Figure 3. Photograph of Profile 4 soil stratigraphy. Uncalibrated radiocarbon age of  $4520 \pm 50$  BP from 88 cm depth.

## Results And Discussion

Results of soil descriptions, particle-size determination and percent  $\text{CaCO}_3$ , soil development indices, radiocarbon age-estimates, and soil nutrient analysis are presented below, along with a discussion of their importance.

### *Soil Descriptions*

Soil descriptions indicate that the two general ages of the alluvial terraces, older (To) and younger (Ty), contain soils that represent very different degrees of soil development (Table 1). Soil A horizons on the younger terraces (Profiles 1 and 5) have consistently darker Munsell colors of 10YR 3/3 (dark brown) compared to lighter colors of the To soils varying from 10YR 4/3 (dark brown) to 10YR 5/3 (brown) to 10YR 5/4 (yellowish brown). The darker colors may indicate more organic matter (OM) in the younger terrace A horizons, as they are nearer the water table and have abundant grasses, suggesting that the A horizons form fairly rapidly in this environment. Older terrace soils have a higher concentration of limestone and sandstone parent material, and perhaps a lower OM concentration. Soils on the younger terraces have weaker soil structure and less pronounced soil consistence.

Based on field observations and soil descriptions, the soil morphology indicated that a complex soil profile existed for Profiles 2 and 4, and that these profiles were similar in many aspects. As can be seen from the horizon designations of Profiles 2 (Figure 2) and Profile 4 (Figure 3) a buried A horizon was assigned to layers at 30-55 cm in Profile 2, and 35-43 cm in Profile 4. In addition, by designating the profiles ABtkb, it was believed that these layers have characteristics of both A and B horizons resulting from the burial of the A horizon and subsequent alteration by pedogenic processes. Briefly, morphologic characteristics suggested that the buried A horizon became slightly enriched in translocated clay, noted by clay films in pores and along ped faces. Also, ped faces are coated with  $\text{CaCO}_3$ , indicating that pedogenic  $\text{CaCO}_3$  precipitated within the zone of the now buried A horizon. Therefore, it appears that these soils represent a vertically growing soil with pedogenic B characteristics progressively moving "upwards", engulfing the buried A horizon. This interpretation is not inconsistent with the designation of a cumulic soil profile (Miller et al., 1992). This interpretation, however, is not supported by laboratory data (see below).

Table 1. Soil Field Descriptions for Soil Pits 1-5, First Fort, Walnut Canyon N.P.

| Horizon   | Depth<br>(cm) | Color     |           | Texture<br>( $<2\text{mm}$ ) | gravel<br>% | Structure          | Consistence |       |       | Cutans    | CaCO <sub>3</sub> |                                         |       | Pores     | Roots             | Bdry | Mottles   |
|-----------|---------------|-----------|-----------|------------------------------|-------------|--------------------|-------------|-------|-------|-----------|-------------------|-----------------------------------------|-------|-----------|-------------------|------|-----------|
|           |               | dry       | moist     |                              |             |                    | dry         | moist | wet   |           | Rxn               | Morph                                   | Stage |           |                   |      |           |
| Profile 1 |               |           |           |                              |             |                    |             |       |       |           |                   |                                         |       |           |                   |      |           |
| A1        | 0-3           | 10YR 3/3  | 10YR 2/2  | sl                           | $<1$        | 2,m,pl-<br>3,f,cr  | so          | vfr   | ss,sp | -         | -                 | -                                       | -     | 2,f,i     | m,f,ip            | as   | -         |
| A2        | 3-11          | 10YR 3/3  | 10YR 2/2  | scl                          | $<5$        | 3,f,cr             | sh          | fr    | ss,sp | -         | -                 | -                                       | -     | 2,f,i     | m,f,ip-pf         | as   | -         |
| A3        | 11-44         | -         | 10YR 2/2  | scl                          | $<5$        | 2,m,sbk            | sh          | fr    | s,sp  | -         | -                 | -                                       | -     | 1,vf-m,i  | m,f,ip            | cs   | -         |
| AC        | 44-67         | -         | 10YR 2/2  | scl                          | $<1$        | 2,m,sbk            | sh          | fi    | s,p   | -         | -                 | -                                       | -     | 1,vf-m,i  | m,f,ip            | cs   | 7.5YR 3/2 |
| CA        | 67-85+        | -         | 10YR 2/2  | sicl                         | 50          | 2,m,sbk            | sh-h        | vfi   | s,p   | f,f,po    | ve                | 1,f-m,<br>fil-cb                        | -     | 1,vf-m,i  | -                 | -    | 7.5YR 3/4 |
| Profile 2 |               |           |           |                              |             |                    |             |       |       |           |                   |                                         |       |           |                   |      |           |
| A1        | 0-2           | 10YR 4/3  | 10YR 3/3  | sil                          | -           | 3,f,pl             | so          | vfr   | ss,sp | -         | ev                | -                                       | -     | 2,vf,ipf  | f,f, inped,pf     | as   |           |
| A2        | 2-19          | 10YR 4/3  | 10YR 3/3  | scl                          | -           | 2,m,abk-<br>2,m,cr | so          | vfr   | vs,p  | -         | ve                | -                                       | -     | 2,vf,ipf  | f,f, inped,pf     | cs   |           |
| A3        | 19-30         | 10YR 3/3  | 10YR 3/2  | sc                           | -           | 3,m,abk-<br>pr     | so          | fr    | vs,vp | -         | ve                | -                                       | -     | 2,vf,ipf  | f,f, inped,pf     | cs   |           |
| ABtkb     | 30-55         | 10YR 4/3  | 10YR 3/3  | sc                           | -           | 3,m,abk-<br>pr     | sh          | fi    | vs,vp | vf,f-d,po | ev-ve             | 3,f,fil-ip                              | I-I+  | 2,vf,ipf  | vf,f,pf           | cs   |           |
| Btkb      | 55-90         | 10YR 4/3  | 10YR 3/3  | sc                           | -           | 3,m,abk            | h           | fi    | vs,vp | f,d,po    | ev-ve             | 3,f-c,fil<br>3,m,pf<br>3,f-m,ir,<br>nod | II    | 2,vf,ipf  | vf,f,pf,<br>inped | cs   |           |
| Bkb       | 90-100+       | 10YR 4/3  | 10YR 3/4  | sc                           | -           | 2,m,abk            | sh          | fr    | vs,p  | -         | es-ev             | 3,f,fil                                 | I+    | 2,vf,ipf  |                   | -    |           |
| Profile 3 |               |           |           |                              |             |                    |             |       |       |           |                   |                                         |       |           |                   |      |           |
| A1        | 0-2           | 10YR 4/3  | 10YR 2/2  | scl                          | -           | 2,f,pl             | so          | vfr   | ss,sp | -         | e                 | -                                       | -     | f,f,inped | f,f-m,<br>inped   | as   |           |
| A2        | 2-10          | 10YR 4/3  | 10YR 2/2  | scl                          | -           | 2,m.abk            | sh          | vfr   | s,sp  | -         | -                 | -                                       | -     | f,f,inped | f,f-m,<br>inped   | cs   |           |
| A3        | 10-40         | 10YR 4/3  | 10YR 2/2  | sc                           | -           | 2,m.abk            | sh-h        | fi    | s,p   | -         | -                 | -                                       | -     | f,f,inped | f,f-m,<br>inped   | cs   |           |
| Bw1       | 40-62         | 8.5YR 4/4 | 10YR 3/3  | scl                          | -           | 3,m.abk            | sh          | vfr   | ss,sp | -         | -                 | -                                       | -     | f,f,inped | f,f-m,<br>inped   | cs   |           |
| Bw2       | 62-78         | 8.5YR 4/4 | 10YR 3/3  | scl                          | -           | 3,m.abk            | sh          | fr    | ss,sp | -         | -                 | -                                       | -     | f,f,inped | f,f-m,<br>inped   | cs   |           |
| Bk        | 78-95+        | 10YR 4/4  | 7.5YR 3/4 | scl                          | -           | 2,m.abk            | so          | vfr   | ss,sp | -         | e-es              | 1,f,fil                                 | I-    | f,f,inped | f,f-m,<br>inped   | -    |           |

Table 1 (cont'd). Soil Field Descriptions for Soil Pits 1-5, First Fort, Walnut Canyon N.P.

| Horizon                                                                                                               | Depth<br>(cm) | Color                 |          | Texture<br>( $<2\text{mm}$ ) | gravel<br>% | Structure             | Consistence |       |       | Cutans              | CaCO <sub>3</sub> |                      |       | Pores           | Roots        | Bdry | Mottles             |
|-----------------------------------------------------------------------------------------------------------------------|---------------|-----------------------|----------|------------------------------|-------------|-----------------------|-------------|-------|-------|---------------------|-------------------|----------------------|-------|-----------------|--------------|------|---------------------|
|                                                                                                                       |               | dry                   | moist    |                              |             |                       | dry         | moist | wet   |                     | Rxn               | Morph                | Stage |                 |              |      |                     |
| Profile 4                                                                                                             |               |                       |          |                              |             |                       |             |       |       |                     |                   |                      |       |                 |              |      |                     |
| A1                                                                                                                    | 0-2           | 10YR 5/3              | 10YR 3/3 | cl                           | -           | 3,vf,pl               | so          | vfr   | vx,p  | -                   | ev                | -                    | -     | 2,vf,<br>l,pf   | m,f,inped,pf | cs   |                     |
| A2                                                                                                                    | 2-5           | 10YR 5/4              | 10YR 3/3 | cl                           | -           | 2,f-m,<br>cr-sbk      | so          | vfr   | vx,p  | -                   | vo                | -                    | -     | 2,vf,<br>l,pf   | m,f,inped,pf | cs   |                     |
| A3                                                                                                                    | 5-19          | 10YR 5/4              | 10YR 3/3 | sicl                         | -           | 3,vc,cr-<br>3,m.abk   | sh          | vfr   | vx,p  | -                   | ve                | -                    | -     | 2,v-mf,<br>i,pf | m,f,inped,pf | cs   |                     |
| A4                                                                                                                    | 19-35         | 10YR 5/3              | 10YR 3/4 | sicl                         | -           | 3,vc,cr-<br>3,m-c,abk | sh          | vfr   | vx,p  | -                   | e                 | -                    | -     | 2,m,<br>i,t,pf  | m,f,inped,pf | as   |                     |
| ABtkb                                                                                                                 | 35-43         | 10YR 4/2              | 10YR 3/2 | sic                          | -           | 3,m,cr-<br>3,f.abk    | sh-h        | vfr   | vs,vp | vf,d,po             | e-es              | dis,pf               | I-    | 3,f-c,t,pf      | m,f,inped,pf | cs   |                     |
| Btkb                                                                                                                  | 43-68         | 10YR 4/2              | 10YR 3/2 | sic                          | -           | 3,m,cr-<br>3,m.pr     | h           | vfr   | vs,vp | vf,f,po-<br>vf,f,pf | ev                | 3,m,fil-<br>f,p,pf   | I-I+  | 3,f-c,t,pf      | m,f,inped,pf | cs   |                     |
| Bkb                                                                                                                   | 68-94         | 10YR 4/3              | 10YR 3/3 | sic                          | -           | 3,m.pr                | h-vh        | fi    | vs,vp | vf,f,po-<br>vf,f,pf | ev                | 3,m-c,fil-<br>m,p,pf | I+-II | 3,f-c,t,pf      | m,f,inped,pf | as   | 4520<br>±50BP       |
| BCb                                                                                                                   | 94-105        | -                     | 10YR 3/4 | sicl                         | -           | 1-2,m.abk             | so          | vfr   | vs,vp | vf,f,po             | es                | 1,f.fil              | I-    | 3,f,t           | m,f,inped,pf | -    |                     |
| Profile 5                                                                                                             |               |                       |          |                              |             |                       |             |       |       |                     |                   |                      |       |                 |              |      |                     |
| A1                                                                                                                    | 0-4           | 10YR 4/3              | 10YR 2/2 | ls-s                         | 10          | 1,f,cr                | so          | vfr   | ss,po | -                   | -                 | -                    | -     | 1,f,ip,t        | 2,f,ip       | aw   | ceramic at<br>17 cm |
| A2                                                                                                                    | 4-33          | 10YR 4/3              | 10YR 2/2 | ls                           | 2           | 2,m,cr-<br>2,f.abk    | so          | vfr   | so,po | -                   | -                 | -                    | -     | 1,f,t           | 2,f-m,ip     | as   |                     |
| A3                                                                                                                    | 33-82         | 10YR 4/2-<br>10YR 4/3 | 10YR 2/2 | ls                           | 10          | 1,m.abk               | so          | vfr   | so,po | -                   | -                 | -                    | -     | -               | -            | cs   |                     |
| Bwj                                                                                                                   | 82-115+       | 10YR 4/3              | 7.5YR3/2 | sl                           | 25          | 2,m.abk               | sh          | fr    | ss,po | f,f,co              | -                 | -                    | -     | -               | -            | -    |                     |
| For a discussion of soil descriptions, nomenclature, and abbreviations, see USDA (1974) and Soil Survey Staff (1993). |               |                       |          |                              |             |                       |             |       |       |                     |                   |                      |       |                 |              |      |                     |

For a discussion of soil descriptions, nomenclature, and abbreviations, see USDA (1974) and Soil Survey Staff (1993).

### *Pedogenic Clay and Calcium Carbonate*

In general, pedogenic clay increases with increasing age of the soil (Birkeland, 1999). Soils on To (Profiles 2, 3, and 4) show evidence of clay translocation with clay films on ped faces and coating pores. The younger soils of Profiles 1 and 5 have minimal evidence of clay movement. Although clay translocation is apparent in the morphology of the clay films, the laboratory data for particle-size distribution does not indicate an increase in clay for the B horizons. Particle-size distributions indicate a generally consistent content of sand, silt, and clay components with depth. Clay percents indicate 10% clay or less for both Soil Profiles 2 and 4, the only profiles for which particle-size data are available (Table 2).

In general, amounts of pedogenic calcium carbonate accumulation increase with increasing age of the soil (Birkeland, 1999). Based on soil morphologic properties, the Ty soils have very little accumulation of pedogenic calcium carbonate whereas the older terrace soils show abundant accumulation of calcium carbonate, with stages of development ranging from very weak (stage I<sup>-</sup>) to moderately developed (stage II<sup>+</sup>). Laboratory data for Profile 4, the only profile for which data is available, indicate that there is generally less than 10% CaCO<sub>3</sub> in the A horizons, and greater than 10% in the lower horizons (Table 3; Figure 4). This increase is evidenced in the soil morphology by CaCO<sub>3</sub> coating peds in the B horizons. The amount of CaCO<sub>3</sub> in the original parent material and that redistributed in the profile, may inhibit clay translocation (see above). CaCO<sub>3</sub> causes clays to flocculate, thereby decreasing the ability of clay to be translocated which, in turn, inhibits argillic horizon formation.

### *Profile Development Indices*

Comparisons of the physical properties of soils with the physical properties of the assumed parent material is the basis for profile development indices (PDI) (Table 1, Figure 5, Appendix A). Results provide an index of relative age between the four soil pits where PDI's were calculated. For details of PDI calculations, see Harden (1982). Older soils of the project area have higher PDI values. Profiles 2 and 4 have PDI's of 27 and 33, respectively whereas Profile 1 has a PDI value of 15. These trends are expected, although a PDI of 15 seems a bit high for soils that may be only 1000 years old or younger (no ages were determined for the younger terrace soils). Interestingly Profile 3 has a PDI value of only 17, much closer to the 15 value for Profile 1. Similar PDI's for soils of clearly very different ages may be due to several reasons, three of

Table 2. Particle-size distribution for Soil Pits 2 and 4.

| Horizon          | Depth  | %Clay         | % Silt (mm) |            |           | % Sand (mm) |           |          |        |             | Total |      |      |
|------------------|--------|---------------|-------------|------------|-----------|-------------|-----------|----------|--------|-------------|-------|------|------|
|                  |        |               | fine        | medium     | coarse    | very fine   | fine      | medium   | coarse | very coarse | Sand  | Silt | Clay |
| <b>Profile 2</b> | cm     | (< 2 $\mu$ m) | (.002-.005) | (.005-.02) | (.02-.05) | (.05-.1)    | (.10-.25) | (.25-.5) | (.5-1) | (1-2)       |       |      |      |
| A1               | 0-2    | 9.3           | 11.4        | 16.9       | 12.6      | 23.7        | 22.7      | 1.9      | 1.4    | 0           | 50    | 41   | 9    |
| A2               | 2-19   | 6.8           | 10.1        | 18.9       | 12.3      | 23.3        | 26.2      | 1.8      | 0.6    | 0           | 52    | 41   | 7    |
| A3               | 19-30  | 5.5           | 7.7         | 18.2       | 17.9      | 25.1        | 24.0      | 1.1      | 0.6    | 0           | 51    | 44   | 5    |
| ABtkb            | 30-55  | 6.5           | 9.0         | 19.3       | 15.2      | 23.4        | 24.4      | 1.5      | 0.7    | 0           | 50    | 43   | 7    |
| Btkb             | 55-90  | 5.7           | 8.0         | 18.7       | 13.7      | 24.2        | 26.8      | 2.2      | 0.7    | 0           | 54    | 40   | 6    |
| Bkb              | 90-100 | 5.6           | 7.8         | 17.1       | 12.0      | 25.2        | 29.5      | 2.1      | 0.7    | 0           | 58    | 37   | 6    |
| <b>Profile 4</b> |        |               |             |            |           |             |           |          |        |             |       |      |      |
| A1               | 0-2    | 10.0          | 13.3        | 20.6       | 15.7      | 19.0        | 14.5      | 3.7      | 3.0    | 0           | 40    | 50   | 10   |
| A2               | 2-5    | 9.5           | 12.4        | 18.1       | 15.5      | 22.3        | 16.8      | 3.5      | 1.9    | 0           | 45    | 46   | 9    |
| A3               | 5-19   | 9.0           | 12.6        | 20.1       | 15.0      | 19.4        | 17.5      | 3.8      | 2.4    | 0           | 43    | 48   | 9    |
| A4               | 19-35  | 9.0           | 12.4        | 22.2       | 17.0      | 19.5        | 15.2      | 3.0      | 1.7    | 0           | 39    | 52   | 9    |
| ABtkb            | 35-43  | 6.9           | 9.6         | 23.2       | 25.1      | 22.0        | 12.6      | 0.4      | 0.2    | 0           | 35    | 58   | 7    |
| Btkb             | 43-68  | 6.8           | 10.4        | 28.3       | 22.5      | 19.7        | 12.2      | 0.1      | 0.0    | 0           | 32    | 61   | 7    |
| Bkb              | 68-64  | 8.0           | 12.5        | 30.0       | 18.4      | 16.8        | 14.2      | 0.1      | 0.0    | 0           | 31    | 61   | 8    |
| BCb              | 94-105 | 7.3           | 11.2        | 29.8       | 20.3      | 19.4        | 11.9      | 0.1      | 0.0    | 0           | 31    | 61   | 7    |

Table 3. Percent calcium carbonate for Profile 4.

| Horizon | Depth (cm) | %CaCO <sub>3</sub> |
|---------|------------|--------------------|
| A1      | 0-2        | 1.5                |
| A2      | 2-5        | 6.7                |
| A3      | 5-19       | 7.2                |
| A4      | 19-35      | 8.5                |
| ABtkb   | 35-43      | 4.1                |
| Btkb    | 43-68      | 12.4               |
| Bkb     | 68-64      | 13.6               |
| BCb     | 94-105     | 10.6               |

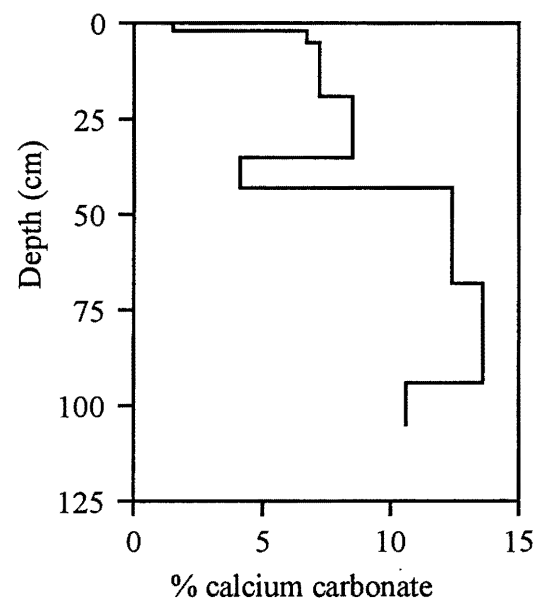


Figure 4. Percent calcium carbonate for Profile 4.

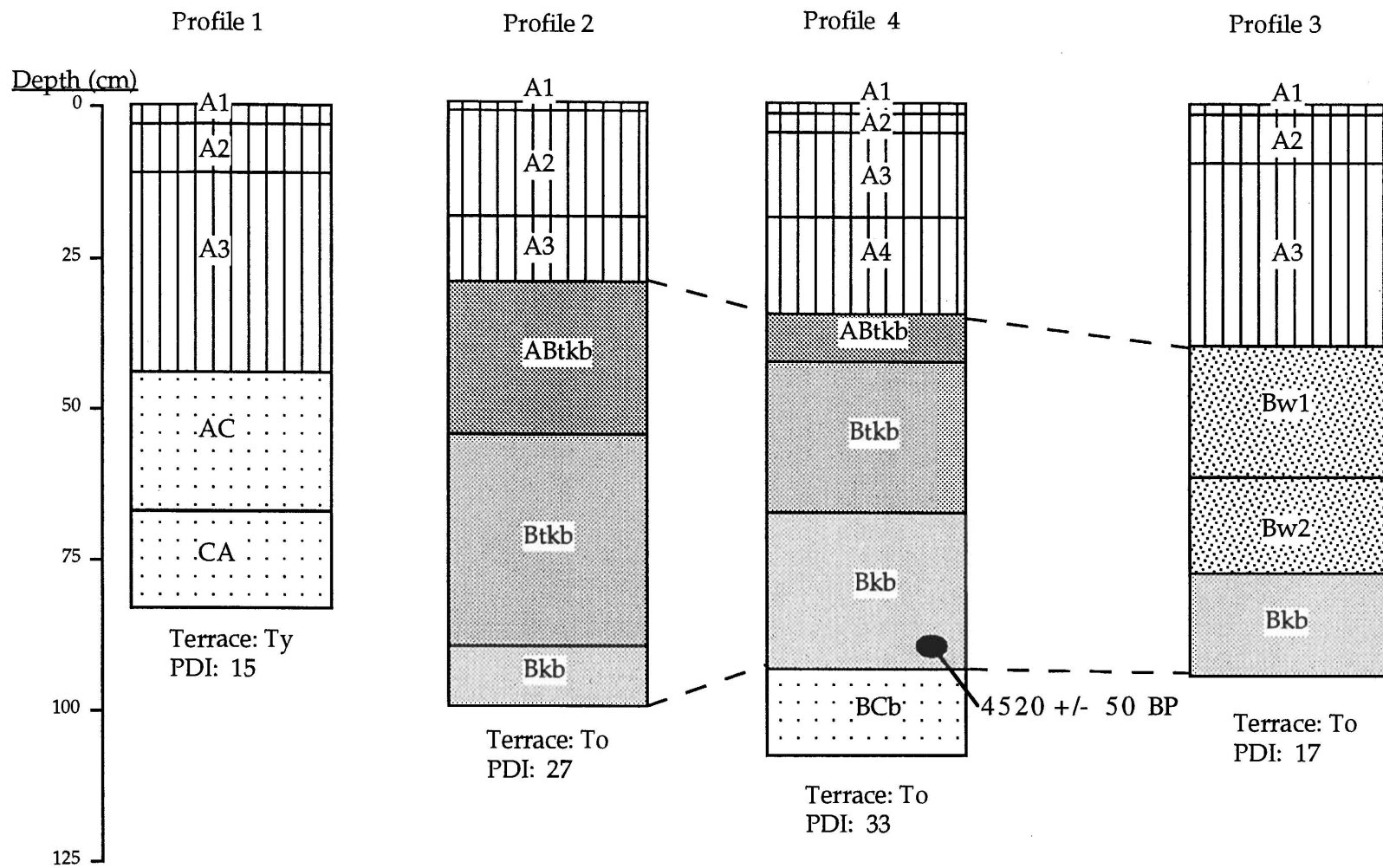


Figure 5. Soil-stratigraphic relations of Profiles 1-4, with associated PDI values.  
See text for details.

which are described below. First, it appears that Profile 1, the Ty soil, consists of material redeposited from an older source. Clasts surfaces are reddened with Fe-coatings, and  $\text{CaCO}_3$  coatings also cover tops and sides of the clasts. This redeposited material may provide the soil with apparently higher degrees of development. Secondly, as stated above, the parent material for the soils is different, the To soils forming in fine-grained alluvium from Paleozoic sedimentary rocks, and the Ty soils forming in coarser textured material derived from Paleozoic rocks, basaltic rocks, and possibly redeposited soils. Finally, Profile 3 appears to be much less well developed than the other two To soils described (Profile 2 and 4), which may indicate that either there is a younger component of the older terrace (the cut-bank exposure is covered with slumped material, making it difficult to discern cut and fill channels), or that this portion of the terrace to the hillslope may have partially derived the parent material from colluvial sources.

#### *Chemical Properties and Soil Nutrient Status*

Interpretation of the nutrient status of the soils is based on several measured variables, including pH, electrical conductivity (EC), percent organic matter, nitrogen, phosphorous, and the exchangeable cations  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and  $\text{Ca}^{2+}$  (Table 4). Although sodium is not considered an essential nutrient, its concentration and activity has an influence on the availability of other nutrients, as well as the soil structure and infiltration capacity, particularly in higher concentrations. Calculations of other variables presented in Table 4 were made using the above measured values, and they include: percent organic carbon, C:N ratios, the sum of the bases, exchangeable sodium percent (ESP), and Ca:Mg ratio. Data is presented in percent (parts per hundred) for organic constituents and parts per million (mg/kg) for N, P, and  $\text{NO}_3\text{-N}$ . Data for exchangeable bases was converted from mg/kg to milliequivalents/100g of soil (meq/100g), which is equal to SI units of centimole charges/gram (c mole<sub>e</sub>). These conversions provide a clearer indication of the cation activity in the context of exchange sites, rather than simply concentrations within the soil solution. In addition, these conversions provide the necessary units for calculating the sum of the bases, ESP, and Ca:Mg ratios.

The pH of the soils tested range from a low of 6.6 for the upper 2 cm of Profile 4 to a high of 7.7 in the Btkb of Profile 4. This range extends from slightly acidic to slightly alkaline, which is considered a healthy range for most soils. Soil pH values in this range allow for most of the

Table 4. Soil Nutrient Data for Soil Pits 2 and 4\*.

| Horizon | Depth  | pH  | EC    | Organic |     | Nitrate- |    | P  | C:N | Exchangeable cations |     |      |     | Sum of |     |       |
|---------|--------|-----|-------|---------|-----|----------|----|----|-----|----------------------|-----|------|-----|--------|-----|-------|
|         |        |     |       | OM      | C   | N        | N  |    |     | K                    | Mg  | Ca   | Na  | Bases  | ESP | Ca:Mg |
|         | (cm)   |     | dS/cm | %       | %   | mg/kg    |    |    |     | meq/100g             |     |      |     |        |     |       |
| A1      | 0-2    | 7   | 0.6   | 3.6     | 2.1 | 238      | 14 | 21 | 88  | 1.1                  | 4.8 | 11.7 | 0.3 | 17.8   | 1.5 | 2.5   |
| A2      | 2-19   | 7.2 | 0.5   | 1.8     | 1.0 | 141      | 13 | 28 | 74  | 0.9                  | 4.1 | 12.2 | 0.1 | 17.3   | 0.6 | 3.0   |
| A3      | 19-30  | 7.2 | 0.7   | 1.8     | 1.0 | 137      | 12 | 22 | 76  | 0.8                  | 4.0 | 12.2 | 0.1 | 17.0   | 0.5 | 3.1   |
| ABtkb   | 30-55  | 7.4 | 0.6   | 1.5     | 0.9 | 122      | 12 | 15 | 71  | 0.6                  | 3.8 | 15.8 | 0.1 | 20.4   | 0.6 | 4.2   |
| Btkb    | 55-90  | 7   | 1.4   | 2.3     | 1.3 | 167      | 13 | 14 | 80  | 0.5                  | 4.7 | 18.0 | 0.1 | 23.4   | 0.5 | 3.8   |
| Bkb     | 90-100 | 7.6 | 0.6   | 2.6     | 1.5 | 179      | 12 | 14 | 84  | 0.4                  | 5.8 | 16.8 | 0.1 | 23.2   | 0.6 | 2.9   |
|         |        |     |       |         |     |          |    |    |     |                      |     |      |     |        |     |       |
| A1      | 0-2    | 6.6 | 3.4   | 3.7     | 2.1 | 276      | 23 | 31 | 78  | 1.9                  | 6.2 | 13.8 | 0.2 | 22.0   | 0.7 | 2.2   |
| A2      | 2-5    | 7.2 | 0.7   | 3.3     | 1.9 | 248      | 21 | 25 | 77  | 1.9                  | 6.0 | 13.3 | 0.1 | 21.2   | 0.5 | 2.2   |
| A3      | 5-19   | 7.4 | 0.7   | 2.6     | 1.5 | 183      | 13 | 23 | 82  | 1.8                  | 5.0 | 17.8 | 0.1 | 24.8   | 0.5 | 3.6   |
| A4      | 19-35  | 7.5 | 0.7   | 2.7     | 1.6 | 188      | 13 | 17 | 83  | 1.8                  | 4.8 | 19.2 | 0.2 | 26.1   | 0.7 | 4.0   |
| Abtkb   | 35-43  | 7.6 | 0.8   | 2.6     | 1.5 | 175      | 11 | 18 | 86  | 2.0                  | 6.1 | 19.5 | 0.1 | 27.7   | 0.5 | 3.2   |
| Btkb    | 43-68  | 7.7 | 0.7   | 2.7     | 1.6 | 184      | 12 | 18 | 85  | 1.4                  | 6.0 | 21.2 | 0.2 | 28.8   | 0.8 | 3.5   |
| Bkb     | 68-64  | 7.7 | 0.6   | 2.4     | 1.4 | 172      | 13 | 16 | 81  | 0.8                  | 7.0 | 20.6 | 0.3 | 28.7   | 0.9 | 3.0   |
| BCb     | 94-105 | 7.2 | 1.8   | 2.7     | 1.6 | 181      | 11 | 15 | 87  | 0.5                  | 8.3 | 19.4 | 0.3 | 28.5   | 1.1 | 2.3   |

\* EC is electrical conductivity; OM is organic matter; Organic carbon calculated by - %OM/1.724 (Birkeland 1999); ESP is the exchangeable sodium percentage.  
1meq/100g = 1 cmole/kg

essential nutrients to be available, and restricts the abundance of more acidic and potentially toxic concentrations of some elements, such as H, Al, and Fe. At pH values of 7.7 micronutrient availability may be hindered, although no micronutrient data have been obtained for these soils. Electrical conductivity is an indication of the salinity of the soil. Values greater than about 4 dS/cm are considered saline. All measured values are below 4 dS/cm for the soils analyzed. The amount of organic matter and the calculated organic carbon percent seems very low in these soils when considering the dark color and abundant vegetation on the surface, including numerous grasses. Nitrogen and nitrate nitrogen appear to be abundant, but the high C:N ration suggests that there is a rather slow decay of organic matter to form nitrogen, which may be a limiting factor, depending on vegetation requirements. When pH values are high, and  $\text{CaCO}_3$  is abundant, the P concentrations may be in non-available forms. However, the measure P values (bicarbonate P) indicate that P is not a limiting factor in these soils.

The exchangeable cations are present in sufficient quantities, and their relative amounts are in the normal order of  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$ . The concentrations presented in Table 4, and the sum of the bases indicate that these important nutrient cations are in sufficiently available amounts for good soil fertility. The low ESP values indicate that Na is not in high enough concentrations to cause negative impacts on the soil fertility or soil structure. The Ca:Mg ratios are within the proper limits of fertile soils.

## Conclusions

### *Soil Fertility and Prehistoric Agricultural Considerations*

- (1) The soil physical properties indicate no limiting factors regarding agricultural potential.

There is good soil structure for water infiltration and soil aeration; loamy soil textures (sandy loam, loam, and silt loam) indicate good soil tilth and workability. The soils are not rocky. There are no “soil hardpans” to restrict root growth or to impede water infiltration. The carbonate morphology and slightly higher EC values in the upper A horizons indicates generally dry soil conditions.

- (2) The analyzed chemical properties indicate no limiting factors regarding agricultural potential.

Eleven chemical attributes were measured including pH, nitrate-nitrogen, total nitrogen (N), phosphorous (P), potassium ( $\text{K}^+$ ), magnesium ( $\text{Mg}^{2+}$ ), calcium ( $\text{Ca}^{2+}$ ), sodium ( $\text{Na}^+$ ),

exchangeable sodium percentage (ESP), electrical conductivity (EC), and percent organic matter. Attributes that provide information on salinity and alkalinity (Na, ESP, and EC) all indicate well-drained soils with no excessive build-up of harmful salts or sodium. Concentrations of N, P, K, Mg, and Ca all indicate sufficient availability for good agricultural potential. Soil pH indicates slightly alkaline conditions (pH between 7 and 8), suggesting no restrictions on nutrient availability or toxicity. Soil organic matter and surface plant litter is sufficient to suggest good organic matter turnover and availability to supply nutrients back to the soil.

#### *Soils geomorphology and age estimates*

- (3) An uncalibrated AMS radiocarbon age of  $4520 \pm 50$  BP was obtained at 88 cm depth from soil pit 4, within the Bkb horizon. This age indicates that the uppermost layers of the older terrace date to about 4500 years ago.
- (4) The carbonate morphology of these older terrace soils also suggests that the soils may be several thousand years old. Stage II<sup>+</sup> morphology in the lower horizons is evidence of a rather long period of carbonate accumulation. Stage II<sup>+</sup> carbonate morphology is characterized by calcium carbonate accumulation manifested as white filaments, nodules, and ped and clast coatings. The amount of carbonate for horizons in soil pit 4 ranges from about 10 to 15%, which is the proper range for Stage II<sup>+</sup> carbonate morphology.
- (5) Field descriptions of the soils suggested the possibility of buried soil horizons nearer the surface, which might indicate processes of accretion after 4500 BP, perhaps by main channel or hillslope activity. This interpretation is supported by the position of flat-lying sherds in soil pit 2 at depths of 9, 14, and 28 cm. In soil pit 4, a similar profile exists with several A horizons over a darker, more clay-rich buried soils. However, the presence of numerous bioturbation casts within the upper horizons suggests intense mixing and may account for the location of the buried sherds at various depths. In addition, the interpretation of a buried soil is not supported by laboratory data, e.g. there is not an increase in OM or a change in the nutrient properties of the buried layers. That is, although A1-A2-A3-A4 soil horizons were

described above a possibly buried ABtkb horizon, there is no laboratory evidence to support this hypothesis.

In conclusion, the soils analyzed are old enough to have been farmed during occupation of the First Fort area. The soils have excellent physical and chemical properties that apparently present no limiting factors to prehistoric agriculture. Other limiting factors such as temperature, numbers of frost-free days, water availability, and micronutrient availability were not evaluated as part of this project. The number of frost-free days and the sporadic and unpredictable rainfall patterns during the growing season may have been problematic to prehistoric farmers.

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Appendix A. Calculations used to determine profile development indices.

**Profile 1**

| <u>horizon</u> | <u>text</u> | <u>plas</u> | <u>stick</u> | <u>tot.text</u> | <u>chr. (m)</u> | <u>chr. (d)</u> | <u>hue (m)</u> | <u>hue (d)</u> | <u>tot.rub.</u> | <u>val. (m)</u> | <u>val. (d)</u> | <u>tot.val.</u> | <u>cons. d</u> | <u>tot. cons. d</u> | <u>cons. m</u> | <u>tot. cons. m</u> | <u>str.</u> |
|----------------|-------------|-------------|--------------|-----------------|-----------------|-----------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|----------------|---------------------|----------------|---------------------|-------------|
| A1             | 0           | 0           | 0            | 0.00            | 0               | 0               | 0              | 0              | 0.00            | 0               | 0               | 0.00            | 10             | 0.1                 | 10             | 0.1                 | 10          |
| A2             | 10          | 0           | 0            | 0.11            | 0               | 0               | 0              | 0              | 0.00            | 0               | 0               | 0.00            | 20             | 0.2                 | 20             | 0.2                 | 10          |
| A3             | 10          | 10          | 10           | 0.33            | 0               | 0               | 0              | 0              | 0.00            | 0               | 0               | 0.00            | 20             | 0.2                 | 20             | 0.2                 | 10          |
| A4             | 10          | 10          | 10           | 0.33            | 0               | 0               | 0              | 0              | 0.00            | 0               | 0               | 0.00            | 20             | 0.2                 | 30             | 0.3                 | 10          |
| AB             | 20          | 10          | 10           | 0.44            | 0               | 0               | 0              | 0              | 0.00            | 0               | 0               | 0.00            | 30             | 0.3                 | 40             | 0.4                 | 10          |

**Profile 2**

|       |    |    |    |      |    |   |   |   |      |   |   |      |    |     |    |     |    |
|-------|----|----|----|------|----|---|---|---|------|---|---|------|----|-----|----|-----|----|
| A1    | 0  | 0  | 0  | 0.00 | 0  | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 10 | 0.1 | 10 | 0.1 | 5  |
| A2    | 10 | 10 | 20 | 0.44 | 0  | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 10 | 0.1 | 10 | 0.1 | 10 |
| A3    | 20 | 20 | 20 | 0.67 | 0  | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 10 | 0.1 | 20 | 0.2 | 10 |
| ABtkb | 20 | 20 | 20 | 0.67 | 0  | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 20 | 0.2 | 30 | 0.3 | 20 |
| Btkb  | 20 | 20 | 20 | 0.67 | 0  | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 30 | 0.3 | 30 | 0.3 | 20 |
| Bkb   | 20 | 10 | 20 | 0.56 | 10 | 0 | 0 | 0 | 0.05 | 0 | 0 | 0.00 | 20 | 0.2 | 20 | 0.2 | 10 |

**Profile 3**

|     |    |    |    |      |    |    |    |   |      |    |   |      |    |     |    |     |    |
|-----|----|----|----|------|----|----|----|---|------|----|---|------|----|-----|----|-----|----|
| A1  | 10 | 0  | 0  | 0.11 | 0  | 0  | 0  | 0 | 0.00 | 0  | 0 | 0.00 | 10 | 0.1 | 10 | 0.1 | 5  |
| A2  | 10 | 0  | 10 | 0.22 | 0  | 0  | 0  | 0 | 0.00 | 0  | 0 | 0.00 | 20 | 0.2 | 10 | 0.1 | 10 |
| A3  | 20 | 10 | 10 | 0.44 | 0  | 0  | 0  | 0 | 0.00 | 0  | 0 | 0.00 | 30 | 0.3 | 30 | 0.3 | 10 |
| Bw1 | 10 | 0  | 0  | 0.11 | 10 | 10 | 0  | 5 | 0.13 | 10 | 0 | 0.14 | 20 | 0.2 | 10 | 0.1 | 10 |
| Bw2 | 10 | 0  | 0  | 0.11 | 10 | 10 | 0  | 5 | 0.13 | 10 | 0 | 0.14 | 20 | 0.2 | 20 | 0.2 | 10 |
| Bkb | 10 | 0  | 0  | 0.11 | 20 | 10 | 10 | 0 | 0.21 | 10 | 0 | 0.14 | 10 | 0.1 | 10 | 0.1 | 10 |

**Profile 4**

|       |    |    |    |      |    |    |   |   |      |   |   |      |    |     |    |     |    |
|-------|----|----|----|------|----|----|---|---|------|---|---|------|----|-----|----|-----|----|
| A1    | 20 | 10 | 30 | 0.67 | 10 | 10 | 0 | 0 | 0.11 | 0 | 0 | 0.00 | 10 | 0.1 | 10 | 0.1 | 5  |
| A2    | 20 | 10 | 30 | 0.67 | 10 | 20 | 0 | 0 | 0.16 | 0 | 0 | 0.00 | 10 | 0.1 | 10 | 0.1 | 10 |
| A3    | 20 | 10 | 30 | 0.67 | 10 | 20 | 0 | 0 | 0.16 | 0 | 0 | 0.00 | 20 | 0.2 | 10 | 0.1 | 10 |
| A4    | 20 | 10 | 30 | 0.67 | 20 | 10 | 0 | 0 | 0.16 | 0 | 0 | 0.00 | 20 | 0.2 | 10 | 0.1 | 10 |
| ABtkb | 30 | 20 | 30 | 0.89 | 0  | 0  | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 30 | 0.3 | 10 | 0.1 | 10 |
| Btkb  | 30 | 20 | 30 | 0.89 | 0  | 0  | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 30 | 0.3 | 10 | 0.1 | 30 |
| Bkb   | 30 | 20 | 30 | 0.89 | 10 | 10 | 0 | 0 | 0.11 | 0 | 0 | 0.00 | 40 | 0.4 | 30 | 0.3 | 30 |
| BCb   | 30 | 20 | 30 | 0.89 | 20 | 0  | 0 | 0 | 0.11 | 0 | 0 | 0.00 | 10 | 0.1 | 10 | 0.1 | 10 |

| <u>str. str.</u> | <u>tot.str.</u> | <u>clay (ab.)</u> | <u>clay (th.)</u> | <u>clay (loc.)</u> | <u>tot. clay</u> | <u>carb. mor.</u> | <u>tot. carb</u> | <u>HCl</u> | <u>tot HCl</u> | <u>TOTAL/9</u> | <u>thick.</u> | <u>HOR. Index</u> | <u>PDI</u> |
|------------------|-----------------|-------------------|-------------------|--------------------|------------------|-------------------|------------------|------------|----------------|----------------|---------------|-------------------|------------|
| 30               | 0.67            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.10           | 3             | 0.29              |            |
| 30               | 0.67            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.15           | 8             | 1.18              |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.15           | 33            | 5.09              |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.17           | 23            | 3.83              |            |
| 20               | 0.50            | 10                | 10                | 5                  | 0.19             | 10                | 0.25             | 10         | 0.25           | 0.26           | 18            | 4.70              | 15.08      |
| 30               | 0.58            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 40         | 1              | 0.20           | 1             | 0.20              |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 10         | 0.25           | 0.14           | 17            | 2.43              |            |
| 30               | 0.67            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 10         | 0.25           | 0.20           | 11            | 2.25              |            |
| 30               | 0.83            | 10                | 20                | 5                  | 0.27             | 10                | 0.25             | 40         | 1              | 0.31           | 25            | 7.87              |            |
| 30               | 0.83            | 20                | 20                | 5                  | 0.35             | 20                | 0.5              | 40         | 1              | 0.37           | 35            | 12.89             |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 10                | 0.25             | 40         | 1              | 0.22           | 10            | 2.20              | 27.84      |
| 20               | 0.42            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 20         | 0.5            | 0.14           | 2             | 0.27              |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.13           | 8             | 1.02              |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.19           | 30            | 5.79              |            |
| 30               | 0.67            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.17           | 22            | 3.72              |            |
| 30               | 0.67            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.18           | 16            | 2.90              |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 10                | 0.25             | 30         | 0.75           | 0.18           | 17            | 3.01              | 16.72      |
| 30               | 0.58            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 40         | 1              | 0.28           | 2             | 0.57              |            |
| 20               | 0.50            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 0          | 0              | 0.19           | 3             | 0.57              |            |
| 30               | 0.67            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 10         | 0.25           | 0.22           | 14            | 3.13              |            |
| 30               | 0.67            | 0                 | 0                 | 0                  | 0.00             | 0                 | 0                | 20         | 0.5            | 0.22           | 16            | 3.58              |            |
| 30               | 0.67            | 10                | 20                | 5                  | 0.27             | 10                | 0.25             | 30         | 0.75           | 0.31           | 8             | 2.47              |            |
| 30               | 1.00            | 10                | 10                | 10                 | 0.23             | 10                | 0.25             | 40         | 1              | 0.35           | 25            | 8.66              |            |
| 30               | 1.00            | 10                | 10                | 10                 | 0.23             | 20                | 0.5              | 40         | 1              | 0.43           | 26            | 11.13             |            |
| 20               | 0.50            | 10                | 10                | 5                  | 0.19             | 10                | 0.25             | 30         | 0.75           | 0.27           | 11            | 2.94              | 33.06      |