TITANIUM SOURCE AND DISTRIBUTION

WITHIN A PALEUSTALF

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Soil is produced by the action of soil-forming processes on parent material deposited or accumulated by geologic agents (Soil Survey Staff, 1975). Horizons develop in response to the combined effects of additions to the ground surface, transformations and translocations within the soil, and losses from the soil (Simonson, 1959). In quantitative pedology, soil scientists attempt to quantify the changes which take place in the soil during soil development. The first step in a soil genesis study is to identify parent material and differentiate between pedologic processes and geologic changes (Barshad, 1955). Once the parent material has been identified, relative changes in the soil can be assessed using resistant and immobile internal standards.

In ascertaining profile uniformity translocation of clay creates parent material variations. The distribution of clay sized particles involves several processes. Clays formed by weathering may move downward with percolating water and reprecipitate in the B horizon. Clays may be formed in situ by precipitating from the soil solution (Soil Survey Staff, 1975).

Because soil development involves the degradation of primary minerals to form secondary minerals, the most resistant and immobile minerals should be chosen to evaluate changes resulting from pedologic processes. Minerals vary in their resistance to weathering. A specific mineral's ability to resist weathering is a function of the structure and chemical composition of that mineral. The use of resistant mineral distribution to identify uniformity of soil with depth is based on the theory that these minerals do not undergo any significant change or translocation during soil formation, therefore, their pattern of distribution would remain undisturbed or even accumulate in the upper horizons due to the losses of weatherable minerals. Determination of parent material uniformity can be assessed by the constancy of a ratio of two resistant minerals. In the absence of decomposition or translocation the ratio of the resistant minerals would also be unaffected and reflect parent material uniformity (Brewer,1964, Barshad,1955, Birkeland,1984).

The tendency for specific mineral species to concentrate within specific size fractions is a function of their resistance to weathering. Minerals which are more resistant to weathering tend to persist in greater quantities in the fine clay fraction. Greater susceptibility to weathering of the less resistant minerals result in their extinction before they reach the fine clay fraction (Jackson and Sherman, 1953). In a weathering

sequence of clay sized minerals, Jackson (1979) identified anatase (also zircon, ilmenite, rutile, leucoxene, corundum,) as exhibiting the greatest resistance to weathering. Because titanium (Ti) occurs in minerals considered resistant to weathering (anatase, rutile, ilmenite, leucoxene) their distribution or the ratio of Ti to another resistant element (e.g. Zr) are employed in evaluating parent material uniformity and quantification of pedologic changes (Brewer,1964, Barshad, 1955).

Preliminary data from the parent material study of a Chigley series fine, mixed, thermic Udic Paleustalf soil profile indicated a lithologic discontinuity. In applying Ti:Zr as criterion to establish a constant ratio thereby reflecting uniformity, it was apparent that there was a lithologic discontinuity causing variations between horizons (Smith, 1985). Field observations as well as Zr distribution indicated a uniform plarent material. Preliminary Ti distribution indicated a depletion of Ti in the A, E, and B horizons as compared to the C horizons. The variations between horizons may be due to the slow additions of material to the soil that could not be detected by field morphological techniques, a variation in granodiorite prior to the inception of soil formation, of that this deeply wathered granodiorite soil contained Ti minerals once considered resistant but may be weatherable causing the unexpected Ti distribution. The objectives of this study were to (1) identify primary minerals sources of

Ti, (2) determine the distribution of Ti in the soil matrix, and (3) evaluate the weathering of Ti bearing minerals and mobility of Ti.

CHAPTER II

REVIEW OF LITERATURE

Titanium is the ninth abundant element in the earth's crust by weight. Titanium minerals common in soils include the oxide minerals (TiO_2) rutile, anatase, brookite, and leucoxene; compound iron oxides (Fe_2O_3) of ilmenite, and pseudorutile; and complex silicates such as sphene (Day,1963, Hutton, 1977, Temple, 1966). In addition to these independent titanium minerals, titanium occurs in the structure of many rock silicates (Deer et al., 1966, Drees and Wilding,1978). Joffe and Pugh (1934) identified titanium as being present as ilmenite or as a titanium phosphate $Ti(HPO_4)_2$. Titanium occurred as primarily anatase in kaolinites while in illite titanium occurred in the form of rutile (Dolcater, 1970, Raman and Jackson, 1965). Titanium was also observed as inclusions in quartz and feldspar grains (Drees and Wilding, 1978). Dolcater (1970) attributed all the titanium which occurred in biotite to the isomorphically substituted form.

Those processes which are associated with the weathering of soils may also be responsible for the weathering of titanium minerals. Weathering at humid soil temperatures may be responsible for the transformation of

5

ilmenite to various forms of leucoxene (Goldschmidt, 1954, Temple, 1966, Tyler and Marsden, 1938). Hydrolysis reactions with ilmenite were found to yield rutile (Joffe and Pugh, 1934). Oxidation and leaching of iron from ilmenite leads eventually to an end product that is essentially TiO_2 (Temple, 1966, Grey and Reid, 1975).

The appearance of Ti in more easily weatherable minerals suggests a potential for change in content of titanium as the particle size distribution changes. As titanium bearing minerals weather distribution of Ti particles may shift to finer particle size. Ti content has been found to increase as particle size decreased (Chapman and Horn, 1968, McLaughlin, 1954). The Ti content of clays and silts has previously been reported as due to the breakdown of ilmenites and biotites (Goldshcmidt, 1954, McLaughlin,1954). Much of the Ti content of clays appears to be due to the occurrence of fine grained TiO_2 (Goldschmidt, 1954, McKeague and Wang, 1980).

The weathering of minerals containing Ti may also release Ti thereby suggesting that the Ti may be mobile in the soil. Leucoxene was identified as coating very fine sand sized grains of quartz and chert which suggested the probable translocation of Ti in soils (Chapman and Horn,1968). At low pH values, humates were found to keep Ti in solution (Joffe and Pugh, 1934). In analysis by Sudom and St. Arnaud (1971) Ti was subject to mobilization in all size fractions and translocation in the clay

fraction.   Sherman (1952) suggested the movement of "colloidal hydrated titanium oxide" to the surface of the soil by capillary action.   Products of weathering such as cutans along with clays have also been identified as containing Ti .   In micromorphological studies, Ti occurred as a cutan component and had a pattern of mobility similar to that of iron (Gillespie and Protz, 1972, McKeague and Wang, 1980).

Based upon the previous study mentioned above, it seems that the use of total Ti in the assessment of parent material uniformity is questionable. Therefore an attempt at studying the mobility of Ti within the soil is needed. A consolidated study of Ti mobility would enhance the future methods of utilizing Ti in assessing parent material uniformity.

CHAPTER III

METHODS AND MATERIALS

Soil Samples

The Chigley soil is located in T3S R5E, Johnston County, Oklahoma. Soil samples were obtained from each horizon to a depth of 257 cm. A profile description appears in Appendix A. Organic matter was destroyed by digestion with 30% H_2O_2. Each sample was fractionated into 8 particle size fractions (coarse sand to fine clay) for x-ray analysis by the standard procedures of sieving, decantation, and centrifugation (Jackson, 1979).

X-Ray Spectrography

All size fractions were prepared for x-ray spectrographic analysis. Soil samples were finely ground to < 50 μ m to minimize particle size microabsorption effects (Jones,1982). At least 2 grams of soil sample and 4 grams of Bakelite (as the backing powder) were pressed into a pellet at 10 tons per square inch (Jones, 1982). Titanium standards were prepared using known USGS rock standards of granodiorite, andesite, granite, and basalt (Flanagan, 1967). Determinations of Ti were made on a General Electric XRD-6 x-ray spectrograph unit by comparing

8

net counts to a regression line. Concentrations were expressed on a parts per million (ppm) basis. For Ti, a Cr tube operated at 45 kv and 40 ma was the source of excitation and the detector was a scintillation counter. Titanium K alpha radiation was counted over 5-7 replications for 10 seconds at 85.6° 2θ for the peak and 89.0° 2θ for the background. Samples were run in duplicate. The 10 second counting time was sufficient to accumulate more than 50,000 counts at the peak position. Likewise, Zr K alpha radiation was counted over 3 replications for 10 seconds at 22.1° 2θ for the peak and 18.2° 2θ for the background.

Petrographic Microscope Determination

Undisturbed soil clods from each horizon as samplable were impregnated with Scotchcast #3 epoxy resin. The soil samples were impregnated with epoxy type resin under vacuum conditions. The vacuum was maintained until the resin fully covered the sample and bubbling had ceased. The impregnated samples were dried at 90 C overnight. The samples were sent to Quality Thin Sections , Tucson AZ for processing into 27x 46 cm slides. Thin sections were hand finished to 30 μ m. Coverglass was attached with Canada Balsam for possible removal later. Thin sections were also mounted on round glass discs 2.5 cm in diameter and were polished. These were to be used with both the petrographic microscope and the scanning electron microscope.

Using the petrographic microscope, the dominant mineralogy of the soil consisted of micas, amphiboles, alkali feldspars and quartz. Relative percentages of minerals were made by taking the average of the percentages across 10 locations on the slides. Pedologic features (eg. cutans) as well as specific minerals were identified for further examination. Features were located under the petrographic microscope and the area (2mm) was circled with a wax pencil. A diamond pencil was used to etch the line of the wax pencil circle. The etched circle was visible for use as a reference point in the scanning electron microscope. Features were photographed under plane polarized light and cross polarized light at 60x magnification.

Scanning Electron Microscopy and Energy Dispersive

X-Ray Analysis

The JEOL JSM 35-U Scanning Electron Microscope (SEM) plus the energy dispersive system (EDAX) was used for surface topography observation and elemental analysis. The thin section discs were coated with carbon and attached to the specimen holder with double faced copper tape strips. The specimen holder is placed into the SEM and the chamber was evacuated. Etched circles were easily located. The specific features of interest were located with the aid of petrographic photographs during EDAX analysis. Magnification was increased and several points along the

surface of the feature were analyzed by energy dispersive x-ray analysis (EDAX).

Specific mineral grains and pedologic features identified in thin section were examined with the SEM. Mineral grains were analyzed at increasing magnifications which allowed observation of polished surface characteristics. EDAX identifies elements with atomic numbers greater than or equal to 11. Electron orbitals of individual elements respond to x-ray excitation and emit a characteristic wavelength. Wavelengths are detected by x-ray counters. Relative peak intensities are related to the amount and mass absorption of the element present.

Amorphous Material Extractions

Ammonium oxalate (0.2 M, pH 3.0) was used to extract amorphous Fe, Al, and Ti (McKeague and Day, 1965). Thirty milliliters of the 0.2M acidified ammonium oxalate were added to 3 grams of soil sample in a tube which was stoppered tightly. The tubes were placed in a shaker , covered by a box, shaken for 3-4 hours and centrifuged. The extract was collected and analyzed by inductively coupled plasma- atomic emission spectrometry (ICP). The instrument was standardized with solutions of Ti of 0.01, 0.1, 0.5, 1.0, 5.0, 10.0, 30.0, 60.0, and 100.0ppm.

Heavy Liquid Separation and X-Ray Diffraction

The objective of heavy liquid separation is to increase the concentration of each mineral species in its typical specific gravity fraction. The technique of "sink or float" was employed to separate heavy minerals. A separatory funnel was filled 3/4 full with S-tetrabromethane. Small amounts of sample were (at least 5 grams) added until the whole sample had been used. The heavy minerals were allowed to sink. Light minerals were siphoned off. Heavy minerals were filtered from the heavy liquid, collected and dried.

After separation minerals were placed into a powder slide using stopcock grease. Nickel filtered Cu alpha radiation generated at 45 kvp and 20 ma on a General Electric XRD-6 X-ray diffraction unit was used for x-ray diffraction analysis.

CHAPTER IV

RESULTS AND DISCUSSION

X-Ray Spectrographic Analysis

The Ti: Zr ratio (fig.1) did not indicate parent material uniformity.   Analysis showed a depletion from horizons A to E.   An increase occurred in the B horizons. This increase was not larger than the ratio of the C horizons and may be interpreted as a zone of mixing between different materials.

The distribution of Zr was typical for a soil of uniform parent material (Table I). This trend indicates that Zr is remaining in horizons where the more weatherable minerals have been depleted.

Typically more Ti was found distributed in the silt fraction of soil but there was considerable evidence to changes associated with particle size distribution. Data obtained from analysis of the Chigley soil (Figure 2,and Table I) indicate an increase of total Ti content from the silt to the clay fraction from the C horizons to the A horizons respectively.

The largest Ti content of the BC and C horizons appear in the coarse silt fraction.   This reflects the
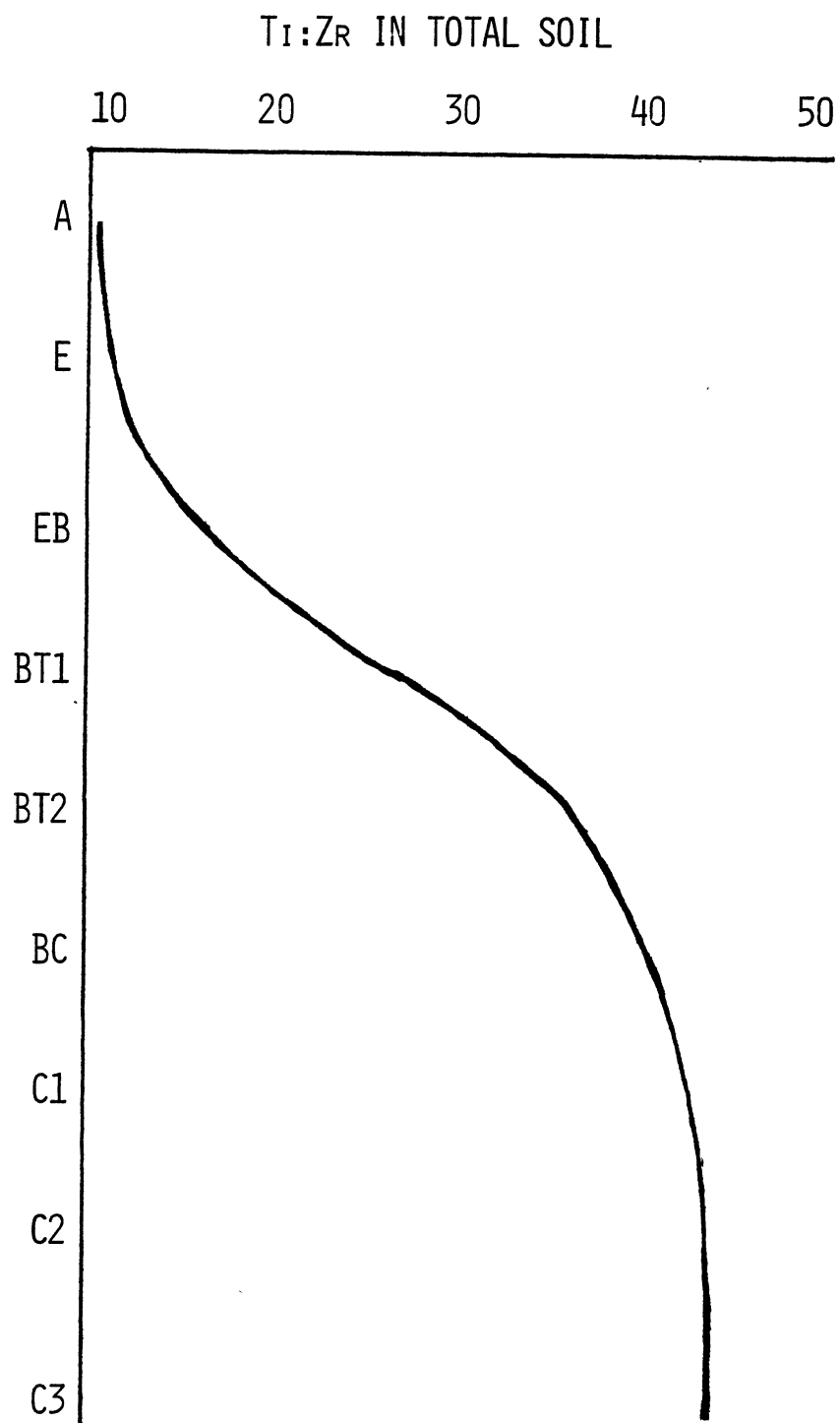
13
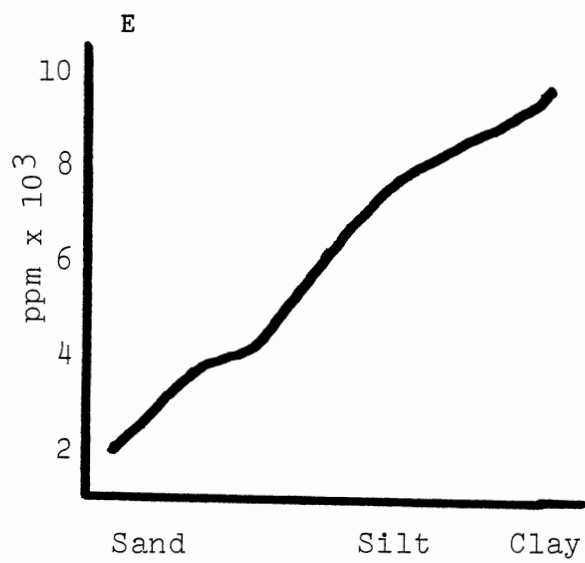
Figure 1.   Ti:Zr   for the total soil.
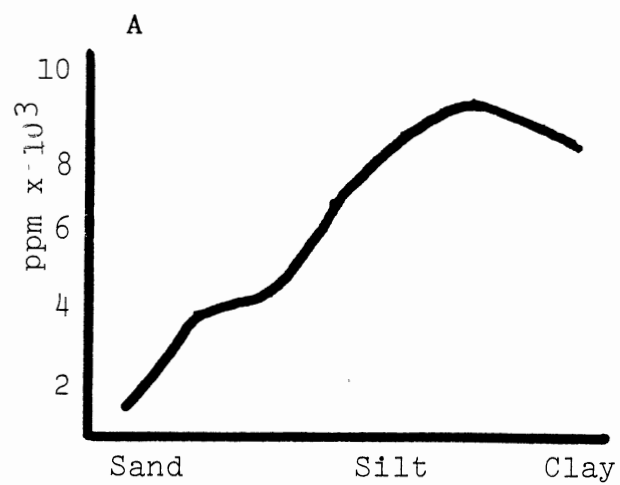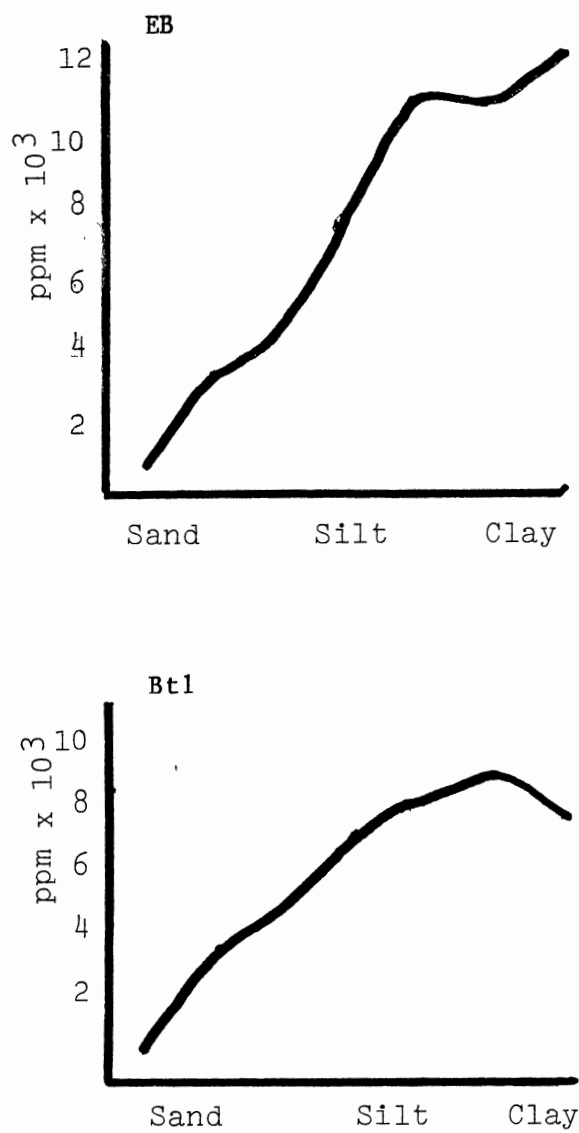
Figure 2. Ti distribution for the A and E horizons.

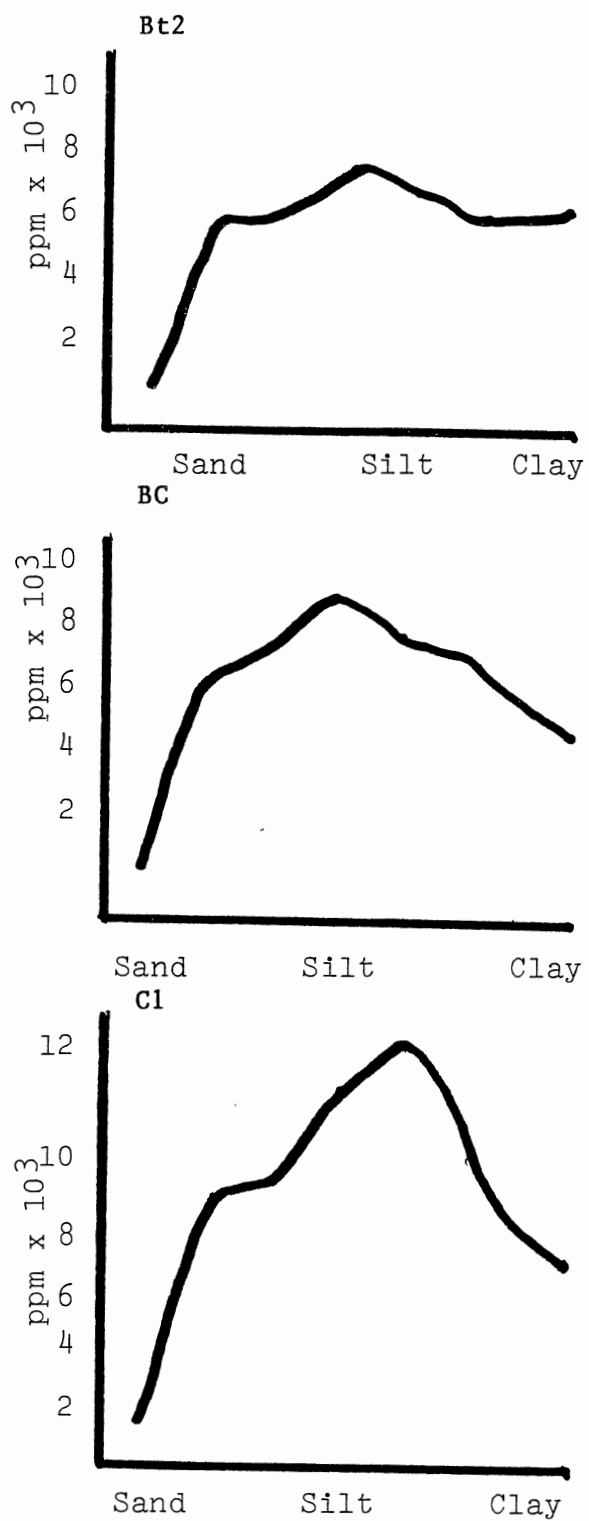Figure 2 continued. Ti distribution for EB and Bt1 horizons.

Figure 2 continued. Ti distribution for the Bt2 and C1 horizons.
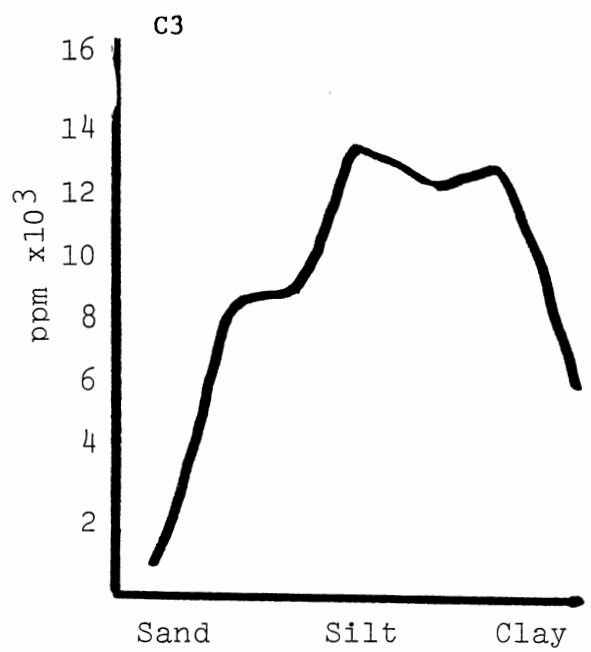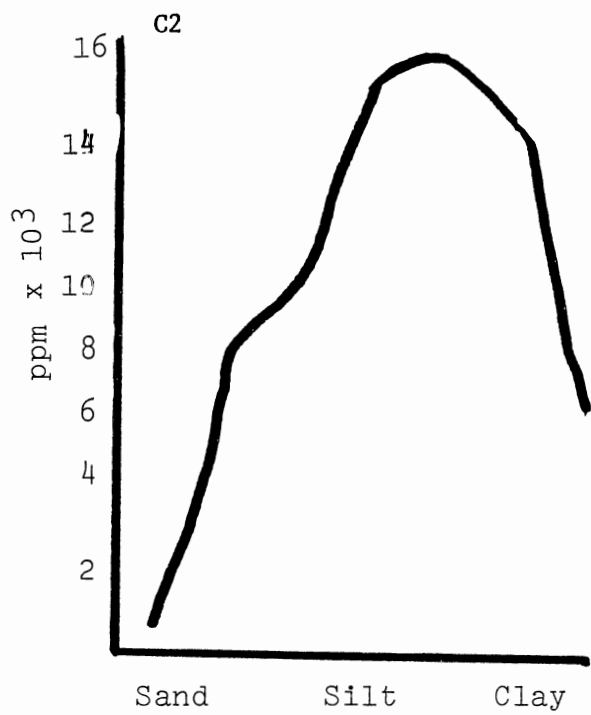
Figure 2 continued. Ti distribution for the C2 and C3 horizons.

TABLE I

TITANIUM CONTENT (PPM) IN PARTICLE SIZE FRACTIONS
AND PERCENT TITANIUM AND ZIRCONIUM IN TOTAL
SOIL BY HORIZONS

Horizon	Particle Size								Total	
	vc-cS	m-fS	vfS	cSi	mSi	fSi	cC	fC	Ti	Zr
A	1010	3190	3680	6281	7840	8493	7760	3274	0.335	0.037
E	1179	3112	3922	6324	8325	8974	10743	4100	0.355	0.033
EB	904	3121	4078	6960	10249	10075	11132	4462	0.370	0.036
Bt1	914	3413	4610	6473	7328	7829	6887	3030	0.470	0.018
Bt2	1055	5296	5651	6661	6186	5432	5722	2492	0.630	0.017
BC	1442	5953	7100	8173	7194	6542	4678	2996	0.635	0.017
C1	1323	6974	7535	9886	11135	7859	5359	3461	0.770	0.021
C2	903	7643	8053	11801	10987	11785	5714	3673	0.770	0.018
C3	804	7794	9510	14943	15878	13593	6602	2810	0.725	0.018

change in particle size from coarse grained to the silt fraction due to incipient weathering.

As the process of physical weathering proceeds the Ti content follows the decreasing particle size. In the Bt2 horizon, a maximum Ti content is reached in the medium silt fraction. The maximum Ti content of the Bt1 horizon shifts to the fine silt fraction.

Further physical weathering in the horizons of active weathering show a shift of Ti content to the finer fractions. Both EB and E horizons show a maximum Ti content in the coarse clay fraction. The A horizon maximum is in the fine silt fraction. The decrease in Ti content in the coarse clay fraction within the A horizon may be due to the loss of clays due to translocations. The increase of Ti of the coarse clay fraction in the E horizon suggests that the form of Ti is not soluble as it remains in the horizon of eluviation.

Petrographic Determination

Minerals were determined by their optical properties as described by Kerr (1977), MacKenzie and Guilford (1984), and Deer et al (1966). Pedologic features were identified and described according to Brewer (1964). Mineralogical characteristics appear in Table V, Appendix C. The mineral composition of the parent material is responsible for the type of minerals present in the soil. The Tishomingo granites are described by Ham et al. (1964) as

consisting of quartz, microcline, plagioclase and biotite. Minerals identified in thin section appear in Table II. Mineralogy as determined by thin section consists of alkali feldspar (microcline and plagioclase), quartz, biotite and hornblende. Opaque minerals were assumed to be normal (magnetite, ilmenite, hematite) and were not further identified under the petrographic microscope.

Changes in soil fabric as fresh rock weathers to soil can be observed in thin sections. The C horizons are characterized as having a fabric of nearly continuous mineral grains (Figure 3c). Fractures and clay ridges are products of incipient weathering. All identified minerals are present in these horizons. The BC horizon consists of fabric of mineral grains commonly interrupted by fracture and pore space. Cutan (including argillans) are characteristic of the pore space. Argillans and inherent red color due to iron become more pronounced within the Bt2 horizon, and fractures of mineral grains are lined by neocutans. All minerals previously identified are present although biotite has begun to exfoliate. There is no soil matrix (s-matrix) present in this horizon. Mineral grains have an angular to subangular shape.

Insepic s-matrix (plasma separations with striated orientation occur as isolated patches within the flecked plasma, (Brewer, 1964)) predominates the Bt2 and Bt1 horizons (Figure 3b). Exfoliated biotite is present. The fabric has a characteristic red color associated with iron

TABLE II

MINERALS IDENTIFIED BY PETROGRAPHIC OBSERVATION

Horizon	Minerals Present
E	Q, KF, NF, (A, Mx, O)
EB	Q, KF, NF, (A, Mx, O)
Bt1	Q, KF, NF, (A, M, Mx, O)
Bt2	Q, NF, KF, (A, M, Mx, O)
BC	Q, NF, KF, (A, M, Mx, O)
C1	Q, NF, KF, (A, M, Mx, O)
C2	NF, KF, Q, (A, M, Mx, O)
C3	NF, KF, Q, (A, M, Mx, O)

Mineral abbreviations: Q= quartz, KF= potassium feldspar, NF= soda feldspar, A= amphibole, M= mica, Mx= mixed complexes of sphene- ilmenite- Ti- Fe, O= opaque minerals of hematite, ilmenite, and magnetite. Parentheses indicate the minerals occurring in lesser amounts.
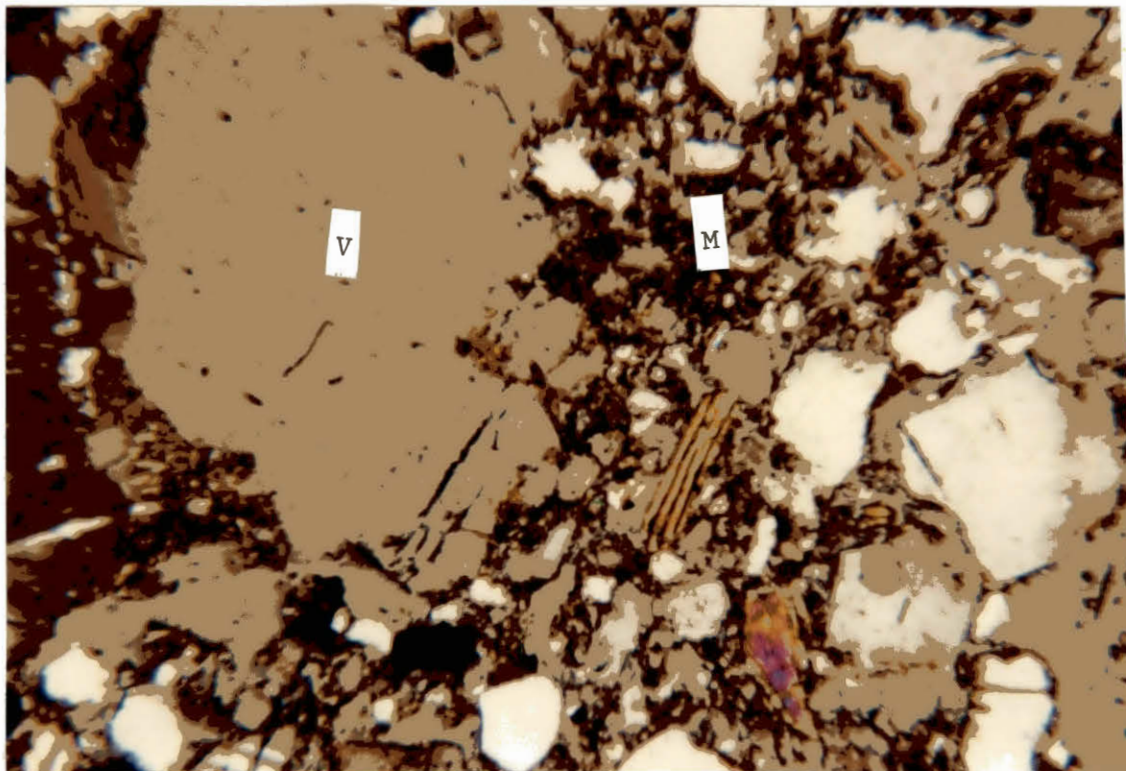
Figure 3a. E horizon photographed at 60x. S-matrix
     occurs as islands associated with resistant minerals.
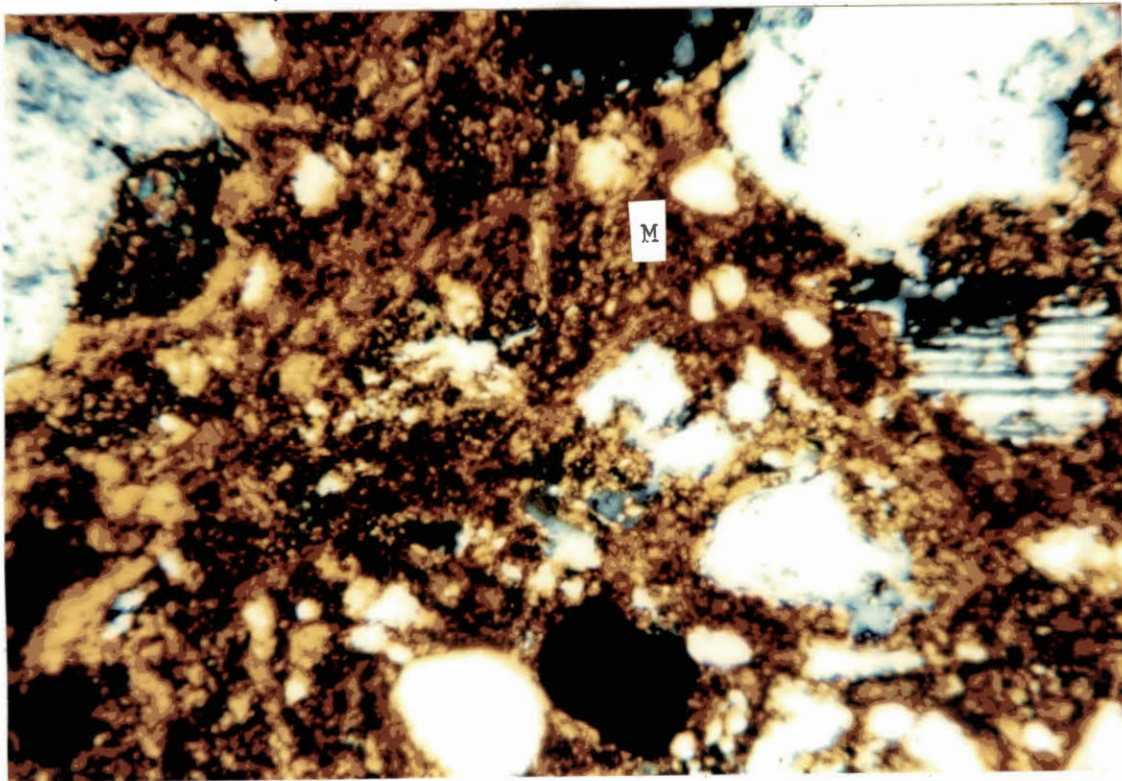   V= voids, M= matrix.

Figure 3b. Bt1 horizon photographed at 60x. Insepic
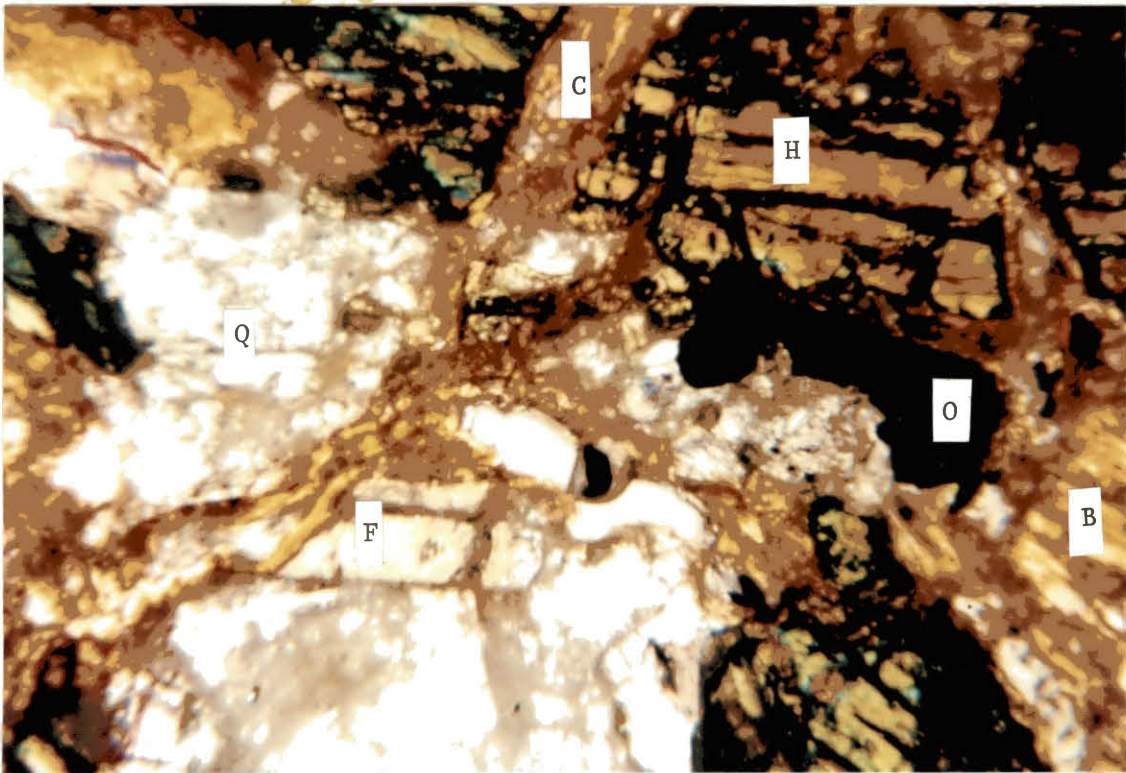   S-matrix dominates. Minerals are embedded in the
     matrix. M= matrix.

Figure 3c. C1 horizon photographed at 60x. Mineral
grains are joined forming a continuous pattern.
Fractures and clay ridges are products of incipient
weathering. C= clay ridge, H= hornblende, B=
biotite, O= opaque minerals, F= feldspar, Q= quartz.

oxides. Argillans and ferroargillans are dominant in the s-matrix as well as filling pore spaces. Angular to subangular mineral grains embedded within the s-matrix are coated by neocutans.

In the EB horizons s-matrix has a mixed brown and red color. Mineral grains are subangular. Quartz, alkali feldspars are the dominant minerals present while hornblende is depleting and biotite has depleted. S-matrix appears as islands and along mineral grains. Pore space has increased in volume. Opaque minerals appear frequently as compared to lower horizons. The E horizon (Figure 3a) is characterized by an increase in pore space and dominant feldspar and quartz. S-matrix occurs as brown islands and mineral grain coatings. Opaque minerals are common along with feldspars and quartz and are subangular to subrounded in shape. Flecks of hornblende can be seen embedded in the s-matrix.

The soil material of the A horizon was too friable to hold together well so that an undisturbed soil clod could not be removed from the field. Consequently, a thin section slide does not exist for the A horizon.

Scanning Electron Microscope and Energy

Dispersive X-Ray Analysis

Opaque minerals left unidentified by the petrographic microscope were now identified by EDAX. Qualitative elemental identifiaction appears in Appendix C. Black
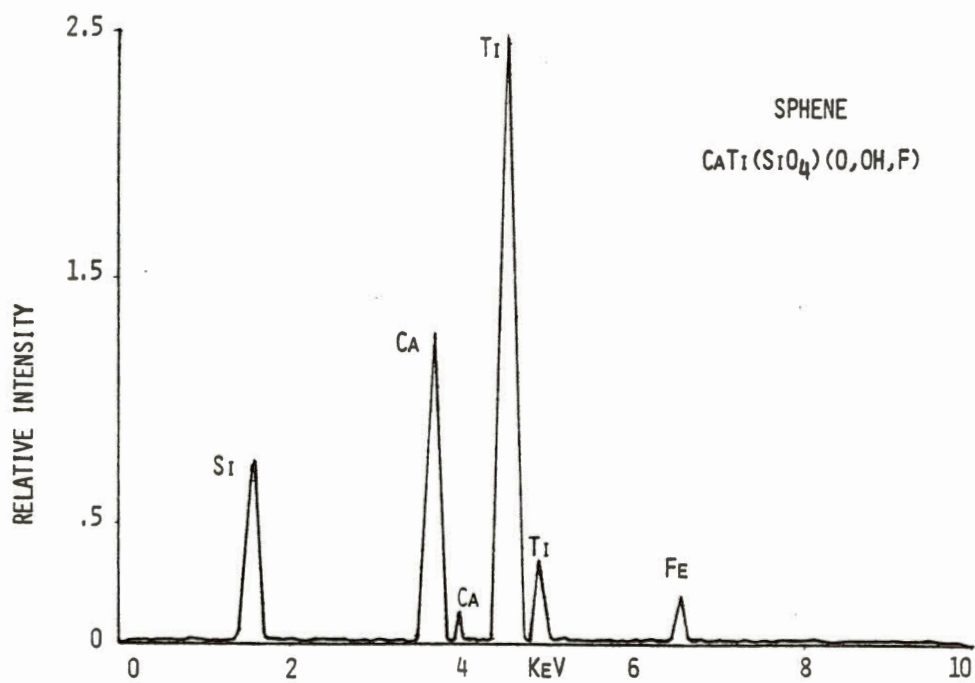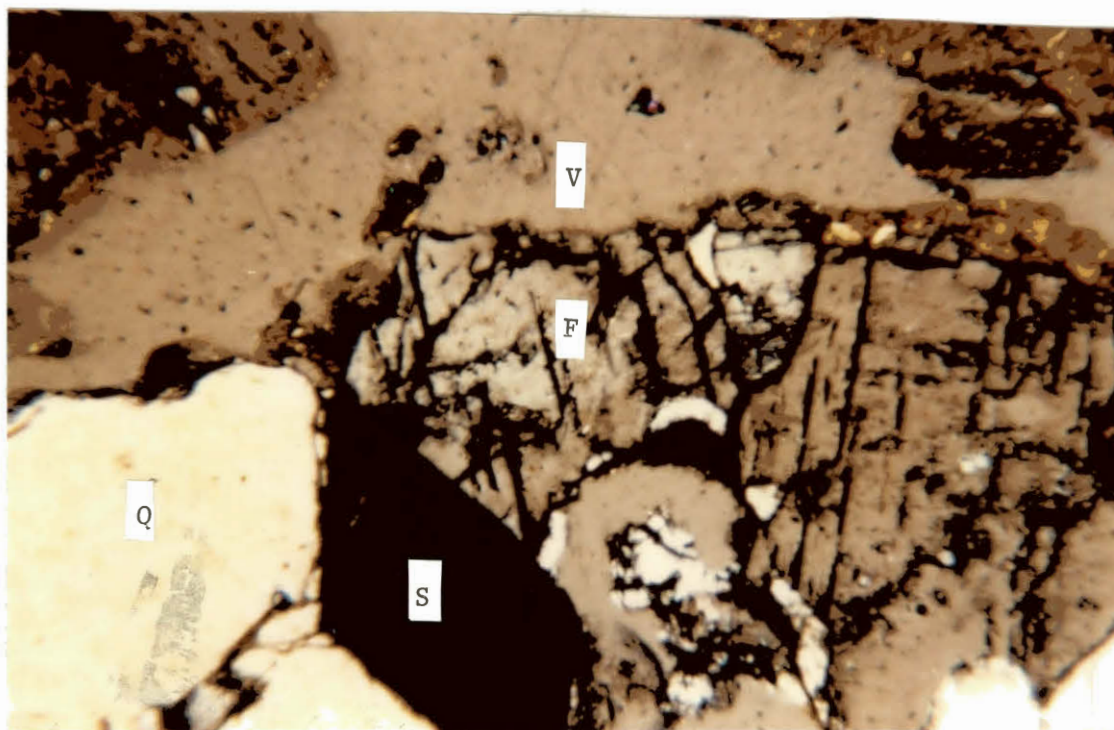
Figure 4. Sphene photographed under crosspolarized light and EDAX identification. S= sphene, Q= quartz, F= feldspar, V= void.

grains were identified as containing predominantly iron. These are inferred to be normative accessory minerals of hematite, magnetite and ilmenite. Brown translucent minerals were identified as consisting of calcium, titanium, silica and in some cases iron. Calcium rich minerals were determined to be sphene (Figure 4). The mineral surface was microcrystalline in nature. Large and fine crystals of sphene and ilmenite occur throughout the soil profile. Variations of elemental composition were noted within the brown translucent minerals Figure 8). Centers of iron oxides were found to be surrounded by complexes of iron and titanium believed to be ilmenite.

Biotite grains were identified as consisting of potassium (K), magnesium (Mg), iron (Fe), silicon (Si), aluminum (Al) and titanium (Ti) (Fig. 5). An elemental distribution pattern indicated that Ti was dispersed through out the biotite grain indicative of isomorphic substitution of Ti in the structure. Hornblende (Figure 6) also revealed Ti within its structure. Ti is believed to be substituted into the structure when the mineral originally formed in the rock. Ti distribution pattern was random across the area analyzed further suggesting substitution rather than inclusion of fine grained TiO_2 crystals (rutile, anatase). Likewise, inclusions were not identified by petrographic microscope analysis.

In the s-matrix optical properties identified products of weathering. Fe, Al, Si, and other component elements
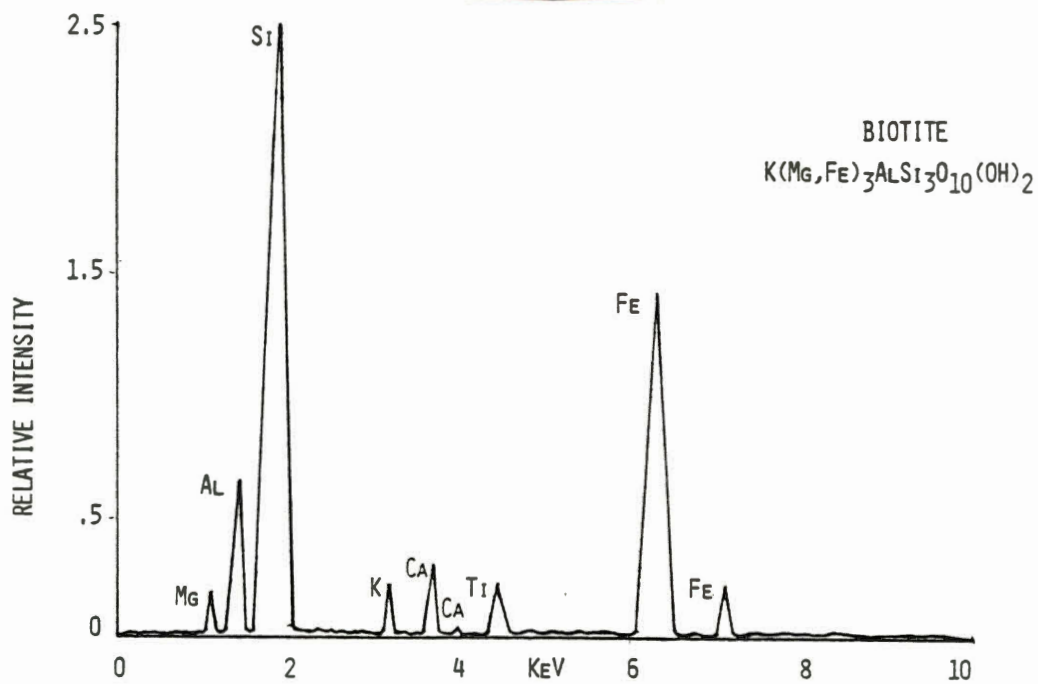
Figure 5. Biotite photographed under crosspolarized light and EDAX identification. B= biotite, M= matrix.

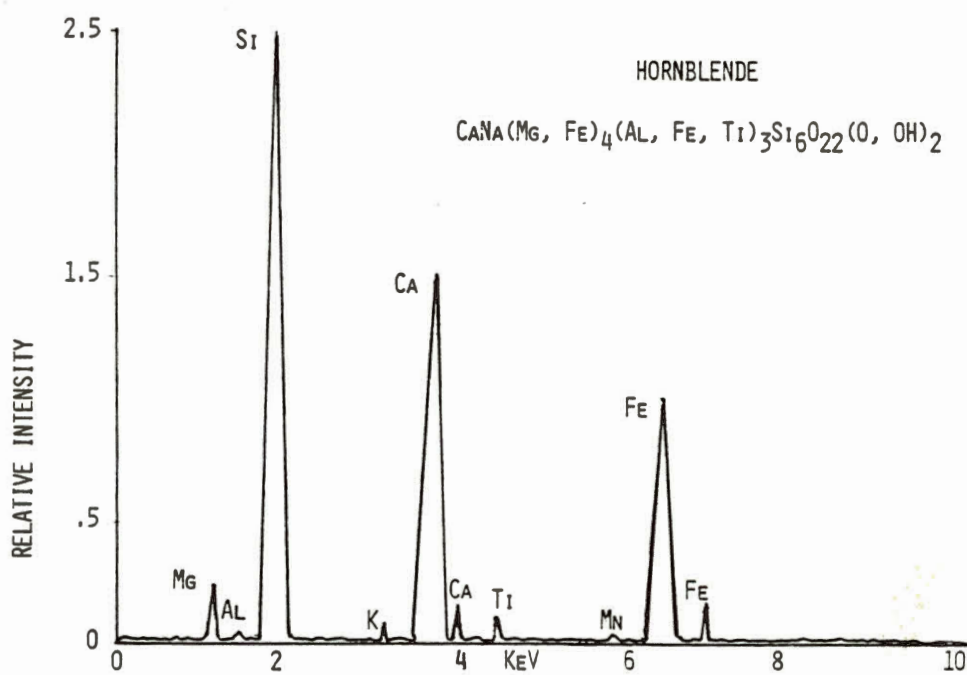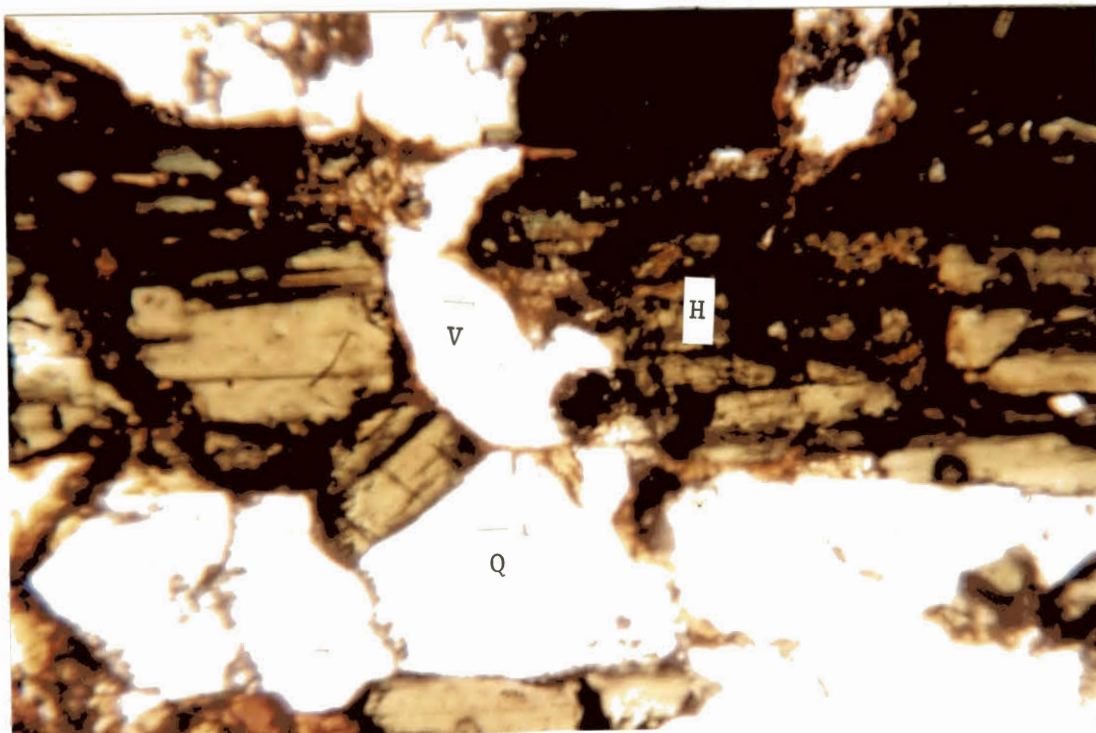Figure 6. Hornblende photographed under planepolarized
light and EDAX identification. H= hornblende, Q=
quartz, V= void.
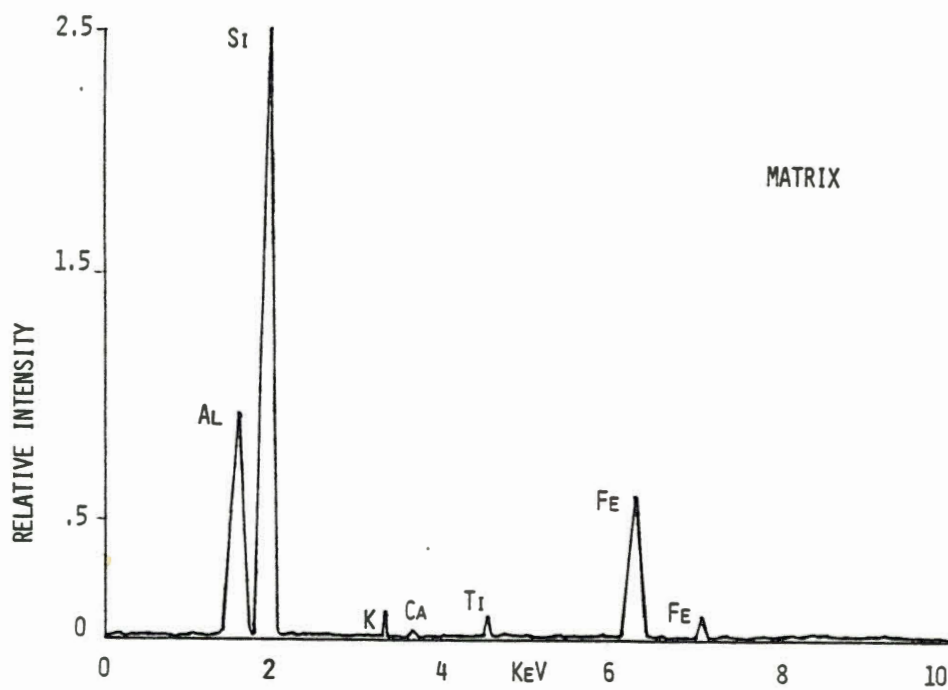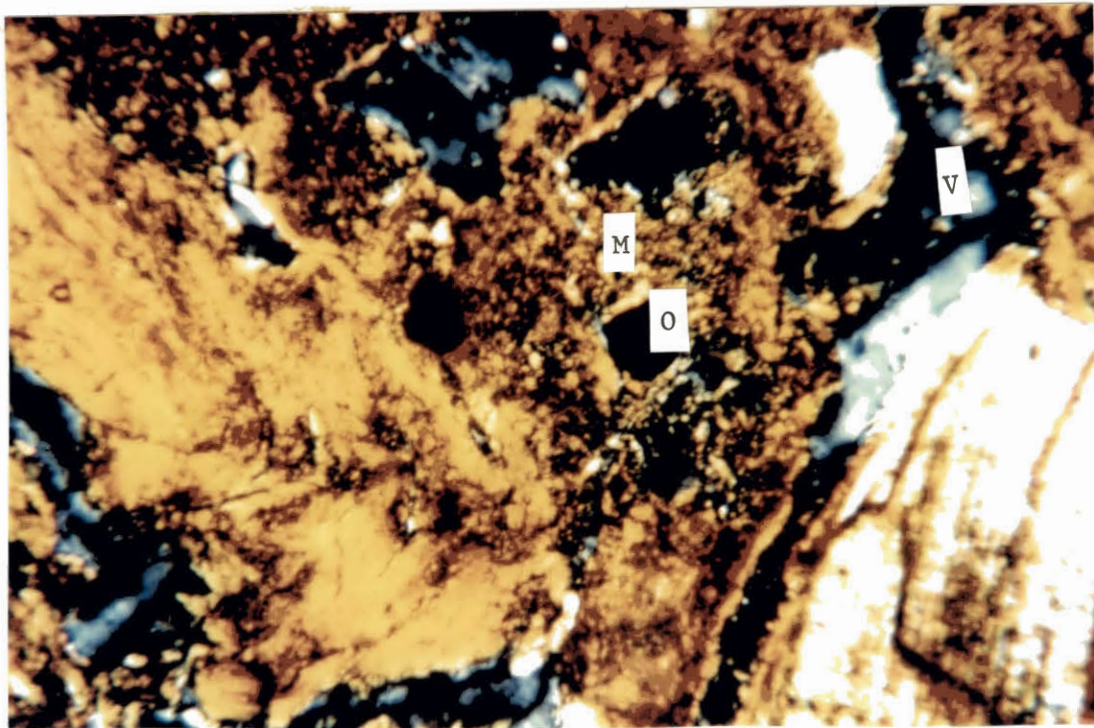
Figure 7. S-matrix photographed under crosspolarized
light and EDAX identification. M= matrix, O=
opaque minerals, V=void.
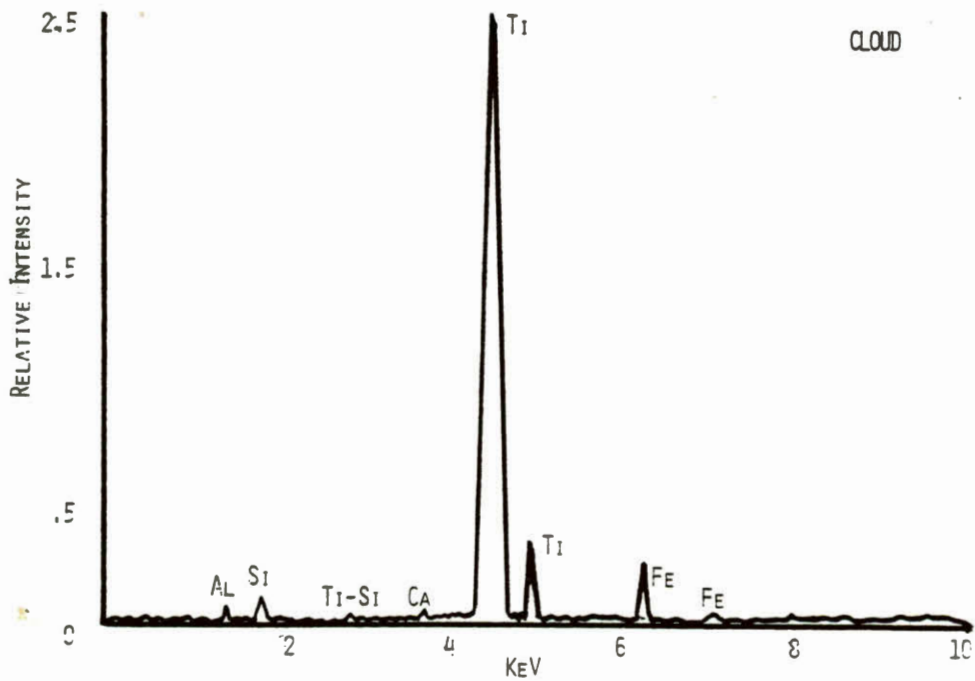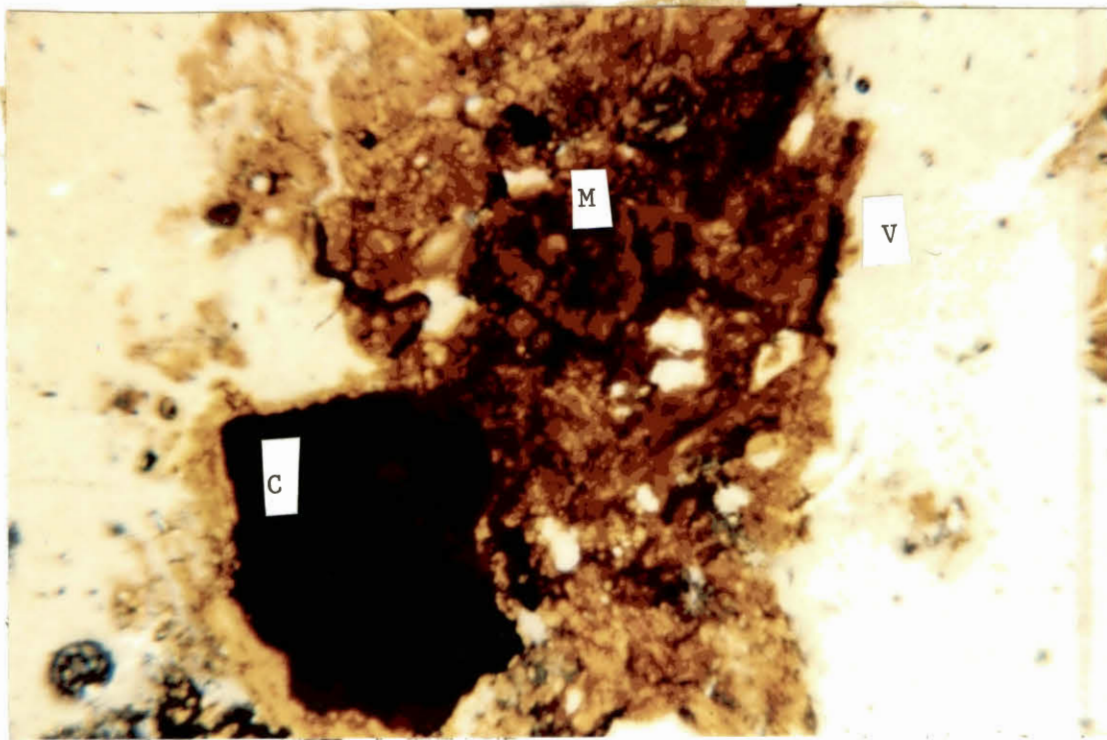
Figure 8. Sphene- ilmenite- TiO2- Fe2O3 complex
photographed under planepolarized light and EDAX
identification. C= complex, M= matrix, V= void.

are expected to be released from primary minerals as they weather. In the s-matrix, Ti was identified (Figure 7). Ti was also discovered as a component element of cutans.

Ammonium Oxalate Extraction Analysis

Schwertmann (1964,1973) found acid ammonium oxalate to dissolve only x-amorphous oxides in darkness. The reagent had little effect on crystalline material. Percent titanium extracted from total soil samples are given in Table III.

The percent Ti extracted was small, but notable. The amount increased with depth to a maximum at the Bt2 horizon. Ti was observed to have a similar distribution to iron and aluminum with depth (Figure 9). This pattern is used as evidence of Fe and Al transformation and translocation. Distribution suggests that the presence of Ti in an amorphous form has been translocated possibly in a similar fashion as Fe and Al. Percent Ti of the oxalate extraction was divided by the total Ti to assess the mobility of Ti (Table II). From this calculation, Ti ranged from 1.0 to 3.0 percent with the maximum occurring in the Bt1 horizon. This indicates that more oxalate extractable Ti is available in the Bt1 horizon per same amount if sample than in any other horizon. When compared to the oxalate, dithionate and total Fe (McKeague and Day, 1965, Schwwertmann, 1973), these Ti levels of oxalate extractable Ti seem to be significant. This indicates that
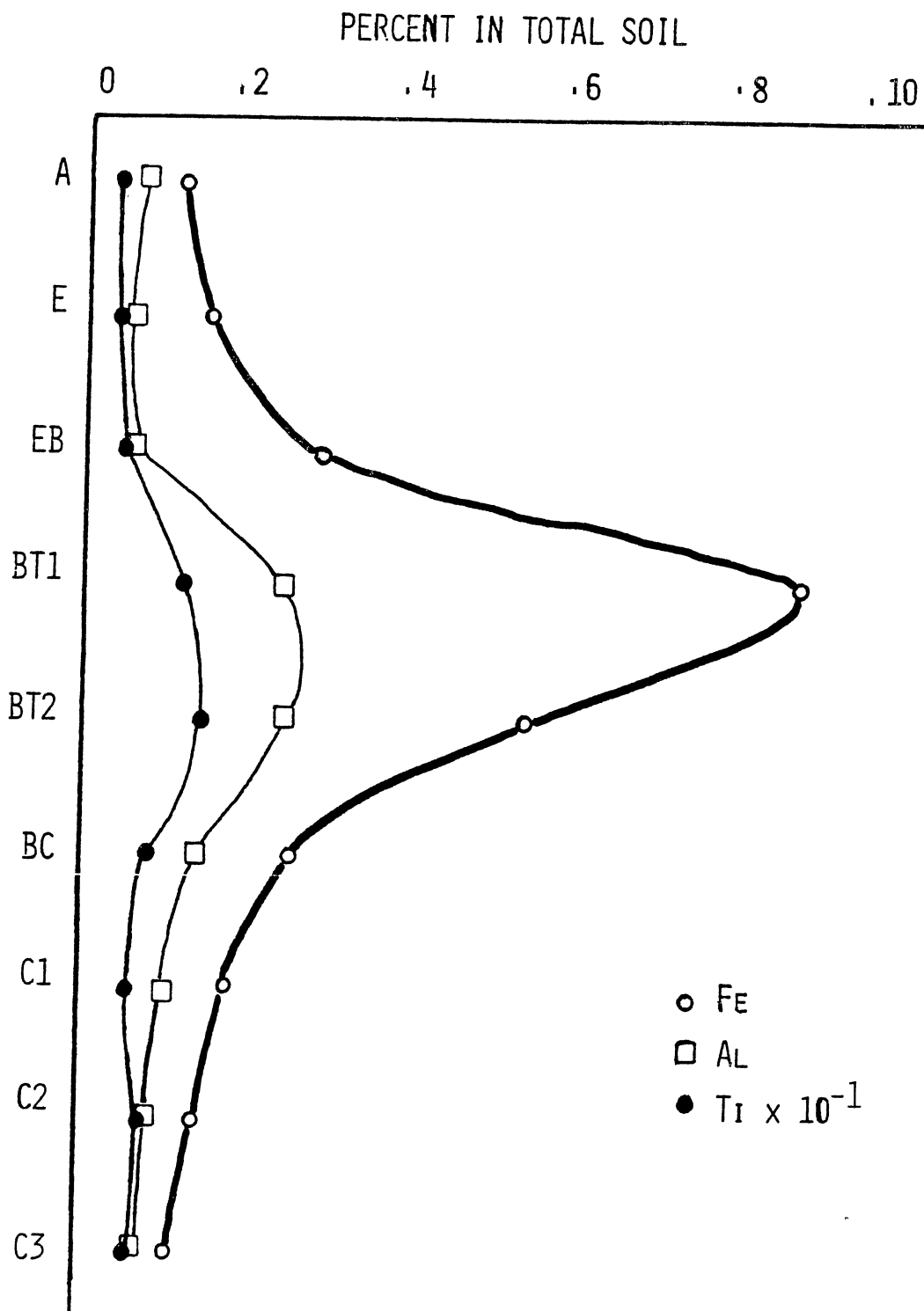
Figure 9. Percent oxalate extractable Fe, Al, and Ti on a total soil basis.

TABLE III

PERCENT OF Ti, Fe, Al IN OXALATE EXTRACTION
ON A TOTAL SOIL BASIS AND PERCENT
EXTRACTABLE Ti ON A TOTAL Ti BASIS

Horizon	%Ti	%Fe	%Al	% Ti of Total Ti
A	.oo4	.138	.077	1.2
E	.004	.173	.056	1.1
EB	.005	.297	.045	1.4
Bt1	.014	.875	.235	3.0
Bt2	.016	.529	.242	2.5
BC	.008	.266	.135	1.3
C1	.007	.166	.084	1.0
C2	.008	.148	.068	1.0
C3	.007	.123	.053	1.2

Ti is available in amorphous forms and subject to movement in the soil.

X-Ray Diffraction Analysis

Analysis of the x-ray diffraction pattern of the heavy minerals (Figure 10) indicated the presence of hornblende and mixed metal oxides. Hornblende was identified at the 3.15A peak. The mixed metal oxides are believed to be ilmenite, magnetite and variations of these. Ilmenite was identified at the 1.71A and 2.55A peaks. Magnetite was identifed by the 1.59A peak.
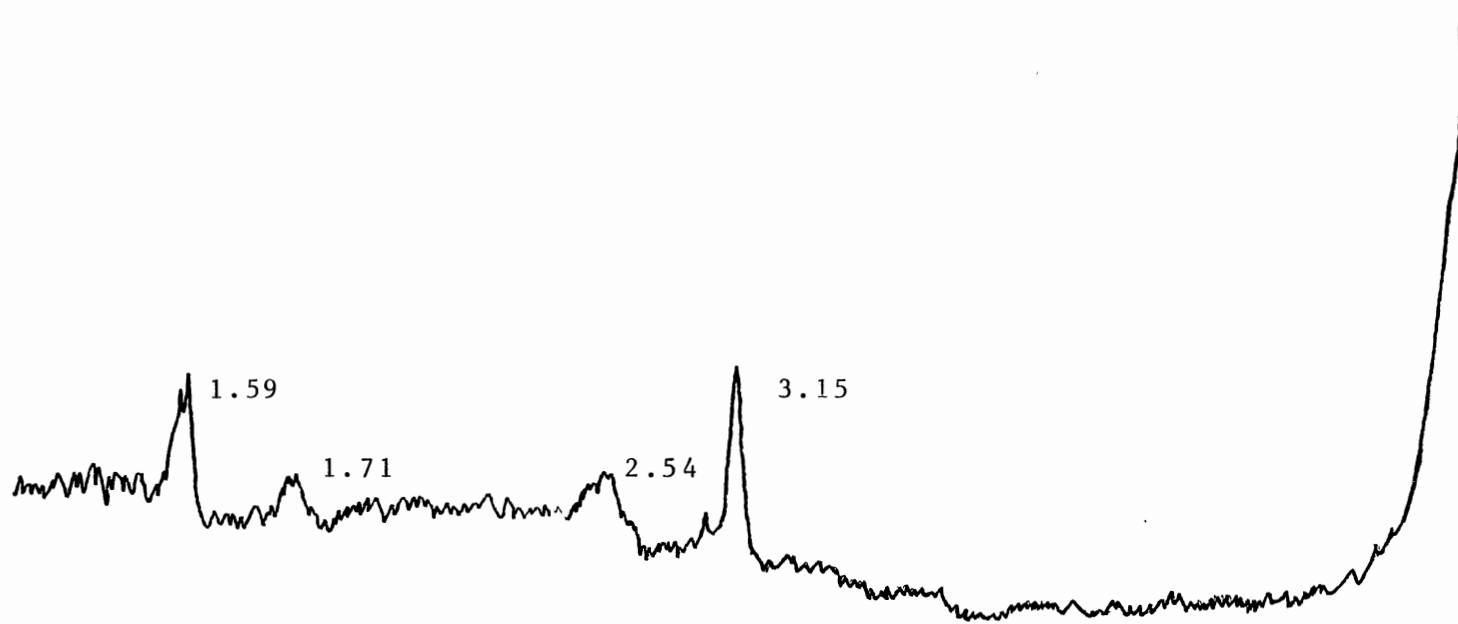
Figure 10. X-ray diffraction pattern of the heavy mineral isolate.

CHAPTER V

SUMMARY AND CONCLUSIONS

Initially Ti was determined in a soil formed from granodiorite to assess parent material uniformity. Clay free particle size analysis indicated a discontinuity between the E and B horizons (Table , Appendix). Likewise, the Ti distribution did not indicate parent material uniformity. The weathering profile as observed in thin section indicated uniform parent materials. Mineral composition remained consistent from the C horizon to the A horizon. No foreign minerals were present.

Titanium source and distribution of Ti were determined to evaluate weathering of Ti bearing minerals and mobility of Ti. Ti content determined by x-ray spectroscopy was found to increase from the silt to the clay fraction from the C horizon upward to the E horizon. This trend is indicative of the physical change of a mineral bearing Ti due to weathering. The Ti content of the fine clay fraction was found to be lower than that of the coarse clay fraction in all horizons. Since Ti was not found in greater quantities in the fine clay fraction it is possible that the minerals bearing Ti is this soil are not as

38

resistant as other Ti bearing minerals. The Ti content in the E horizon is notable because in the zone of maximum leaching increased Ti is found in the coarse clay fraction. This suggests that at least one form of Ti is not soluble.

Using the petrographic microscope, SEM and EDAX major Ti bearing minerals were identified. Solid solutions varying from sphene and ilmenite to TiO_2 and Fe_2O_3 were commonly found. Sphene was identified as the principal primary mineral source of Ti. Ti also occurred in biotite, ilmenite, hornblende, clay and pore coatings. No inclusions of TiO_2 were observed in the biotite or hornblende and therefore it is believed that the Ti is isomorphically substituted into the crystal lattice when the mineral originally formed in the rock. Evidence of Ti in the clay and pore coatings corresponds to the release of Ti from Ti bearing minerals as they weather. The appearance of Ti in the more easily weatherable minerals of biotite and hornblende as well as in clay and pore coatings supports the Ti distribution data. As the minerals bearing Ti weathered and changed particle size the Ti distribution shifted. Given the slight solubility of Ti as evidenced by the occurrence of Ti in river waters (Livingston, 1963) the total depletion of Ti from the upper horizons of the profile may be explained as losses due to leaching.

Oxalate extraction of total soil produced small but notable amounts of Ti. The Ti distribution was similar to iron. The increase in the Bt horizons and depletion of the

A and E horizons is indicative of translocation. Percent Ti on a total Ti basis indicates an increase in the amount of Ti removed from the Bt1 horizon over the horizons of larger Ti content. This trend further supports the translocation of Ti.

X-ray diffraction data further supported the mineral identification by microscopic techniques. Magnetite, hornblende, and ilmenite were identified among the mixed metal oxides of the heavy mineral fraction.

This study of Ti content of a granodiorite soil has given the following conclusions. Sphene, biotite, hornblende, and ilmenite weather to produce secondary Ti minerals and in amorphous material. Secondary products are removed from the A and E horizons into the B horizon as suggested by the oxalate extraction data.

As a result of this study, further research was found to be needed concerning the dissolution of Ti bearing minerals. Dissolution of sphene and ilmenite should be compared to anatse, rutile and brookite. Further identification of secondary forms of Ti is needed. A method of concentrating Ti minerals in the clay fraction which would not destroy any form of Ti is needed to adequately identify the Ti occurring in the clay fraction.

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APPENDIXES

APPENDIX A

PROFILE DESCRIPTION

Soil: Chigley

Location: Johnston County, OK

Slope: 1- 3 percent

Parent Material: Granodiorite

Vegetation: Forest with an understory of grasses

Soil Classification: Fine, mixed, thermic Udic Paleustalf

Soil Profile:

Horizon	Depth(cm)	Description
A	0- 8	Very dark gray (10 YR 3/1) gravelly sandy loam; weak coarse granular structure; loose; many fine and medium roots; 10 percent gravel by volume; 15 percent rock fragments; pH 5.8; clear smooth boundary.
E	8- 20	Dark brown (10 YR 4/2) gravelly sandy loam; weak medium subangular blocky structure; very friable; many fine and medium roots; 10 percent gravel by volume; 20 percent rock fragments; pH 5.7; gradual smooth boundary.
EB	20-33	Dark brown (2.5 YR 3/6) gravelly sandy loam; weak medium subangular blocky structure; very friable; roots are common; 15 percent gravel by volume; 20 percent rock fragments; pH 6.1; abrupt smooth boundary.
Bt1	33- 46	Dark red (2.5 YR 3/6) gravelly clay loam; moderately coarse subangular blocky structure; very firm; clay films on surfaces of peds; few roots; 10 percent gravel by volume; 10 percent rock fragments; pH 5.8; clear smooth boundary.
Bt2	46- 84	Red (2.5 YR 4/6) gravelly sandy clayloam; moderately coarse subangular blocky structure; very firm; thick clay films on peds; 10 percent gravel by volume; 10 percent rock fragments;pH 5.7; diffuse smooth boundary.

BC	84-112	Red (2.5 YR 4/6) gravelly sandy loam;weak coarse subangular blocky structure; firm; 15 percent gravel by volume; 10 percent rock fragments; pH 5.9; diffuse smooth boundary.
C	112- 257	Dark brown (7.5 YR 4/4) gravelly loamy sand; weak coarse subangular blocky structure; friable; matrix ped faces; 15 percent rock fragments; pH 6.1.

APPENDIX B

CHEMICAL COMPOSITION

TABLE IV

TYPICAL X-RAY SPECTROGRAPH RUN

Sample	Counts per 10 seconds						Peak - Background	PPM
	1	2	3	4	5	6		
Standards								
G-2	21123	20098	21137	21168	21736	21232	18951	2713
	2317	1859	2150	2588	2489	2281		
GSP	25052	24803	25180	24824	25172	25001	22717	3613
	1981	2551	2362	2393	2231	2284		
AGV	38726	38906	39084	39221	38431	38874	36476	6033
	2347	2456	2567	2284	2335	2398		
BCR	76516	76831	76194	77075	76886	76700	74526	12111
	2628	2246	2013	1846	2135	2174		
Fine Silts								
Bt2	40294	40467	40237	40923	39642	40313	35625	5693
	5488	5628	5598	3937	2790	4688		
BC	48119	49418	49400	51058	49182	49435	49342	7081
	5483	5305	5484	5778	5421	5494		
C3	84674	84743	84945	84616	84338	84705	82893	13593
	1613	1990	1774	1713	1808	1768		

r = 0.999172   y= 0.166689x - 244.61

TABLE V

PARTICLE SIZE DISTRIBUTION ON A CLAY FREE BASIS
AS A TEST FOR UNIFORMITY OF PARENT MATERIALS

		Percent	
Horizon	Depth (cm)	Sand	Silt
A	0- 8	66	34
E	8-20	76	24
EB	20-33	79	21
Bt1	33-46	66	34
Bt2	46-84	66	34
BC	84-112	83	17
C1	112-142	82	18
C2	142-188	80	20
C3	188-257	88	12

Source: Smith, Norman W. Unpublished Master's
thesis. Oklahoma State University, 1985.

APPENDIX C

MINERALOGICAL PROPERTIES

TABLE VI

QUALITATIVE ELEMENTAL IDENTIFICATION OF
MINERALS IN THIN SECTION

Feature	Horizon	Elements Identified	Peak
Opaque Mineral	E, Bt2, C	Si, P, Al, Mn, K Fe, Ca, Ti	KA KA,KB
Translucent Mineral	E, Bt2, C	Fe, Si, Al, K Ti, Ca	KA KA,KB
Isotic Cutan	C	Si, K, Al, Ca, Mg Fe, Ti	KA KA,KB
Pore Coating	C	Si, Al, K, Ca, Ti Fe	KA KA,KB
S-matrix	Bt2	Si, Al, K, Ti, Ca Fe	KA KA,KB
Biotite	E, Bt2, C	Si, Al, K, Mg Fe, Ca, Ti	KA KA,KB
Hornblende	E, Bt2, C	Si, Mg, Ti, K, Al, Mn Ca, Fe	KA KA,KB

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