Primary Sediment Production from Granitic Rocks in Southeastern Arizona

Item type	text; Thesis-Reproduction (electronic)
Authors	Acaba, Joseph Michael
Publisher	The University of Arizona.
Rights	Copyright © is held by the author. Digital access to this material is made possible by the Antevs Library, Department of Geosciences, and the University Libraries, University of Arizona. Further transmission, reproduction or presentation (such as public display or performance) of protected items is prohibited except with permission of the author or the department.
Downloaded	16-Sep-2016 04:51:41
Link to item	http://hdl.handle.net/10150/231212

PRIMARY SEDIMENT PRODUCTION FROM GRANITIC ROCKS IN SOUTHEASTERN ARIZONA

by

Joseph Michael Acaba

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOSCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 9 2

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Joseph M. Acaba

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Joseph F. Schreiber, Jr.
JOSEPH F. SCHREIBER, JR.
Professor of Geosciences

May 7, 1992
Date

ACKNOWLEDGMENTS

I would like to thank British Petroleum Exploration for providing financial support through their minority scholarship. I thank the owners of Adams Ranch, Post Ranch, and Empirita Ranch for allowing me access to their land. Use of the Mineral Separation Lab run by Muhammad Shafiqullah and X-ray equipment supervised by Wesley Bilodeau both in the Department of Geosciences, is greatly appreciated. I thank Dr. Austin Long, Department of Geosciences, for his revisions of the manuscript and addition of new ideas. Dr. David Hendricks, Department of Soil and Water Science, helped in clay mineral identification, allowed the use of his soil laboratory, and revised the manuscript; I appreciate is help. I gratefully acknowledge Dr. Joseph F. Schreiber, Jr., whose assistance throughout this entire thesis has been invaluable. His knowledge, advice, and criticisms are greatly respected and appreciated . Finally I would like to thank my entire family for their unending support throughout my education.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

LIST OF TABLES

ABSTRACT

Isolated granitic rock bodies (granites, granodiorites, quartz monzonites) in the vicinity of Benson in southeastern Arizona were studied to trace the behavior of rock weathering. Thin sections of fresh granites were examined to characterize the original mineralogy which consisted mainly of quartz, feldspars, and micas. The weathering products show up on the granites as grus and soil profiles as well as down slope in the basin deposits. X-ray diffraction studies of the < 2 micrometers fraction of the weathering products proved illite, smectite, illite-smectite mixed layer, and kaolinite to be the dominant clays; quartz and feldspar also persisted into this size fraction. Silt sized material produced similar results. The quartz monzonite of Texas Canyon afforded a special study of the initial weathering stages of feldspars and micas. In the < 2 micrometers fraction obtained from granitic material placed in an ultra sonic bath, the feldspars weathered to a Na-montmorillinite while biotite weathered to vermiculite.

CHAPTER 1

INTRODUCTION

Purpose of Study

The weathering of granitic rock bodies has been described by many authors (Fields and Swindale, 1954; Grant, 1963; Stoch and Sikora; 1975, Wang and others, 1980; and Cullers, 1988). The term granitic is used in the general sense to encompass the following igneous rocks: granite, quartz monzonite, and granodiorite. The majority of the studies on granitic rock weathering have been done in humid regions where chemical weathering is more intense. It is well known that climate plays a very significant role in rock weathering and soil formation. Retallack (1990) states: "During the founding period of soil science, climate was considered one of the most important factors in soil formation." Therefore the results reported in previous papers cannot be used directly in looking at weathering in more arid climates. Other studies, especially laboratory experiments, have opted to investigate the weathering of a particular mineral present in granitic bodies, such as feldspar or biotite (Berner and Holdren, 1979; Chou and Wollast, 1985; and Rebertus and others, 1986). While the studies mentioned above have described granitic weathering processes and products, they have left a gap in the subsequent changes brought on by soil formation and sediment transport in an arid environment.

The purpose of this study was to investigate the weathering process of granitic rocks from inception through stable soil formation to debris transported in the existing fluvial system. The approach used was to determine what minerals are present in the different stages of weathering in order to describe the processes that are occurring or have occurred.

SITE LOCATIONS

Five granitic rock field areas were chosen for this study. Each site provided an ideal situation in which to trace the behavior of the weathering rock with the least amount of contamination by other sources. Benson, Arizona, approximately 72.4 km (45 miles) southeast of Tucson, is centrally located to all of the study areas (Figure 1).

The first site is located in the Johnny Lyon Hills about 33.8 km (21 miles) northeast of Benson along the gravel but well- maintained Willcox-Cascabel Road. In this location the Johnny Lyon granodiorite crops out along the road in sections 19, 20, and 21, T.14 S., R.21 E. on the Dragoon 15 minute quadrangle and in section 24, T.14 S., R.20 E. on the Happy Valley 15 minute quadrangle. It covers almost an entire township east of the San Pedro river. Although the existing geologic maps show the terrain to the west of section 24 to be

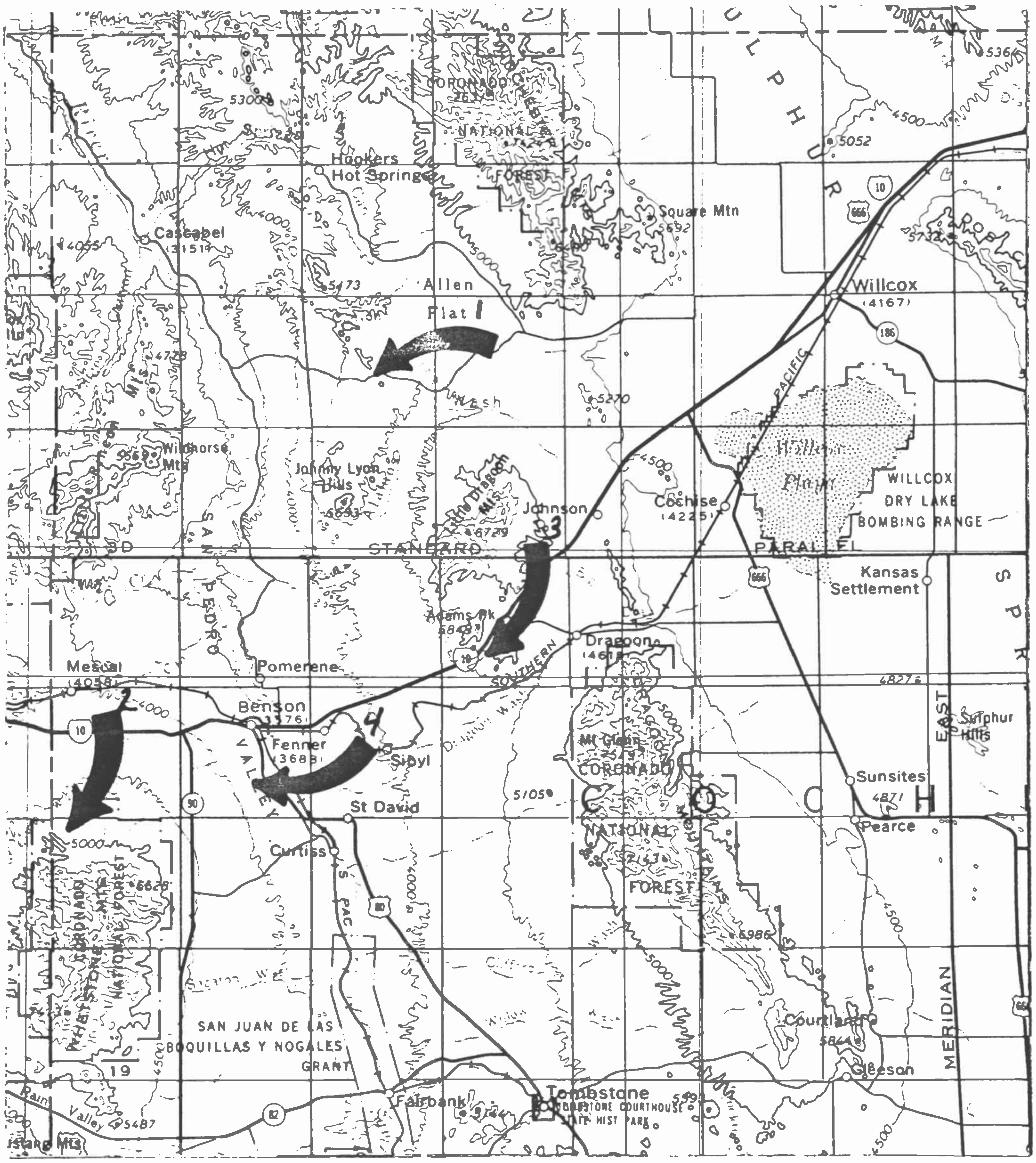

Figure 1. Site location map. 1=Johnny Lyon Hills, 2=Whetstone Mountains, 3=Texas Canyon, 4=Post Ranch and Apache Powder Plant Areas. Distance between townships is 6 miles (9.6 km).

covered by Quaternary alluvium, the granodiorite is in most places a few centimeters to 50-60 centimeters below the surface, and in many areas it crops out (Cooper and Silver, 1964; Drewes, 1980).

The second site is located at the northern end of the Whetstone Mountains approximately 9.7 km (6 miles) west of Benson, 4.8 to 6.4 km (3 to 4 miles) south of Interstate 10, and just west of Arizona State Highway 90. The granitic rocks (granite and granodiorite) crop out over an area of about 64 km^2 (25 $miles^2$) (Tyrrell, 1957). Erosion has removed a tremendous quantity of "granite wash" to the north, northeast, east, and southeast to form a giant apron (Gray, 1965). Granitic rock outcrops are accessible by numerous ranch roads which cross the slopes and hills. The "granite wash" crops out along I-10, State Highway 90, and in the numerous stream cuts immediately adjacent to the main granitic rock exposures.

The third site is the Texas Canyon area, located 29.0 km (18 miles) east of Benson on I-10 in the south end of the Little Dragoon Mountains. Quartz monzonite crops out on both sides of I-10 and weathers to typical pedestal rock topography (Leonard, 1927). Sampling was confined to the Adams Ranch located just south of I-10.

Additional sampling was done on the material called the "granite wash". The late Pleistocene "granite wash" consists mainly of weathered material from the granitic bodies in the

Whetstone and Dragoon Mountains. It overlies the Pliocene-Pleistocene St. David Formation (Gray, 1967) and covers an area of approximately 520 km^2 (200 $miles^2$). The fourth study area consisted of the "granite wash" in the hills and drainages east of the Post Ranch, which is located about 4.0 km (2.5 miles) south of Benson on U.S. Route 80 and covers sections 27, 28, 29, 30, 31, and 32, T.17 S., R.20 E. on the Benson 7.5 minute quadrangle.

The location called the "Apache Powder Plant Area" was the last study site to be sampled. This general locality is found on sections 13, 14, 23, and 24, T.18 S., R.20 E. on the McGrew Spring 7.5 minute quadrangle and sections 11 and 12, T.18 S., R.20 E. on the Benson 7.5 minute quadrangle. The majority of the samples taken here were from a cliff face showing the contact between the "granite wash" and the underlying St. David Formation.

Previous Work

Although work has been done in the above mentioned study areas, most are regional studies and have not described the granitic weathering products in any detail. Leonard (1927) discussed pedestal rock formations in Texas Canyon and briefly described the soils along with biotite and feldspar alteration. Further information on Texas Canyon along with the Johnny Lyon Hills can be found in the extensive work done by

Cooper and Silver (1964). Their studies were preceded by Silver (1956) who worked on the structure and petrology of the Johnny Lyon Hills, and Damon's (1959) geochemical dating of the igneous and metamorphic rocks in Arizona.

In the Whetstone Mountains, the geology of Middle Canyon, which includes the Whetstone Mountain granite, was first discussed by Burnette (1955). Tyrrell (1957) studied and mapped the stratigraphic units in the Whetstone Mountains for his doctoral dissertation at Yale University in some detail; Creasey's U.S. Geological Survey Map of the Benson Quadrangle was published in 1967. This was followed by Drewes' work (1981) on the tectonics of southeastern Arizona with mention given to the Whetstone Mountains.

Almost no work has been done on the "granite wash". Most geologic maps merely map it as part of the Quaternary alluvium (Drewes, 1980). Gray (1965) very briefly defines and discusses the "granite wash" in his doctoral dissertation.

CHAPTER 2

METHODS OF STUDY

Samples were collected from the different study areas in a manner that would best represent the entire weathering scheme. This included sampling four separate, yet interrelated parts of the study area. The first was the "fresh" granitic rock outcrop. The term "fresh" as used in this thesis refers to a granitic outcrop on which the least possible amount of weathering may be detected; for example, the feldspars still display a good vitreous luster and there is little sign of reddish iron-oxide formation from biotite or hornblende. The next area to be sampled was grus. The Johnny Lyon Hills, Whetstone Mountains, and Texas Canyon possess well developed grus, and though the thickness ranged from about 30 centimeters to over 2 meters, sampling was easy. This was followed by soil samples. Because most of the soils lacked a good A horizon, most soil samples were taken from the clay-rich B horizon. The final stage of weathering to be sampled was obtained from stream channel debris and soils developed along their banks.

Dry sieving was done on all of the unconsolidated materials mentioned above. This was accomplished by passing the sample through a series of sieves of one phi increments ranging from -2 phi to 4 phi. The material < 4 phi will be referred to as the pan fraction. After shaking in the Tyler Ro-Tap for ten minutes the amount of material remaining on each sieve was weighed and recorded. This sieving was done first to characterize the grain-size distribution, and second to obtain the pan fraction, which consisted of silt- and clay-size material.

The silt and clay fractions were obtained by sedimentation methods following Stokes' Law. Five to 10 grams of material were combined with 2.5 grams of sodium hexametaphosphate dispersant, a few milliliters of 30% H_2O_2, and distilled water, and then "mixed" in a Hamilton Beach blender for 10 minutes. The dispersant prevented flocculation while the hydrogen peroxide solution removed any organic matter. The < 2 micron fraction, in this study considered clay material, was separated by siphoning off material still in suspension at a certain depth and time according to Stokes' Law. After all of the clay was removed, the fine silt (7 and 8 phi; > 4 and < 15.6 microns) and coarse silt (5 and 6 phi; > 15.6 and < 62.5 microns) fractions were separated in a similar manner.

X-ray diffractometry was performed on selected silt and clay fractions. A Siemens D-500 diffractometer producing Cu K alpha radiation was used. All samples were run at 30 kilovolts and 40 milliamps, 2° theta per minute scan rate and 2 cm per minute chart speed. The majority of samples were scanned at a rate of 1 x 10^3 impulses per second. At other times the measuring rate was adjusted in order to enable a pattern to be interpreted as precisely as possible. Sample suspensions were transferred to glass slides with a medicine dropper in order to obtain a preferred basal oriented mount (Moore and Reynolds, 1989). They were then scanned from 3° 2 theta up to 65° 2 theta depending on the minerals being identified and the size fraction being tested. Various saturation and heat treatments, such as those described in Moore and Reynolds (1980) and Brown and Brindley (1980), were used in order to identify individual clay minerals and more commonly, mixtures of clay minerals.

Extractable iron tests were run on selected samples. This was done in order to characterize the total amount of extractable iron along with poorly crystallized, mainly ferrihydrite ($Fe_5(O_4H_3)_3$), and more crystallized, goethite (FeOOH) and hematite (Fe_2O_3), extractable iron. Total and poorly crystallized extractable iron were obtained by the dithionite-citrate and acid oxalate methods, respectively, as described by Blakemore and others (1987) and modified by Hendricks (personal communication, 1992).

Thin sections were prepared from fresh granites, other more weathered yet consolidated granites, along with selected unconsolidated material. They were viewed under both the petrographic and binocular microscopes in order to supplement information given in previous works as well as to supplement

X-ray diffraction data.

CHAPTER 3

CLIMATE

Benson is centrally located to the study areas; therefore its climate will be used as a reference. According to Sellers and others (1974):

> "Benson lies in a section of Arizona that receives most of its rainfall in July, August, and September, when moist unstable air invades the state from the Gulf of Mexico. Almost 60% of Benson's annual precipitation comes from these showers. A secondary wet season is experienced in winter, when very extensive storm systems move into the state from the Pacific Ocean."

The average daily maximum and minimum temperature is 26.8°C (80.3°F) and 7.3°C (45.2°F), respectively with an average yearly precipitation of 29 cm (11.40 inches) (Sellers and others, 1985). This brief description of climate of the Benson area places it and much of the surrounding region in an semi-arid climate (Hendricks, 1985).

Of the five soil-forming factors proposed by Jenny (1941) - climate, topography, biota, parent material, and time - climate may be the most influential. Ten glacial cycles have been documented in ocean floor and loess sequences in the last million years (Smiley and others, 1991). These changes in climate are also supported by paleobotanical, lacustrine, and geomorphological evidence found locally in the southwestern United States (McFadden and Tinsley, 1985).

Since the middle Pleistocene, deglaciation occurred approximately every 100,000 years with interglacial periods lasting approximately 10,000 years (Ruddiman and Wright, 1987). The majority of studies agree that during glacial times average temperatures were approximately 7-10°C cooler (Galloway, 1969; Brackenridge, 1978; Smiley, 1984). Also during glacial times there was a decrease in precipitation. Galloway (1983) states that annual precipitation in glacial periods was approximately 80% of present precipitation. The cooler temperature (decreased evaporation) and decreased rainfall would produce an increase in soil moisture (Brackenridge, 1978).

This makes it difficult to determine exactly when the majority of soil formation has taken place. Hendricks (1985) states: "The properties of soil which are evident today are not always a reflection of the present climate. In fact climate conditions of the past have probably been more influential in the creation of present soil characteristics."

There are two possible ways of looking at the effect of climate on the rates of soil formation in southeastern Arizona. First, one can say that the more moist climate of the past had a greater influence on the overall weathering of parent material and thus the creation of soils. On the other hand, it can be stated that as soils develop, an accumulation of fines and other soil material can create " a less permeable soil with commensurate increases in water-holding capacity" (McFadden, 1988). This increase in water-holding capacity could in turn lead to an increase in chemical weathering. At this time the debate over the effects of paleoclimate versus present climate on weathering has not been adequately settled.

CHAPTER 4

ILLITE/ILLITE-SMECTITE MIXED LAYERING

A brief note should be given on illite and illite-smectite interstratifications before the mineralogy of the weathering products are discussed. The definition of illite depends upon the scientific field defining it (Fanning and others, 1989). The definition of illite used in this paper is that proposed by Srodon and Eberl (1984): "illite refers to a nonexpanding, dioctahedral, aluminous potassium mica-like mineral which occurs in the clay-size fraction." It is identified in X-ray diffraction patterns by a basal spacing peak at 10 Angstroms along with peaks at 4.98, 3.34, 2.58, and 1.99 Angstroms. For a more comprehensive definition, see Clay Minerals Society Nomenclature Committee (1984).

Mixed layer clays, particularly illite-smectite in this study, present a problem in describing the order/randomness of the mixed layer along with the percentage of each end member. Illite-smectite mixed layers have been studied and described by many authors (Reynolds and Hower, 1970; Srodon, 1981; Srodon, 1984; and Eslinger and others, 1988). One reason for all this effort is that "illite-smectite interstratifications are the most common clay components of sedimentary rocks and are the most sensitive clay indicators of the degree of diagenesis and low-grade metamorphism (Srodon, 1980)."

In this study the < 2 micrometers clay fraction was separated by conventional sample preparation techniques (see Methods of Study). For this and other reasons the available literature was little help in characterizing the mixed layers. Reynolds and Hower (1970), one of the most referenced papers on this subject, used computer generated patterns that were not applicable to this study. Srodon (1980, 1981, and 1984), a leader in the study of illite and illite-smectite mixed layers, examined mixed layers in the < 0.2 micrometers fraction which is generally free of other minerals. His techniques also could not be used, especially on material <2 microns. He sums up the problem of mixed layering very well: "Based on the author's experiences with illite-smectites in mixtures with illite, there is no universal identification approach applicable to the whole range of mixed-layering" (Srodon, 1981). For the above mentioned reasons, only the presence and relative amount of these mixed layered clay minerals will be discussed.

CHAPTER 5

WINDBLOWN CONTRIBUTIONS

The contamination of soils in arid regions by eolian dust is another uncertainty that must be discussed. It has been shown that eolian dust is a major contributor of secondary carbonates (Giles and others, 1966; Lattman, 1973) and fines (McFadden, 1988). McFadden states that an excess of silt from that which would be produced by the parent material is indicative of windblown contributions. However, this view is not universally accepted. Borchardt and Hill (1985) state that an "increase in silt (in lower horizons) exceeding that of the parent material should indicate in situ weathering." Unlike clays, silt and sand sized material is not normally translocated to lower horizons in medium textured soils. These contradictions made it necessary to do additional sampling in order to characterize the effects of windblown debris.

Samples were taken of material resting on the Bolsa Quartzite in both the Whetstone Mountains and the Johnny Lyon Hills. Because little to no weathering and in situ clay production takes place on quartzite, the debris deposited on it must be windblown. In the northwest corner of the Whetstone Mountains one sample locality was the ridge crest on the Bolsa Quartzite (Cambrian) on Haystack Mountain. This area is accessible via ranch roads on the Empirita ranch. The lowest 45 to 50 feet of the Bolsa Quartzite, which is feldspathic, is located well below the ridge crest. X-ray patterns of the < 2 micrometers fraction, separated from what is most probably windblown material resting on Bolsa Quartzite from Haystack Mountain showed illite as the main clay mineral with a trace of smectite and kaolinite. Small amounts of quartz and feldspar were also present. In the fine silt fraction, illite is even better displayed than in the clay fraction with a noticeable increase in kaolinite and less smectite.

Samples of the debris on top of granite in a nearby location, contained smectite in equal amounts to kaolinite and illite. Once again only a small amount of quartz and feldspar is present. The fine silt fraction was very similar to the fine silt fraction mentioned above with less smectite and more kaolinite than the clay fraction.

The main difference between the material on the Bolsa Quartzite and the material on the nearby granite is the greater proportion of kaolinite and smectite on the granitic debris. This indicates that the excess smectite and kaolinite is due to the weathering of the granite. It is also possible that the illite derives from either in situ weathering, windblown transportation, or both.

The same sampling process was carried out on the Bolsa Quartzite in the Johnny Lyon Hills. The Johnny Lyon Granodiorite/Bolsa Quartzite contact is well exposed in the road cut along the Willcox-Cascabel road and on the ridge to the north (Figure 2). This is a prime locality to see the effects of windblown dust. Here the < 2 micrometers Bolsa material contained smectite $\geq$ illite and a trace of kaolinite. Compared to the < 2 micrometers fraction the fine silt fraction lost the smectite and had less illite and kaolinite. As usual there was the increase in quartz and feldspar in the fine silt.

Debris derived from the granite in the same general area contains more illite, kaolinite, smectite, and mixed layered clays than the debris on the quartzite. Again the increase in kaolinite and smectite along with the introduction of mixed layered clays, must be due to the weathering of the granitic body.

In addition to the analyses described above, the carbonate content of selected samples was determined. The presence of carbonates in the sediment produced from the granitic rocks could indicate eolian contributions. Determinations by the microdiffusion method (Bundy and Bremner, 1972) indicate extremely small amounts of carbonate in all samples selected (Table 1). In fact, the debris lying on quartzite in both the Johnny Lyon Hills and the Whetstone Mountains contained an order of magnitude less carbonate than material derived from the granitic rocks in these same locations. The "granite wash" from the Apache Powder Plant Area with 0.13% carbonate was the only material to contain a

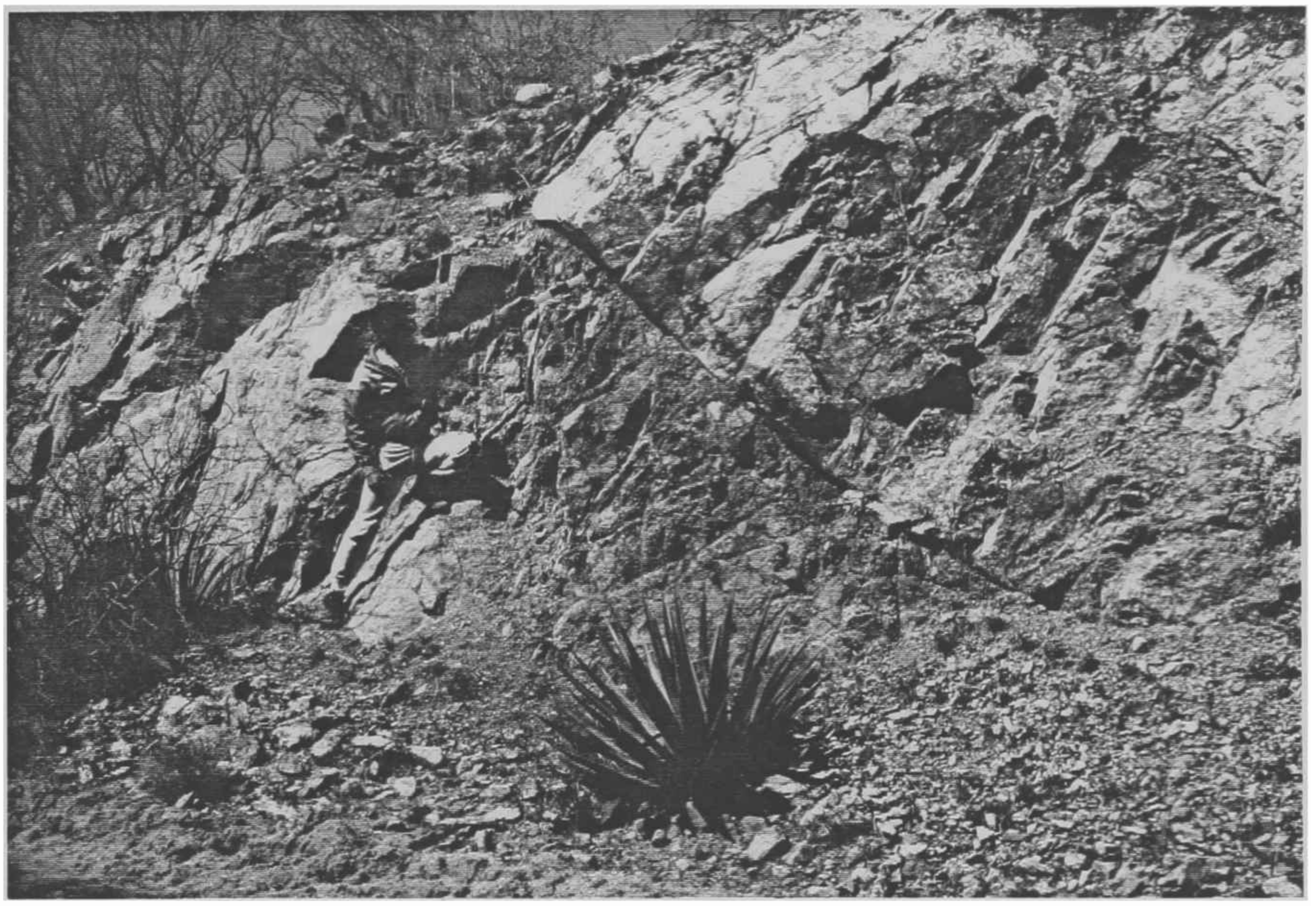

Figure 2. Johnny Lyon Granodiorite/Bolsa Quartzite, Johnny Lyon Hills.

Table 1. Carbonate results from the five study areas. (See Appendix A for sample locations) Note: A percentage of zero is given for samples with less than 0.001% carbonate.

SAMPLE	DESCRIPTION	% CARBONATE
JLH-4	SOIL ON GRUS	0.00
JLH-11	WINDBLOWN/QUARTZITE	0.00
WM-11	SOIL ON GRUS	0.00
WM-14	WINDBLOWN/QUARTZITE	0.00
WM-16	DEBRIS ON GRANITE	0.00
AR-5	SOIL ON GRUS	0.00
PRA-1	STREAMBED	0.00
PRA-3	STREAM BANK	0.00
AP-6	GRANITE WASH	0.13
AP-9a	GRANITE WASH	0.048

significant amount of carbonate. This higher amount would be expected from material which has gone though the cycle of weathering-transportation-deposition. Dust collected during the Desert Project in southern New Mexico contained between 1.3-5.7% carbonate (Giles and others, 1981). The low carbonate content of the material sampled in this study is another indicator of in situ weathering with little contribution from windblown material.

In general, the material deposited on quartzite (assumed to be primarily windblown) differs from that weathered on granitic rock. Care was taken when sampling the granite, grus, and soils in order to minimize the possibility of contamination by windblown material. Also, there does not appear to be an excess of either secondary carbonates or fines which can be indicators of eolian contamination. While the author appreciates the possible contributions of windblown debris, he feels secure that the data obtained in this study truly represents weathering in place. It should also be noted that samples taken from stream channels and the "granite wash" (Post Ranch and Apache Powder Plant Area) are much more susceptible to contamination from windblown dust.

CHAPTER 6

JOHNNY LYON HILLS

Introduction

The Johnny Lyon Granodiorite (Damon, 1959; Cooper and Silver, 1964) is the source of the weathering products sampled from the Johnny Lyon Hills. This Precambrian granodiorite unconformably underlies the Cambrian Bolsa Quartzite. Since little to no weathering occurs on the quartzite, the Johnny Lyon Hills is an excellent area in which to trace the weathering of the granodiorite with almost no outside contamination.

Cooper and Silver (1964) described the granodiorite in hand specimen as "a medium- to coarse-grained somewhat porphyritic gray to gray-green hornblende-biotite granodiorite." In thin section they described it as "medium to coarse grained hypidiomorphic-granular, commonly with a slight seriate porphyritic texture." Estimates of the major constituents were given as follows: quartz-25%, plagioclase-44%, K-feldspar-13%, biotite-9%, hornblende-5%, and sphene-0.5%.

Initial weathering of many granitic rocks is due to the expansion of biotite. Fordham (1989) succinctly states that "oxidation of iron in biotite causes internal stresses which are relieved by physical deformation of the crystals." In the field one can see how unconsolidated a granite can become even in the early stages of weathering (Figure 3). Joint control also plays an important role in determining how the granodiorite weathers (Figure 4).

Grus is an important stage in granitic weathering and is often only briefly studied or overlooked completely. Grus, as defined by Bates and Jackson (1980), is: "the fragmental products of in situ granular disintegration of granite and granitic rocks." The grus in the Johnny Lyon Hills, Whetstone Mountains and Texas Canyon yielded much information for this study. As stated earlier, grus with thicknesses of 2 meters or more, were well exposed in road cuts and fluvial channels making sampling fairly easy. The author was indeed fortunate to be able to view and sample such well developed grus which gave interesting results.

X-ray Results

The dull orange (7.5YR 6/4) grus, the initial stage of granitic weathering, will be discussed first. The clay minerals present in the < 2 micrometers fraction are illite-smectite mixed layers > smectite $\geq$ illite > kaolinite. These approximate relative amounts were attained by viewing the area under the curve produced by the (001) peaks. Traces of possible hydrobiotite were present. Quartz and feldspar from the parent material were also present in trace amounts (Figure 5).

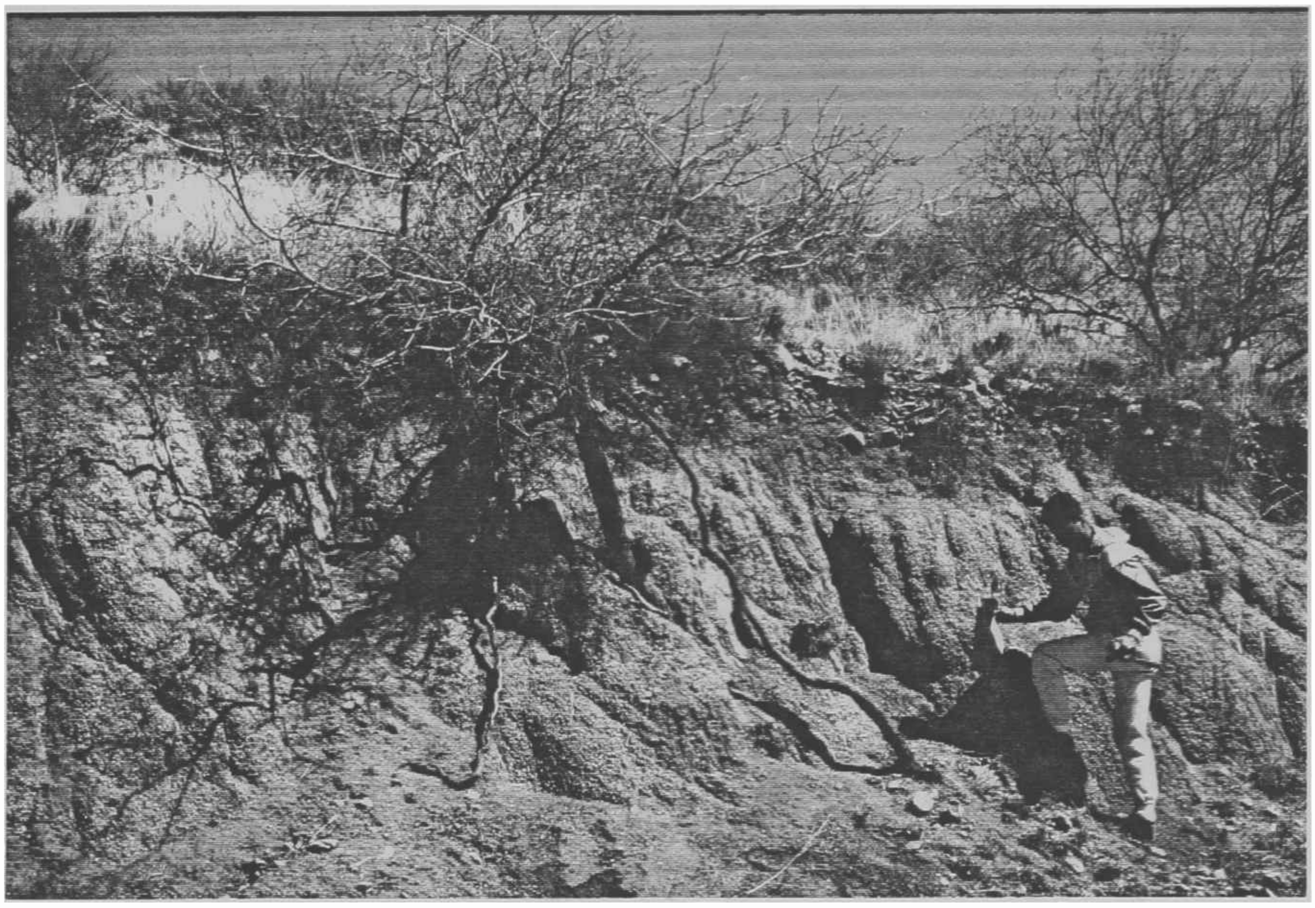

Figure 3. Grus formation on the Johnny Lyon Granodiorite, Johnny Lyon Hills.

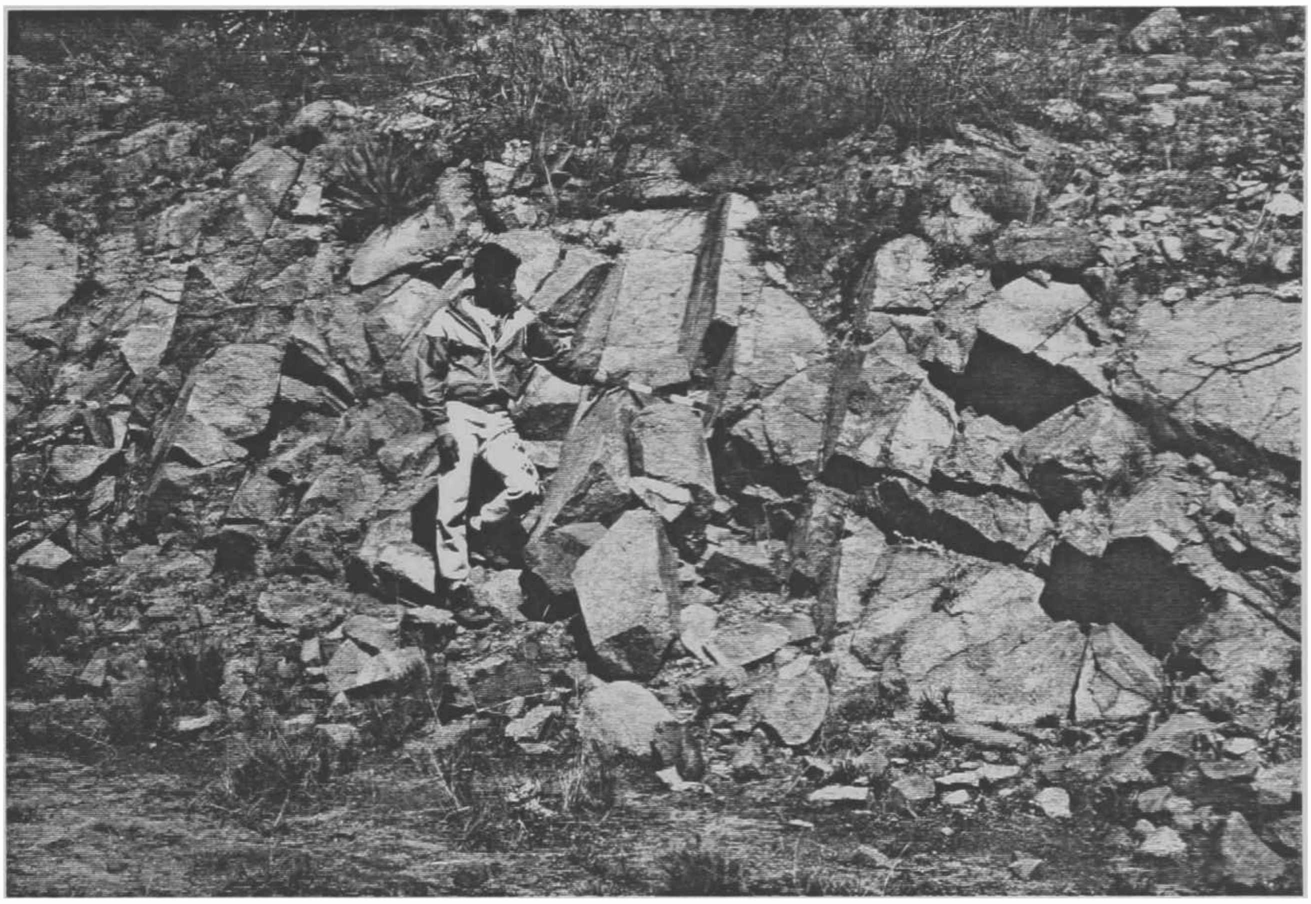

Figure 4. The role of jointing in the weathering of the Johnny Lyon Granodiorite, Johnny Lyon Hills.

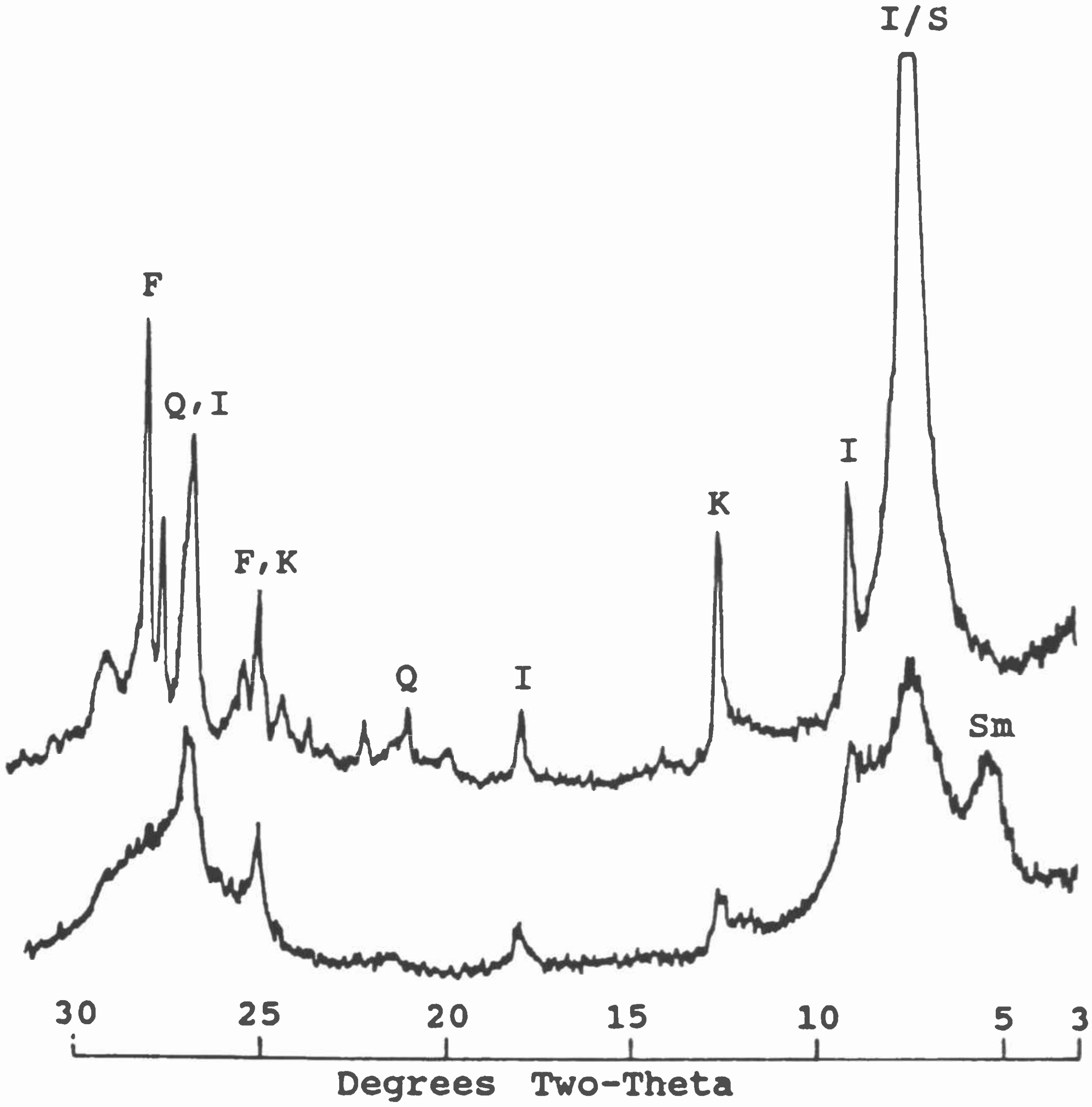

Figure 5. X-ray diffraction pattern of grus formed from the Johnny Lyon Granodiorite. Bottom: < 2 micrometers. Top: fine silt. I=illite, Sm=smectite, I/S=illite smectite mixed layer, K=kaolinite, F=feldspar, Q= quartz.

X-ray diffraction of the fine silt fraction (7 and 8 phi) produced a different pattern (Figure 5). It contained an illite-smectite mixed layer > illite $\geq$ kaolinite with still minor traces of hydrobiotite. Quartz and feldspar of the parent material dominate this size fraction.

A very clay-rich, iron-stained, dark reddish brown (5YR 3/3) soil formed on the grus produced a slightly different pattern. Here illite > kaolinite > smectite with small amounts of illite-smectite mixed layers. The kaolinite in this sample is better crystallized and is much more pronounced than in the grus.

The debris derived from the grus and soils eventually transports through the existing fluvial system producing stream sediments composed of quartz and feldspar grains that are not too different in size from the original granodiorite. The fine grained weathering products are removed in suspension. This process is very quick in stripping the debris of its iron stain leaving it a dull orange (7.5YR 7/3) (Figure 6). X-ray patterns of stream sediments indicate the "working" and destruction of the minerals present. Smectite peaks are broad and only trace amounts of illite and kaolinite are found. The feldspar peaks are also diminishing compared to the grus and soil samples.

"Free" Iron Oxide Analysis

The "free" iron oxide analyses showed a slight increase

Figure 6. The stripping of the red iron oxides after entering the fluvial system, Johnny Lyon Hills.

in the total amount of free iron oxide from the grus to the soil with a decrease in ferrihydrite and corresponding decrease in the Crystallinity Index (percent ferrihydrite/percent total free iron oxide ratio) (Table 2). This confirms the almost obvious fact that soil has undergone more weathering than the grus and is nearer to a climax stage (McFadden and Hendricks, 1985).

Thin Section Descriptions

Evidence of initial weathering can be seen even in thin sections of "fresh" granite. Unaltered biotite grains in this location are usually brown to reddish brown and pleochroic. It also has high birefringence in the third or fourth order (Nesse,1986). Biotite is undergoing two phases of alteration. First, the typical brownish black color is "bleached" to a medium green color because of the loss of iron (Folk, 1980). Second, the biotite is becoming chloritized. One can distinguish between bleached biotite and chlorite by the lower birefringence colors (in this case a dark blue) of chlorite.

In general the potassium feldspars show less evidence of weathering than the plagioclase feldspars. Almost all of the feldspar grains have a turbid appearance (Figure 7). Folk (1980) states that: "water-filled vacuoles are responsible for the cloudy, brownish appearance of altered feldspars, and vacuolization is the most common type of alteration." The more weathered plagioclase crystals are being altered to sericite.

Table 2. Results of the iron analyses from the five study areas. (See Appendix A for sample locations)

SAMPLE	DESCRIPTION	% TOTAL FREE IRON OXIDE	% FERRIHYDRITE	CRYSTAL. INDEX
JLH-1	GRUS	2.324	0.210	0.090
JLH-4	SOIL	2.453	0.208	0.085
WM-3A	SOIL	2.826	0.377	0.133
WM-11	GRUS	1.442	0.237	0.164
AR-5	SOIL	1.752	0.286	0.163
AR-7	GRUS	1.225	0.227	0.185
PRA-9	HILLS	1.483	0.208	0.140
PRA-16	STREAM BANK	1.995	0.244	0.122
AP-3	CLAY RICH	1.355	0.172	0.127
AP-6	NON CLAY RICH	0.506	0.072	0.142

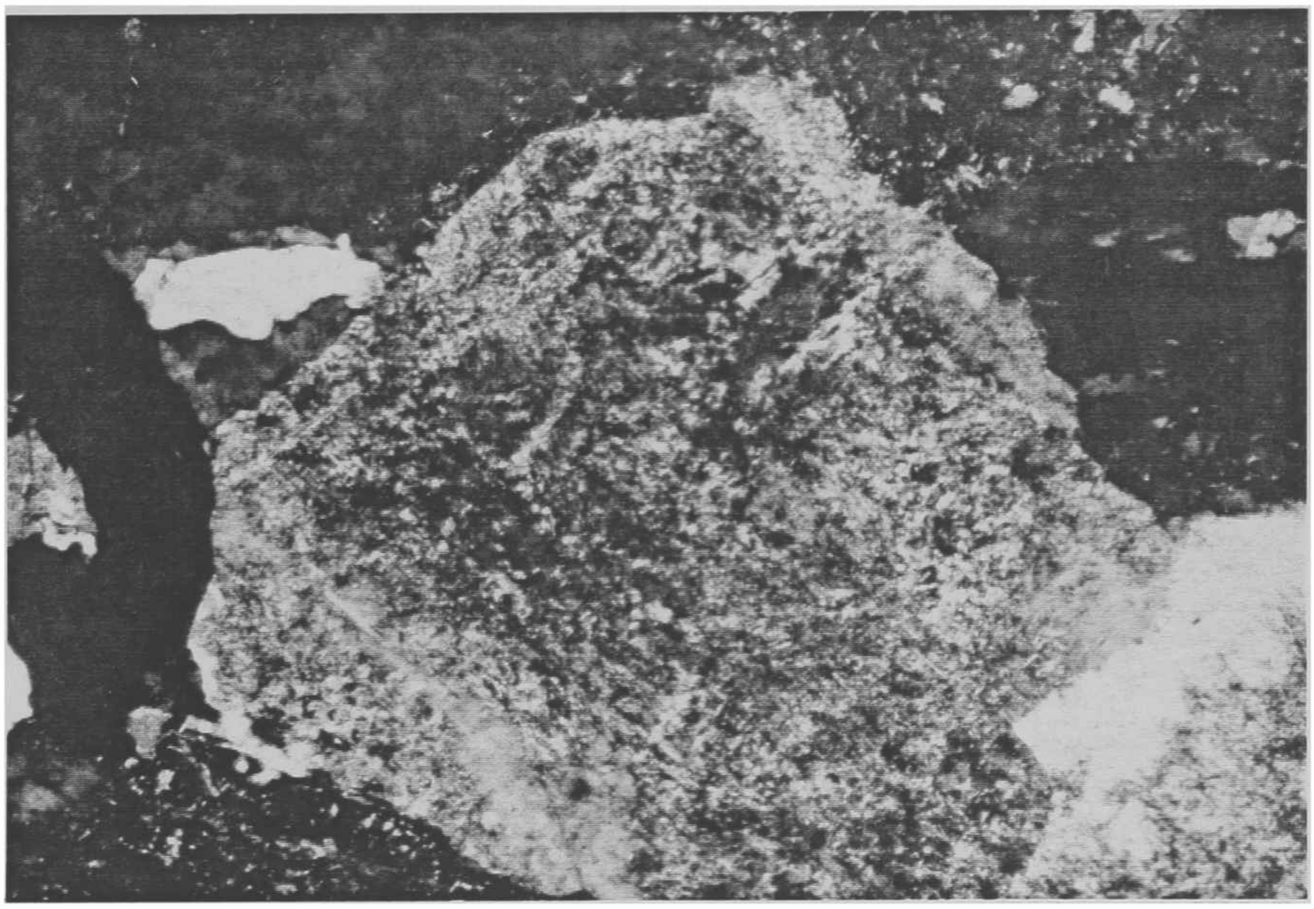

Figure 7. Turbid feldspar grain, Johnny Lyon Hills, Crossed polars. Length of the grain is 1.8 mm.

This is a common occurrence with the sericite forming along cleavage and twin planes. In the text of this study sericite is defined as a very fine grained mica, similar to a muscovite depleted of some potassium (Folk, 1980). X-ray diffraction of sericite would probably give a pattern similar to illite. The quartz and hornblende present in the granodiorite show no visual signs of alteration.

Summary

As the granodiorite is transforming from the grus to soil stage, there is a loss in the mixed layered clays and the smectite. At the same time there is an increase in both illite and kaolinite. The formation of free iron oxides also increases. As the weathering debris enters the fluvial system there is a general loss of the clay minerals and the less resistant parent material minerals, in particular the plagioclase feldspars (Figure 8). Thin sections show the chloritization of biotite and the alteration of plagioclase to sericite. Potassium feldspars are less weathered than the plagioclase feldspars.

GRANODIORITE

Color

7.5YR 6/4 Grus

I/S > Sm > I > K} < 2 micrometers (clay)

I/S > I ≥ K >> H.B.} f/silt

5YR 3/3 Soil

I > K > Sm >> I/S} < 2 micrometers (clay)

7.5YR 7/3 Stream Channel

broad Sm, trace of I and K} < 2 micrometers (clay)

Figure 8. Summary of the weathering in the Johnny Lyon Hills. I/S= illite-smectite mixed layer, Sm=smectite, I=illite, K=Kaolinite

CHAPTER 7

WHETSTONE MOUNTAINS

Introduction

The northern Whetstone Mountains are also an excellent location in which to view the effects of granite weathering. Tyrrell (1957) described the Precambrian granite in hand specimen as "a medium to coarse (grains average 2 to 10 mm.) equiangular pinkish rock; commonly the rock is porphyritic and contains phenocrysts of feldspar up to 3 inches long." In thin section he describes it as mica (muscovite and biotite) rich. Examination of hand specimens and thin sections of the granite in four sites within this study area reveal no biotite; muscovite is the only mica present. Estimates of the major minerals present are: quartz (30%), orthoclase (30%), microcline (10%), albite (20%), and micas (10%).

X-ray Results

X-ray patterns of the dull reddish brown (5YR 4/3) grus produced results very similar to those of the Johnny Lyon granodiorite. The clay minerals present in the $<$ 2 micrometers size fraction are illite-smectite mixed layers $>$ illite $\geq$ smectite $>$ kaolinite. Good feldspar peaks are present with only small amounts of quartz detected. This small amount of quartz is probably due to the fact that quartz is extremely resistant to weathering and is just not being reduced to grain sizes this small.

As soil development proceeds, the mixed layered clay is lost, there is an increase in equal amounts of smectite and illite, and the color becomes more red (2.5YR 4/4). Kaolinite begins to appear with good quartz and feldspar peaks. In the dark reddish brown (5YR 3/2) A horizon of the same soil, illite is the dominant clay. It is followed by subequal amounts of kaolinite and smectite. The A horizon is similar to the underlying clay-rich horizon except that smectite is present in only trace amounts.

"Free" Iron Oxide Analysis

The iron analyses in the Whetstones produced results similar to the Johnny Lyon Hills (Table 2). There is almost twice as much total free iron in the clay-rich soil horizon as in the grus. The crystallinity index is also less in the soil. Once again this indicates a greater degree of weathering.

Thin Section Descriptions

Upon viewing of the "fresh" granite in thin section, a few observations can be made. The feldspar grains are "cloudy", with mainly the plagioclase altering to sericite (Figure 9). Large muscovite crystals are the only mica present. There is no evidence of bleached or unaltered

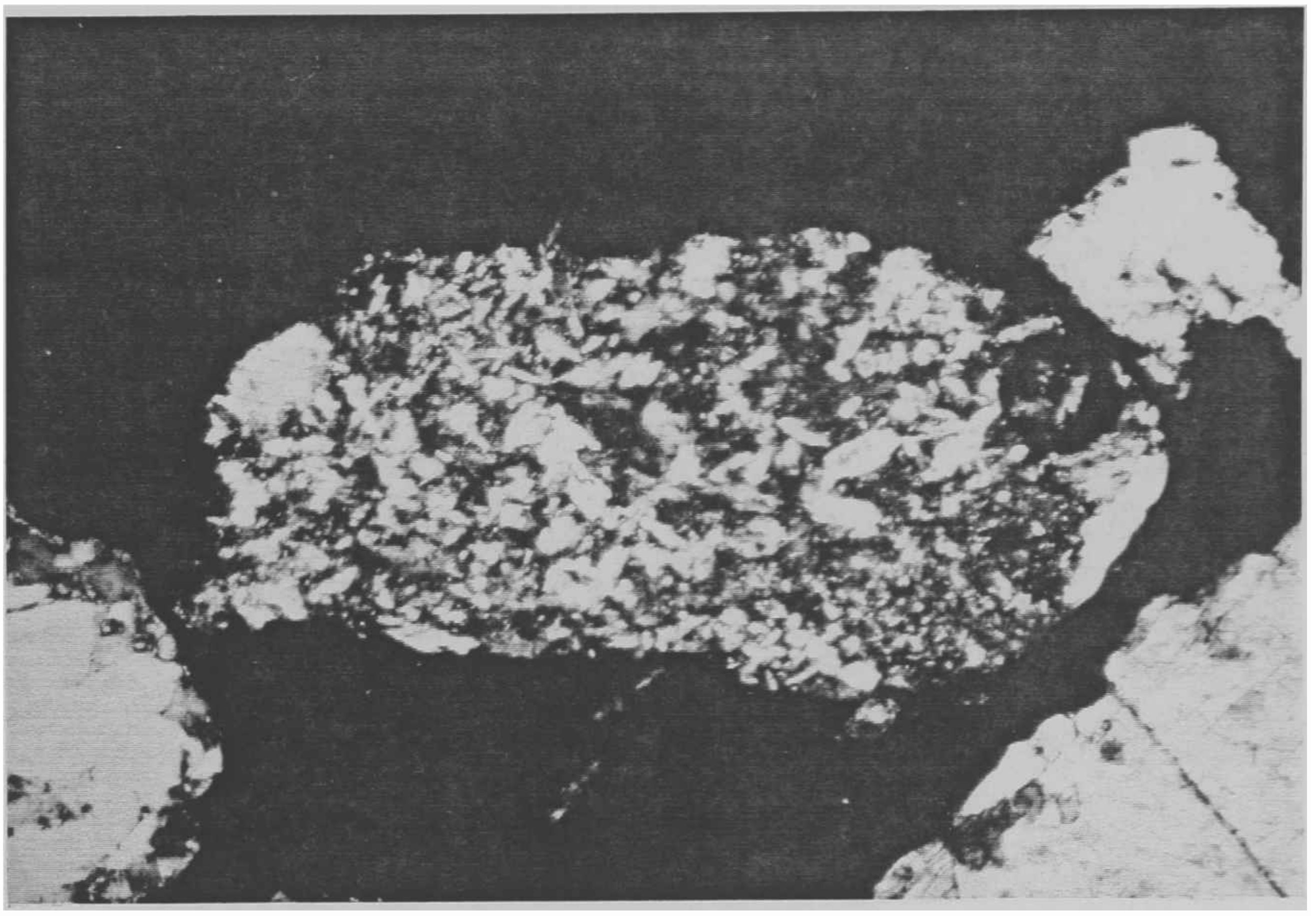

Figure 9. Feldspar alteration to sericite, Whetstone Mountains. Crossed polars. Length of grain is 0.71 mm.

biotite. Muscovite is a rather stable mica (Velbel, 1984) and therefore shows no sign of incipient weathering. The unaltered quartz grains can be quite euhedral. Epidote is present in "accessory" amounts, and probably is derived from the alteration of potassium feldspar.

Summary

In summary, as the granite goes from grus to a clay-rich soil it loses the illite-smectite mixed layered clay. At the same time smectite and illite become more prevalent. The amount of smectite is lower in the soil's A horizon than in the clay-rich soil horizon. Through the entire process there is a gradual increase in kaolinite (Figure 10).

GRANITE

Color

5YR 4/3 — Grus

I/S > I $\geq$ Sm > K} < 2 micrometers (clay)

2.5YR 4/4 — Soil

Sm $\geq$ I > K} < 2 micrometers (clay)

5YR 3/2 — A Horizon

I > K $\geq$ Sm} < 2 micrometers (clay)

Figure 10. Summary of the weathering in the Whetstone Mountains. I/S=illite-smectite mixed layer, I=illite, Sm=smectite, K=kaolinite

CHAPTER 8

TEXAS CANYON

Introduction

Texas Canyon is the third prime location to see the effects of granite weathering. The Texas Canyon Quartz Monzonite weathers to typical pedestal rock formations. All phases of weathering, accelerated by the presence of extensive jointing, can be recognized and described very easily. Weathered debris travels westward through the existing fluvial channels and is eventually deposited in the San Pedro River. The quartz monzonite has been radiometrically dated at 50 Ma. B.P. and is near the Laramide-Post Laramide boundary (Drewes, 1976).

The quartz monzonite was also described by Cooper and Silver (1964). Large potassium feldspar grains, up to 10 centimeters long, are "in medium - grained groundmass of quartz, feldspar, and biotite." Estimates of the major rock forming minerals are as follows: quartz (30-35%), plagioclase (30-40%), potassium feldspar (25-30%) and mica (5%). At this locality there are similar amounts of both biotite and muscovite.

X-ray Results

The light gray (7.5YR 8/1) grus contained clay minerals similar to those at the first two locations. The clay fraction contained illite-smectite mixed layer > smectite > illite $\geq$ kaolinite. However, in this locality the grus clay fraction also contained significant amounts of quartz and feldspar. The presence of quartz in this size fraction could be due to the smaller quartz crystals which are very abundant inclusions within individual feldspar grains. As the feldspar grains are weathered and destroyed, the more resistant quartz grains are released.

The reddish brown (5YR 4/6), clay-rich soil developed on the grus lost the illite-smectite mixed layered mineral completely and had some loss of smectite. Illite and kaolinite are the dominate clay minerals. Unlike the grus, there is almost no quartz or feldspar present in the clay-rich soil.

The stream channel sediment contained approximately equal amounts of illite and smectite, both in small amounts. A weak kaolinite pattern occurs. Quartz and feldspar peaks are also present. Again, transportation in the fluvial system is quick to remove the iron staining minerals, leaving the debris light gray (7.5YR 8/2).

"Free" Iron Oxide Analysis

The iron analyses again produced similar results as in the first two locations (Table 2). Percent total free iron oxides was greater in the soil than in the grus. The crystallinity index, which is the ratio of percent ferrihydrite to percent total free iron oxides, was less in the soil than the grus which indicates a greater degree of weathering in the soil.

Thin Section Descriptions

Thin sections of material representing various stages of weathering allowed one to see the corresponding alteration products. The micas separated from the quartz monzonite (see A Special Study section below) were mounted on a petrographic slide. In reflected light a few observations could be made. The iron removed from the biotites was quick to form red iron oxide haloes around both the muscovite and biotite. At times this iron oxidation is quite extensive with only the core of the mica being unaffected. The expansion of the biotite can also be seen in reflected light. This enables an observer to appreciate how a usually small component of a granite can destroy the integrity of an otherwise durable rock.

At this locality it can be difficult to differentiate between muscovite and bleached biotite. When chloritization is occurring it can be said that the mica being altered is biotite, because muscovite does not alter to chlorite. Excellent examples of chloritization can be seen (Figure 11). Incipient formation of hematite in a mica can be identified (Figure 12).

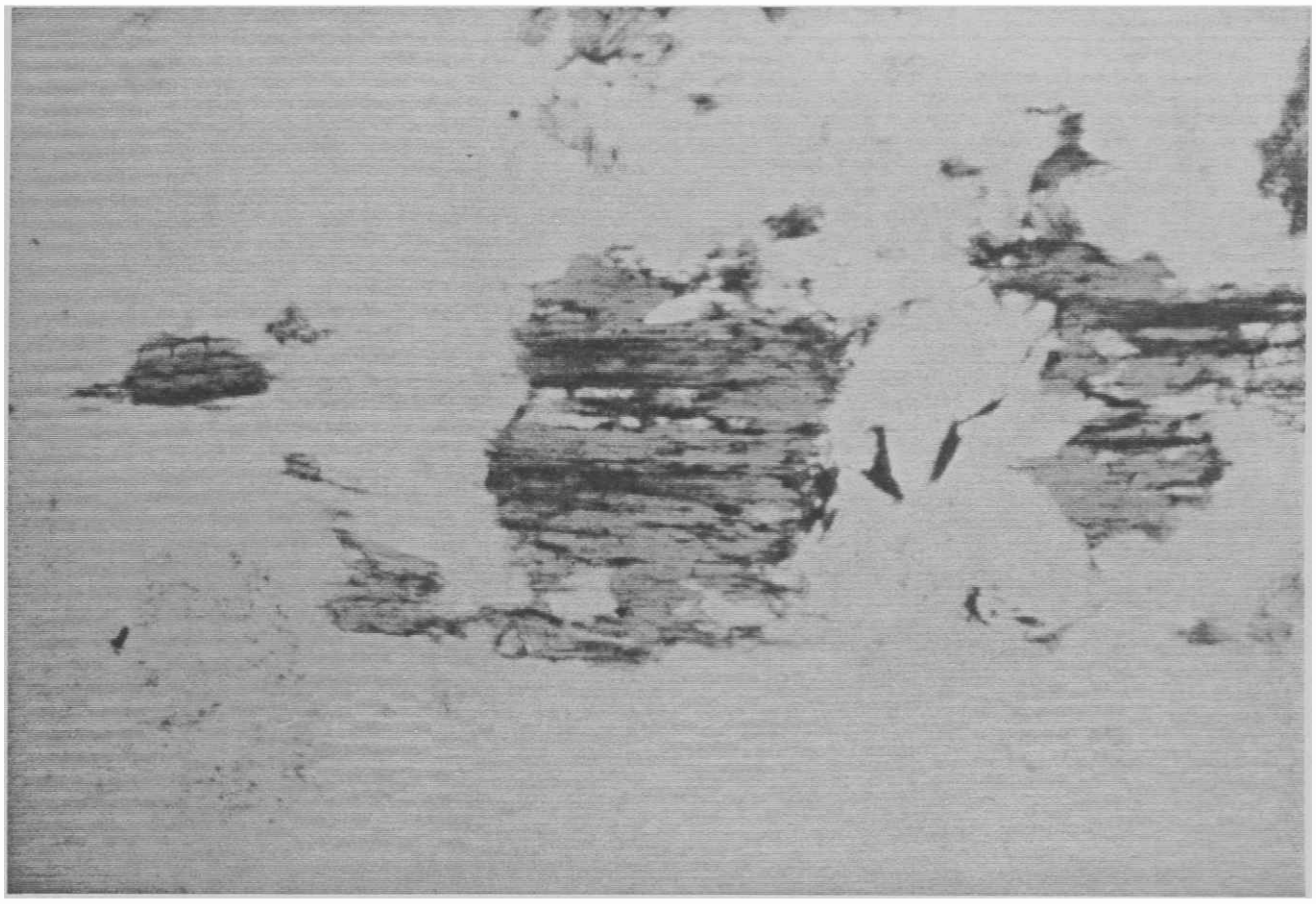

Figure 11. Biotite altering to chlorite, Texas Canyon. Plane polarized light. Length of grain is 0.58 mm.

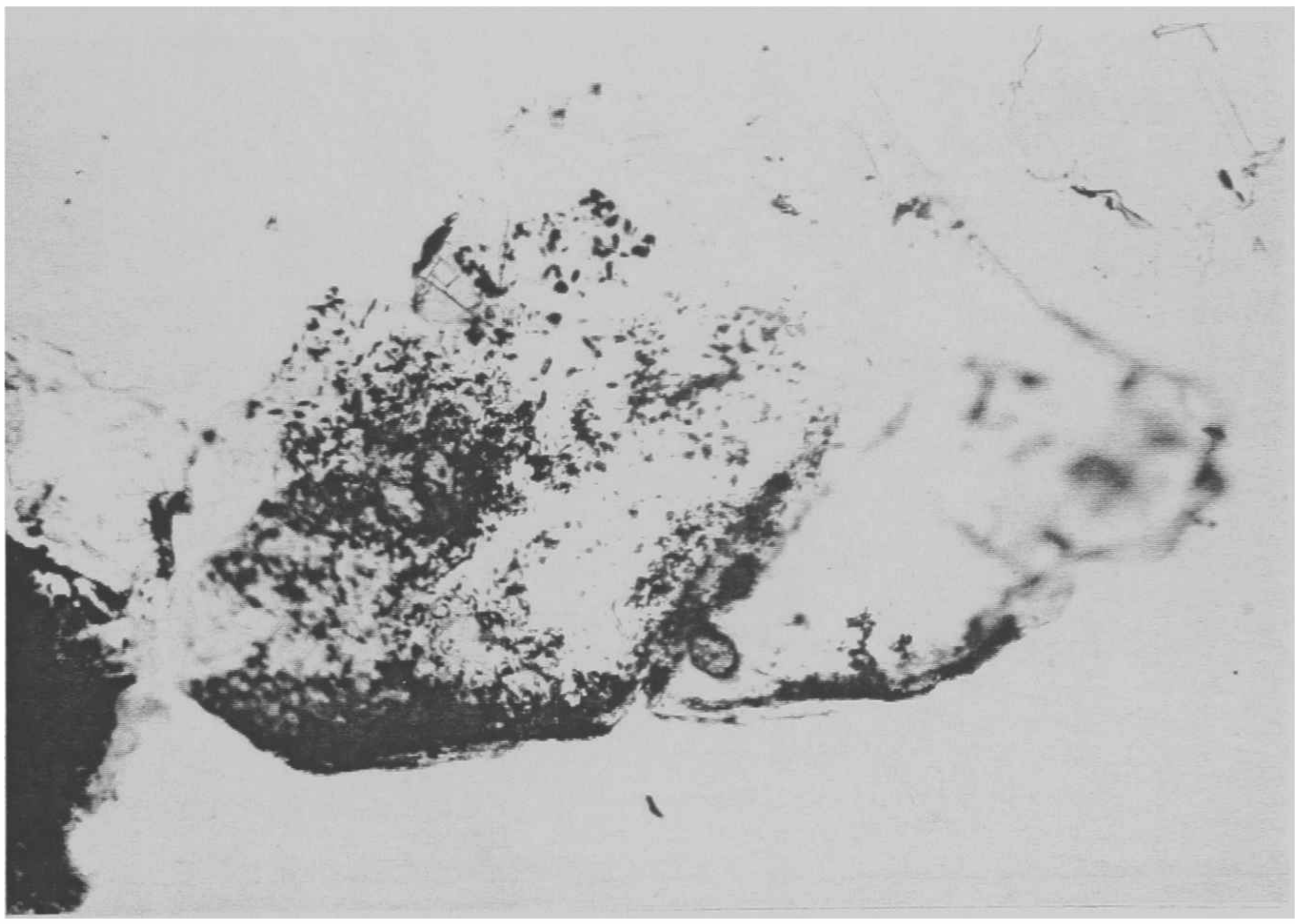

Figure 12. Incipient hematite formation in a mica, Texas Canyon. Plane polarized light. Length of grain is 0.82 mm.

Feldspar alteration is typical. The majority of the feldspar grains are turbid. The potassium feldspars are relatively less weathered. Again plagioclase crystals appear to be weathering very quickly to sericite (Figure 13). But, the samples viewed under the petrographic microscope were still well consolidated and considered "fresh". Therefore much of the feldspar and biotite alteration could be due to deuteric alteration (Hyndman, 1985). Quartz is not being altered. Epidote is also present in small amounts.

A Special Study

Because Texas Canyon provided such an excellent opportunity to study the weathering of a granitic rock in all phases, additional analyses were done. A large specimen of granite, intermediate between the "fresh" granite and the grus phase, was collected. Upon initial viewing the granite appears to be well consolidated, but the application of a moderate amount of force (such as jumping up and down) can break up the granite. In hand specimen the quartz grains in the granite show no signs of weathering. Some feldspar grains have taken on a "chalky" appearance while others seem to be unweathered. The majority of the biotite grains are surrounded by rings of iron oxide (Figure 14).

In the laboratory the granite was initially crushed with a hammer into individual grains of quartz, feldspar, biotite, and muscovite along with quartz and feldspar

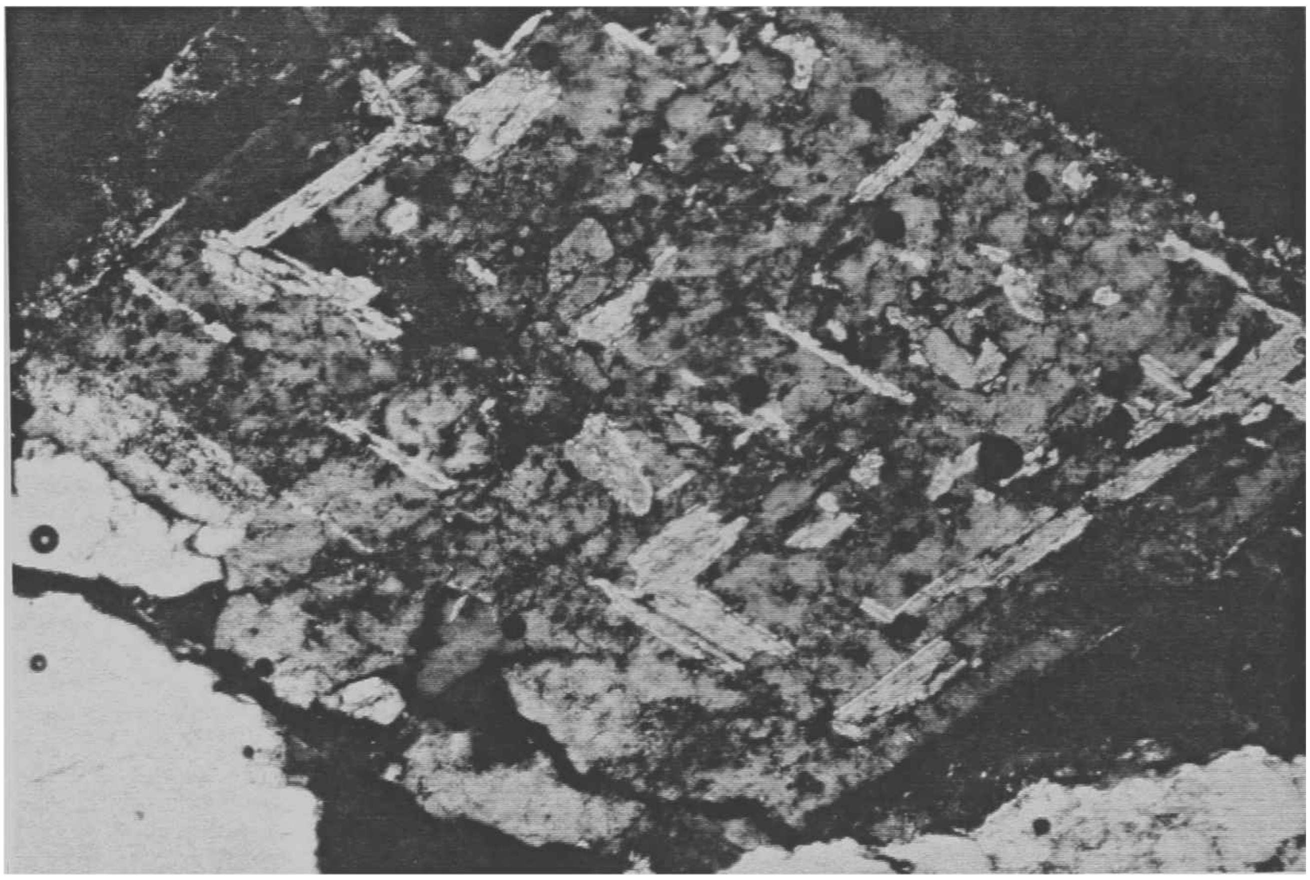

Figure 13. Feldspar alteration to sericite, Texas Canyon. Crossed polars. Length of grain is 2.2 mm.

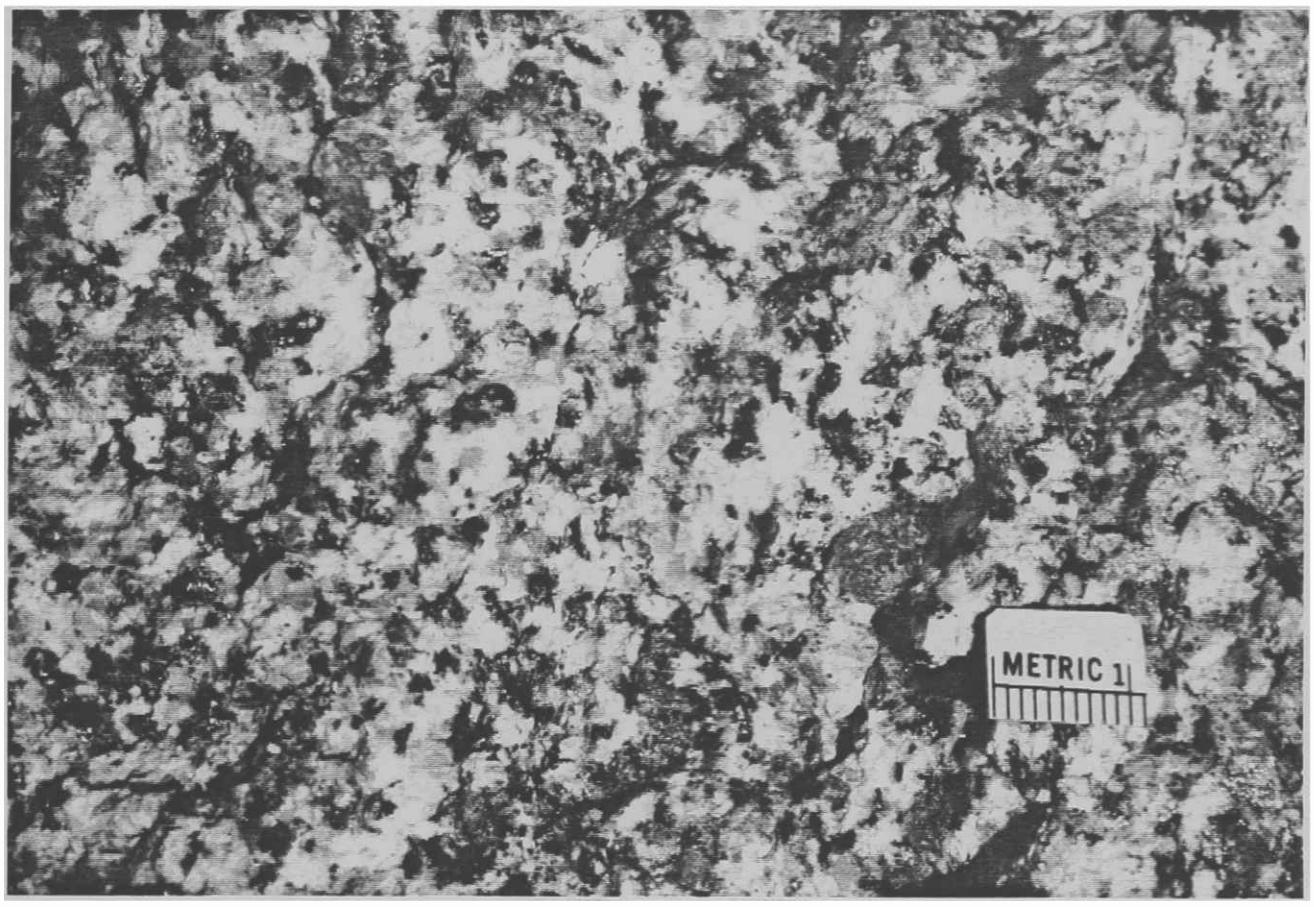

Figure 14. Iron oxide haloes surrounding biotite grains on a fresh granite surface, Texas Canyon.

aggregates. The crushed material was sieved in order to obtain a size fraction rich in micas. The biotite and muscovite in the material captured on the 2 phi sieve were separated from the other grains on a shaker table, crushed finer in a small mortar and analyzed by x-ray diffraction. As expected, an excellent ten Angstrom (mica) peak was found. There were also traces of quartz and feldspar which are probably due to incomplete separation. Vermiculite and hematite were also present (Figure 15).

Individual feldspar grains were also picked from the crushed granite and ground to a fine powder with a plate grinder. X-ray analysis showed good patterns of both K-feldspar and plagioclase. A 10 Angstrom mica (illite/sericite ?) and quartz patterns were vaguely distinguished.

Several kilograms of the "crushed" bulk sample were placed in a 5 gallon plastic bucket and covered with distilled water containing 2.5 grams of sodium hexametaphosphate per 1000 ml of water. The sodium hexametaphosphate was to act as a dispersant. The bucket with the sample was placed in a large ultra-sonic bath for 2 hours. At this point in time the distilled water had turned gray because of the material in suspension. The material in suspension was further separated by sedimentation methods.

The < 2 micrometers fraction recovered contained chiefly Na-montmorillinite (smectite) and minor amounts of illite. These were the only two minerals present. The fine

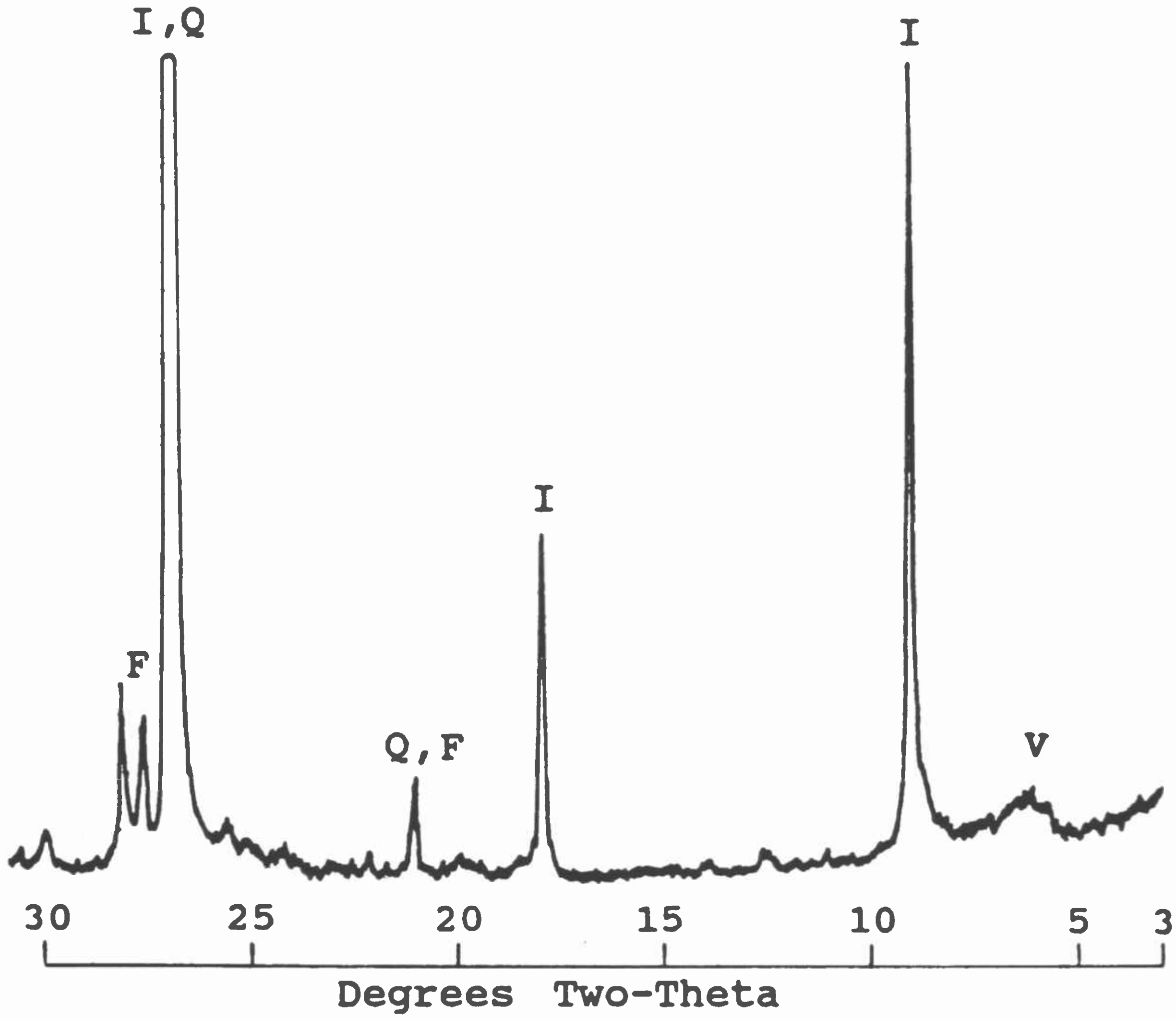

Figure 15. X-ray diffraction pattern of the crushed micas in Texas Canyon. I=illite, Q=quartz, F=feldspar, V=vermiculite.

silt (7 and 8 phi) fraction contained vermiculite >> illite > kaolinite. Excellent K-feldspar and plagioclase patterns were present while quartz was present in small amounts. The coarse silt (5 and 6 phi) fraction showed a very similar pattern (Figure 16).

Summary

In summary, the illite-smectite mixed layered clay is lost and the amount of smectite diminishes from the grus phase to the soil phase. At the same time both the illite and kaolinite content increased along with total free iron oxides. The debris within the fluvial system produced a weak pattern indicating general degradation (Figure 17). Thin sections showed incipient formation of iron oxides and chlorite from biotite while plagioclase appears to be highly altered to sericite, probably due to deuteric alteration. X-ray analysis of mica crystals showed signs of vermiculite. The < 2 micron fraction of the material obtained through the ultrasonic bath contained Na-montmorillinite with some illite. The fine silt fraction of the same material contained vermiculite and small amounts of kaolinite.

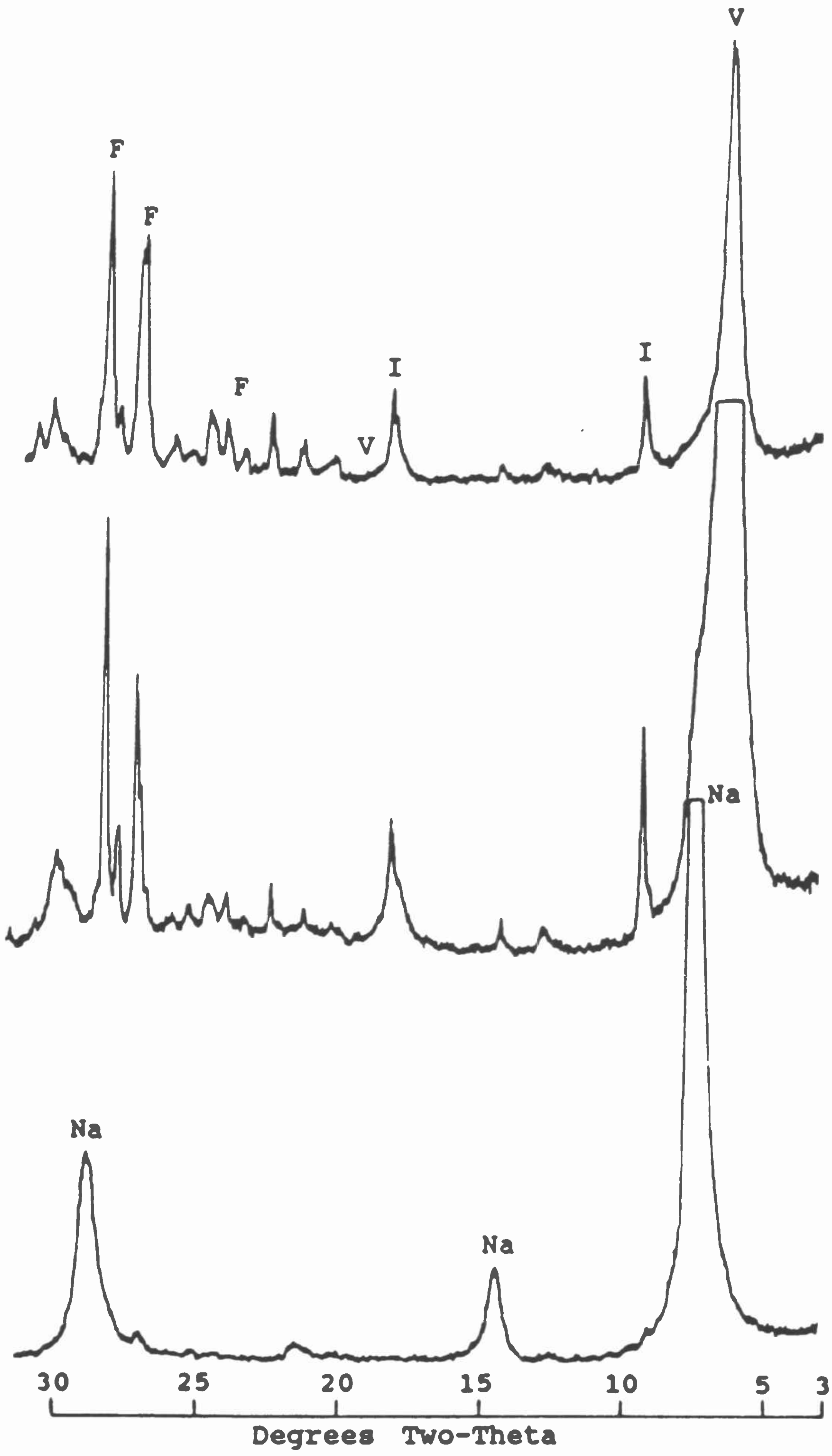

Figure 16. X-ray diffraction pattern of the material derived from the ultra sonic bath, Texas Canyon. Bottom: < 2 micrometers. Middle: fine silt. Top: coarse silt. Na= sodium montmorillinite, I=illite, F=feldspar, V=vermiculite.

QUARTZ MONZONITE

Color

7.5YR 8/1 — Grus

I/S > Sm > I $\geq$ K} < 2 micrometers (clay)

5YR 4/6 — Soil

I $\geq$ K} < 2 micrometers (clay)

7.5YR 8/2 — Stream Channel

I $\geq$ Sm, both in trace amounts} < 2 micrometers (clay)

Figure 17. Summary of the weathering in Texas Canyon. I/S=illite-smectite mixed layer, I=illite, Sm=smectite, K=kaolinite.

CHAPTER 9

POST RANCH AREA

Introduction

Sampling in the Post Ranch area was performed on the "granite wash" material located in stream beds and their banks along with material deposited on the surrounding hills. Underlying the "granite wash" is the St. David Formation described by Gray (1965). Gray (1965) describes the "granite wash" as heterogeneous granitic alluvium consisting almost entirely of quartz and feldspar grains with granite, gneiss, quartzite, and schist fragments.

This site was chosen for several reasons. First, one is able to determine the minerals present within the "granite wash" after it has been "parked" for a long period of time, during which soil formation has taken place. Second, one can compare the mineralogy of this "granite wash" soil to debris being transported in fluvial channels and to "granite wash" with no apparent soil development resting on the surrounding hills. Finally, this site provided the opportunity to compare the mineralogy of the stream bed debris along the length of the channel.

X-ray Results

Sediment derived from the Northern Whetstone Mountains and being transported in existing stream channels was sampled. The streams in this area are now actively aggrading as can be seen by the burial of trees which are growing in stream channels (Figure 18). Samples were taken nearly 0.3 km apart along a dry stream over a distance of approximately 4.82 km (3 miles). Along the length of the fluvial channel there were no significant differences in grain size or sorting. The stream debris is poorly sorted, as determined by the graphic mean (Folk, 1980), with the majority of material in the sand size fraction (> 1/16 mm and < 2 mm). The mineralogy of the stream channel material also did not vary throughout the length of the stream.

In the < 2 micrometers material, the two major clay minerals present are illite and kaolinite. Both produce sharp peaks with the amount of illite being greater than that of kaolinite. Traces of quartz and feldspar are also present. The fine and coarse silt fractions are very similar to each other and to the clay fraction in composition. Once again good illite and kaolinite patterns are produced with the amount of illite being greater than kaolinite. However, in the silt fraction and unlike the clay fraction, quartz and feldspar are abundant.

While distinct soil horizons could not be identified, good clay development could be found in the banks of the stream. The major clays identified (in the clay fraction) were illite > smectite > kaolinite. The loss of smectite from

Figure 18. Aggrading stream in Post Ranch Area.

soil to stream channel debris is consistent with the previous study sites. Only trace amounts of quartz and feldspar were found.

Lastly, samples were taken from material lying on the small hills near the Post Ranch. At the top of the hills one is only able to dig down approximately 15 cm (6 inches). Again the two clay minerals present are illite and kaolinite; quartz and feldspar also occur.

Small stream channels located in the hills expose the "granite wash" down to depths of approximately half a meter. Clay development in place is visible and the X-ray diffraction patterns of the material is very similar to the material mentioned above.

"Free" Iron Oxide Analysis

Iron analyses were performed on samples taken from the hills and from those in the stream banks. The stream banks contain more total free iron oxides and more poorly crystallized iron oxide, ferrihydrite, than debris deposited on the surrounding hills (Table 2). The crystallinity index of the stream bank was lower than that of the surrounding hills. These results indicate a greater degree of weathering in the stream banks.

Summary

It should be noted that the "granite wash" in the Post

Ranch area is much more susceptible to windblown contamination than material sampled in the first three localities. This is due to the fact that as the "granite wash" was being transported and deposited, it was constantly open to eolian material unlike a grus which develops in place.

The main clays in the stream bed are illite > kaolinite. The material from the stream banks contain illite and kaolinite along with smectite. The mineralogy of the hills is similar to the that of the stream bed in having only illite and kaolinite.

CHAPTER 10

APACHE POWDER PLANT AREA

Introduction

The Apache Powder Plant study site is very similar to the Post Ranch area. Once again the St. David Formation is overlain by the "granite wash". In the Apache Powder area the "granite wash" was sampled at two sites. The northern site is found along a stream channel (located in the northeast corner of section 12, T.18 S., R.20 E., on the Benson 7.5 minute Quadrangle) and is exposed by stream erosion (Figure 19). At this site the "granite wash" is approximately 6 meters thick and the contact with the St. David Formation is abrupt.

The "granite wash" sampled from the southern site (located in section 24, T.18 S., R.20 E., on the McGrew Spring 7.5 minute Quadrangle) was taken from a cliff face approximately 24 meters high (Figure 20). Dark "bands" within the "granite wash" suggest the presence of paleosols. The contact between the "granite wash" and the St. David Formation is not visually discernible due to "mud drapes". The thickness of the "granite wash" is less than 12 meters.

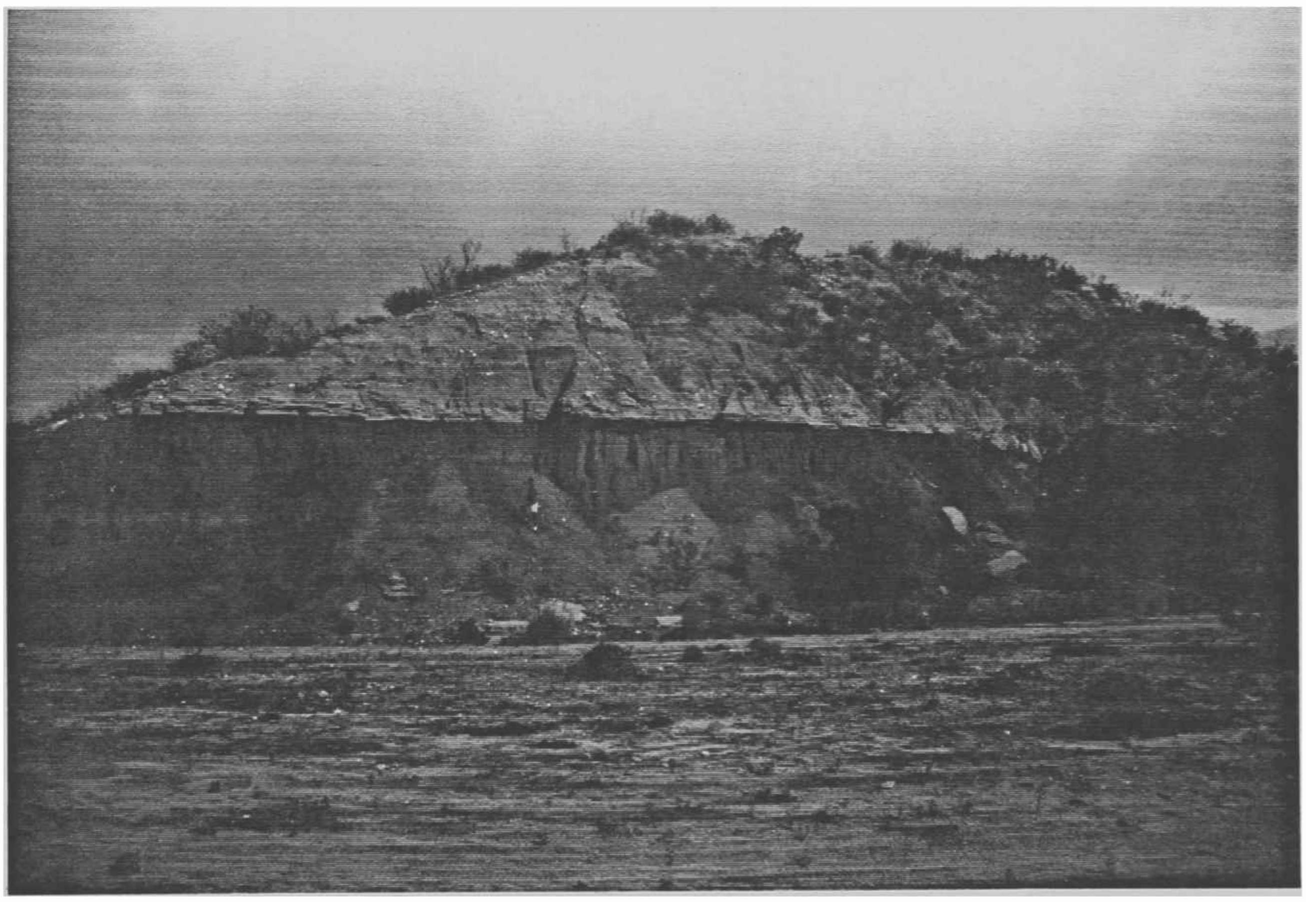

Figure 19. Northern Site - St. David Formation underlying "granite wash", Apache Powder Plant Area.

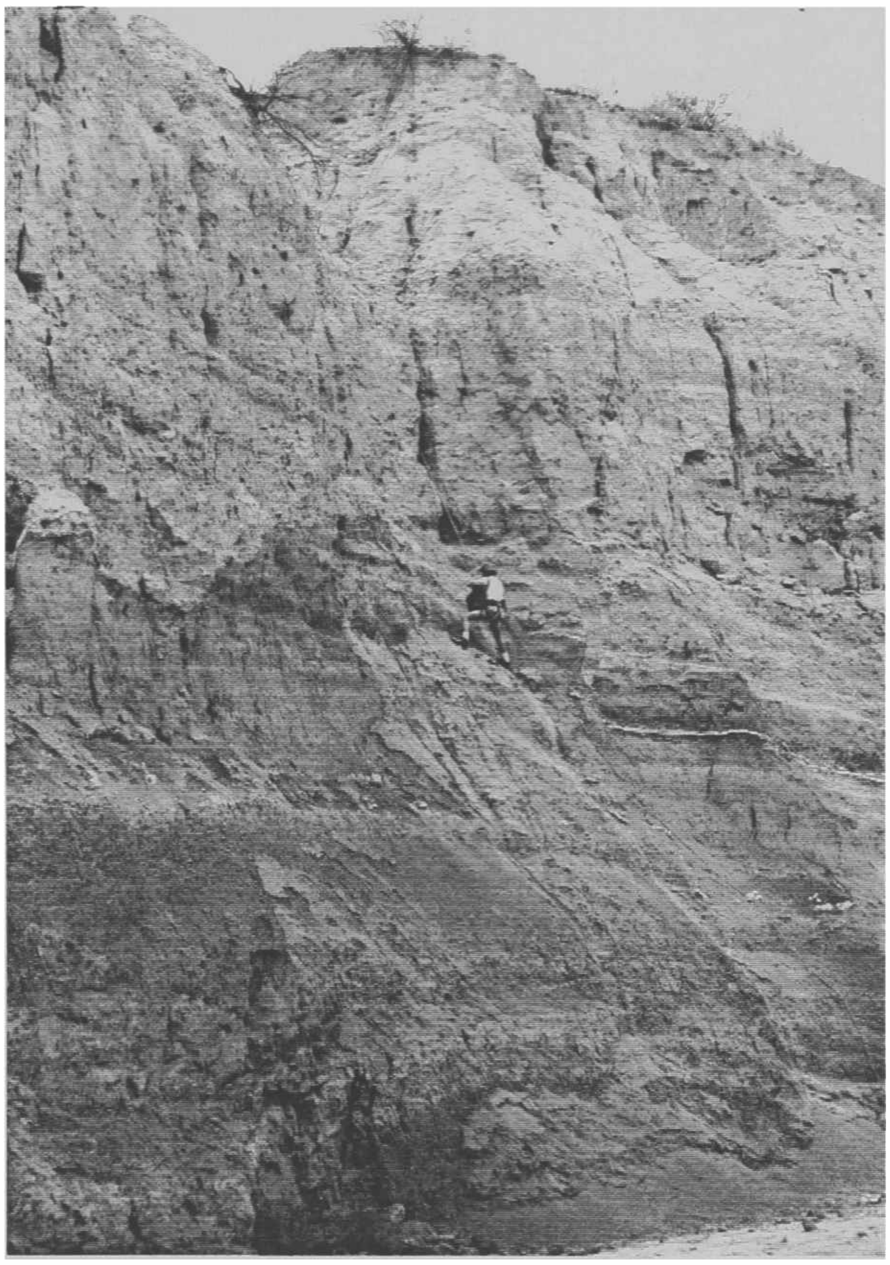

Figure 20. Southern Site - St. David Formation underlying "granite wash", Apache Powder Plant Area.

X-ray Results

Northern Site

Samples were taken from the base and surface of the "granite wash" in order to characterize any vertical variability. At the base the < 2 micrometers fraction contained well crystallized illite > kaolinite with a trace of smectite. Quartz and feldspar are also present.

Material near the surface of the "granite wash" produced X-ray patterns similar to those of stream channels. These patterns are indicative of poorly crystallized or weathered minerals. The kaolinite peak is fairly sharp and there is a trace of illite and smectite. Trace amounts of quartz and feldspar are also present.

Southern Site

As stated above, site two consisted of material from a 24 meter high cliff face. Samples were taken approximately one meter apart unless a distinct difference or division was visually noticed. Because the contact between the St. David Formation and the "granite wash" could not be seen, a sample was taken from the St. David Formation in order to discover any differences between the two which could help in defining the contact.

The mineralogy throughout the cliff face is fairly constant. The three main clay minerals found are illite, smectite, and kaolinite. All of the samples contain approximately the same amounts of quartz and feldspar. The only difference throughout the exposure is the relative amounts of the clay minerals. See Figure 21 for a description of the relative amounts of each mineral present throughout the section.

X-ray analysis of the "granite wash" and the St. David Formation did not supply conclusive evidence to exact location of the contact between the two. Their clay mineralogy is very similar. This suggests that the St. David Formation may have contributed sediment to the formation of the "granite wash" along with the surrounding granitic bodies.

"Free" Iron Analysis

Samples from clay rich "granite wash" and "granite wash" with minimal clay development were analyzed. The clay-rich "granite wash" has almost three times the amount of total free iron oxides than the non clay "granite wash" (Table 2). The ferrihydritye content is also much higher in the clay-rich "granite wash". Although the clay-rich "granite wash" has more total and poorly crystallized free iron oxides, it has a lower crystallinity index indicative of an advanced stage of weathering.

Summary

Throughout the Apache Powder Plant area illite ,

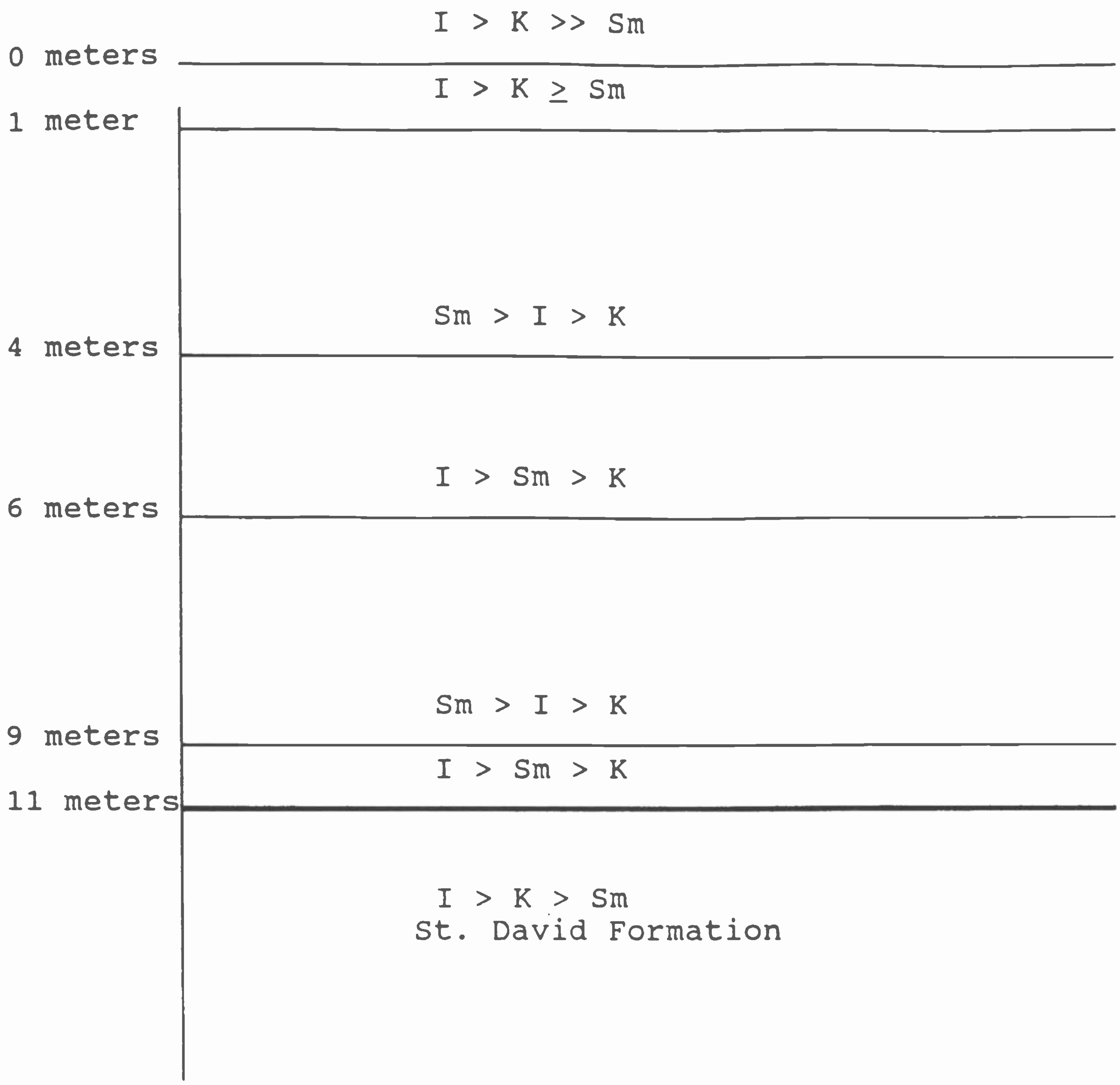

Figure 21. Relative abundances of the clay minerals in the southern site, Apache Powder Plant Area. I=illite, K=kaolinite, Sm=smectite.

kaolinite, and smectite are the three main clays present. The only variability is in their relative abundances. Quartz and feldspar can also be found throughout the study area.

At the northern site smectite is present in trace amounts both at the surface and base of the "granite wash". The main difference is that kaolinite is the main clay mineral at the surface and illite is dominant at the base. This indicates a more advanced degree of weathering at the surface (Rebertus and others, 1986).

The southern site also varies in the amount of illite, kaolinite, and smectite. Kaolinite is never the dominant clay mineral which suggests that climax weathering has not been reached in the section. Portions containing smectite as the dominant clay mineral are probably areas with the least amount of weathering.

CHAPTER 11

BRIEF SITE COMPARISONS

In order to better characterize the processes involved in the weathering of granitic rocks a brief comparison of the study sites will be given. Because a single source for the "granite wash" cannot be determined, the Post Ranch and Apache Powder Plant areas will be omitted from this discussion. The three study areas to be compared are the Johnny Lyon Hills, Whetstone Mountains, and Texas Canyon, which contain granodiorite, granite, and quartz monzonite rocks, respectively.

The quartz percentages of the three granitic rocks are similar at 25-35%. The percentage of plagioclase feldspar is higher in the granodiorite, 44%, compared to 30-40% in the quartz monzonite and 20% in the granite. The percentage of potassium feldspar is 13% in the granodiorite, 25-30% in the quartz monzonite, and 40% in the granite. Mica percentages are approximately equal at 10%, with the granodiorite containing mainly biotite, the granite containing mainly muscovite, and the quartz monzonite containing a combination of the two. Despite these differences, the three study sites contain a similar clay mineralogy in the different stages of weathering.

All three localities in the grus stage of weathering contain the same clay minerals in similar relative abundances. The illite-smectite mixed layered clay is dominant. The amount of smectite is greater than or equal to illite. This leaves kaolinite as the least abundant clay mineral in all three localities. Quartz and feldspar are present in all grus samples.

As the granitic rocks go from the grus phase to the soil phase, the illite-smectite mixed layer is almost completely lost. It is present in the soils of the Johnny Lyon Hills in only trace amounts. Illite is now the dominant clay mineral. Kaolinite is more abundant than smectite at both the Johnny Lyon Hills and Texas Canyon, while the opposite is true in the Whetstone Mountains. Quartz and feldspar are still present but in smaller amounts.

When present, the A horizon of the soils contain illite $>$ smectite $\geq$ kaolinite. The smectite peaks are becoming broad indicating poorer crystallinity. On the other hand, the kaolinite peaks are becoming sharper, indicative of good crystallinity. Feldspars are no longer present while quartz is present in only trace amounts.

Stream channel debris, the final stage of weathering, is quick in destroying and/or transporting the clay minerals. Smectite peaks are very broad and present in small amounts along with traces of illite and kaolinite. Quartz and feldspar are present in trace amounts. For a quick reference to the relative abundances of the clay minerals present in each weathering stage the reader is referred to Figure 22.

The iron analyses of all the sites produced similar results. For each locality, samples with greater clay development contained a greater percentage of total free iron oxides. The crystallinity index (percent ferrihydrite/percent total free iron oxide ratio) is lower in these same clay rich samples.

<u>GRANITIC ROCK</u>

<u>Grus</u>

I/S > Sm ≥ I > K} < 2 micrometers (clay)

<u>Soil</u>

I > K ≥ Sm >>> I/S} < 2 micrometers (clay)

<u>A Horizon</u>

I > broad Sm ≥ sharp K} < 2 micrometers (clay)

Figure 22. Generalized weathering summary of the Johnny Lyon Hills, Whetstone Mountains, and Texas Canyon. I/S=illite-smectite mixed layer, I=illite, Sm=smectite, K=kaolinite.

CHAPTER 12

SUMMARY OF WEATHERING PROCESSES

The primary minerals present in the parent materials are quartz, plagioclase, potassium feldspar, muscovite and biotite. The main products of the weathering of the parent minerals are illite, smectite, illite-smectite mixed layers, kaolinite, and the iron oxides (ferrihydrite, goethite, and hematite). Although vermiculite and hydrobiotite are not common, they too will be discussed. The purpose of this chapter is to explain how the weathering products could be derived from the parent granitic rocks.

The weathering of biotite is responsible for the formation of many of the clay minerals mentioned throughout this study. The first steps in the weathering of biotite include the oxidation of Fe^{2+} to Fe^{3+} and the replacement of K^{+} by H_2O. It is not completely clear whether the oxidation of iron occurs first forcing out the potassium, or if the replacement of potassium by water induces iron oxidation (Foster, 1963; Gilkes and others, 1979). These first two steps lead to the formation of vermiculite (Fields and Swindale, 1954; McFadden and Hendricks, 1985; and Fordham, 1990) and possibly hydrobiotite. Hydrobiotite is defined as the regular interstratification of biotite and vermiculite (Gruner, 1934).

However, Boettcher (1966) believes that hydrobiotite is not a simple weathering product. He states that: "hydrobiotite is a high-temperature alteration product in which the 1:1 stacking sequence represents the attainment of homogeneous equilibrium at the time of alteration." Therefore the hydrobiotite identified in X-ray analysis may not be due to the weathering of biotite in the soil environment, but rather it occurred much earlier, perhaps during deuteric alteration.

Vermiculite was not common in the different weathering stages studied. Under acid conditions in arid and semi-arid regions vermiculite is not stable (Bohn and others, 1985). Surface horizons of soils formed on granitic rocks in arid to semi-arid regions are usually slightly acidic unless affected by eolian deposition of carbonates or soluble salts (Hendricks, personal communication, 1992). Therefore the reason vermiculite is not abundantly found is that it is an unstable, intermediate mineral under acidic conditions which is quick to alter to smectite or stable kaolinite.

The smectite found throughout this study could be formed through various reactions. As was just stated, smectite could be formed by the alteration of vermiculite. The displacement of Al by Si from the tetrahedral sheet, along with transfer of Al to the octahedral sheet to compensate for losses in Fe and Mg could change a high-charged biotite to a low-charged smectite (Fordham, 1990). The loss of silica from feldspars could also lead to the formation of a smectite through "synthesis from solution" (Fields and Swindale, 1954; Hendricks, 1991). While Stoch and Sikora (1976) have identified the formation of smectite from muscovite, it is unlikely that this reaction would occur in arid soils.

The term illite, as used in this study, was defined in Chapter 4. Illite is more resistant to weathering than the coarser micas such as muscovite and biotite. It is similar to sericite, a fine grained white mica more depleted in potassium than muscovite. It has poorer crystallinity than muscovite, and by definition is finer grained than muscovite (Fanning and others, 1989). The presence of illite could be due illitization of smectite by wetting and drying. A Na-smectite undergoing wetting and drying in the presence of a potassium-containing mineral, such as K-feldspar or muscovite, can lead to the formation of illite or an illite-smectite mixed layer (Srodon and Eberl, 1984). The majority of illite in this study is probably derived from the muscovite in the parent material. As the muscovite is weathered, decreasing in size and losing potassium, illite is formed. The sericite formed within the feldspars is another probable source for illite.

The illite-smectite mixed layer is probably an intermediate stage of the two end members that occurs through the partial removal of potassium from the micas (Sawhney, 1989). However, Nadeau and others (1984) have questioned the existence of these mixed layered clays as true minerals. They claim that "interparticle diffraction" produces the peaks in x-ray analyses which are identified as mixed layers. As the slides are prepared, sedimentation occurs which gives the appearance of a mixed layered clay in proportion to the amount of each end member present.

Kaolinite was present in almost every stage of weathering. Most kaolinite in soils is derived through near surface reactions and is usually present in fine silt material. In many soils it is indicative of intense or climax weathering (Allen and Hajek, 1989). The majority of kaolinite found in this study is probably derived from the alteration or weathering of feldspars and smectites. Smectites deficient in alkalis, alkaline earths, and silica could alter to kaolinite. Feldspars can alter directly to kaolinite under certain pH values and silica concentrations (Fields and Swindale, 1954; Velbel, 1984; Allen and Hajek, 1989). While it has been observed that kaolinite can form directly from muscovite and biotite, it is unlikely that this has occurred in this environment (Stoch and Sikora, 1976).

The iron oxides are formed primarily from biotite, but hornblende, when present, is also a source. Much of the iron available for the formation of the iron oxides occurs when the biotite grains are attacked by water and become oxidized (McFadden and Hendricks, 1985; Allen and Hajek, 1989; Fordham, 1990). Ferrihydrite, formerly thought to be an amorphous iron oxide, is similar to hematite structurally and "forms in an environment containing Fe^{2+} which is oxidized in the presence of high concentrations of organic matter and/or silicate" (Schwertmann and Taylor, 1989). Goethite and hematite, the well crystallized iron oxides, are almost always found together. Schwertmann and Taylor (1989) state that hematite forms from ferrihydrite "through aggregation, dehydration, and internal structure rearrangement" while goethite develops by "solution formation through nucleation and crystal growth". Therefore the formation of one is usually at the expense of the other.

CHAPTER 13

CONCLUSION

The purpose of this study was to investigate primary sediment production from granitic rocks. This included characterizing the three stages of granitic rock weathering: grus stage , soil stage , and stream stage by identifying the minerals present and describing possible pathways by which they may have been formed. The original granitic rocks are composed mainly of quartz, feldspars, and micas. Because quartz is relatively very stable, most clay formation comes from the weathering and alteration of the feldspars and micas.

In the grus stage, the dominant clays are illite-smectite mixed layer, smectite, and illite along with trace amounts of kaolinite. In this stage the illite-smectite mixed layer clay and illite are probably derived from the micas. The majority of the smectite is coming from feldspar weathering. Weathering of the feldspars and smectite is responsible for incipient kaolinite formation.

The soil stage is dominated by illite, kaolinite and smectite with trace amounts of the illite-smectite mixed layered clay. The increase in the amount of illite from the grus stage is caused by the additional weathering of smectite and muscovite. The increase in the relative abundance of kaolinite in the soil stage is due to increased weathering of smectite and the continual weathering of the feldspars. The amount of smectite is decreased because it is weathering to kaolinite. The mixed layered clay is almost completely lost as it weathers to its end members.

Once debris enters the existing fluvial system, there is a general loss in the clay minerals. Because of their small size they are being transported away from their source rock. The stream channel environment is also responsible for increased weathering and degradation of the clay minerals. For these reasons, coarser quartz and feldspar grains dominate the stream channel material.

The Special Study conducted in Texas Canyon provided the opportunity to see the true initial stages of sediment production. X-ray analysis of crushed micas revealed the presence of vermiculite, proving that biotite does alter initially to vermiculite. Crushed feldspars revealed a 10 Angstrom mica, probably illite/sericite. The less than two micrometers clay fraction of material obtained through the ultrasonic bath, contained primarily a Na-montmorillinite. This was most likely the initial, fine-grained, weathering products of the feldspars. The vermiculite present in the fine silt fraction is probably related to the vermiculite obtained from the crushed micas mentioned above.

The author believes that the information provided in this study is beneficial to anyone interested in rock weathering or soil formation in an arid to semi-arid environment. However, a few problems still exist which could be taken up in future studies. Arizona contains many granitic rocks which could be further investigated to see if any similarities or differences occur in their weathering processes. The role of eolian dust must be examined further. Excellent locations can be chosen in southeastern Arizona to see the true contribution of windblown material to soil formation. Finally, the problem of mixed layered clays must be addressed. The question of whether they are true minerals or the product of sample preparation must be addressed and answered.

APPENDIX A

LOCATION OF SAMPLES MENTIONED IN TABLES 1 AND 2

JLH-1	0.16 km (0.1 mi) east of the Bolsa Quartzite/Johnny Lyon Granodiorite contact along the Willcox-Cascabel Road in section 21, T.14 S., R.21 E. on the Deepwell Ranch 7.5 minute Quadrangle.
JLH-4	0.32 km (0.2 mi) east of the Bolsa Quartzite / Johnny Lyon Granodiorite contact mentioned above.
JLH-11	0.80 km (0.5 mi) northwest of the Bolsa Quartzite/ Johnny Lyon Granodiorite contact mentioned above.
WM-3A	0.64 km (0.4 mi) northwest of Trask Well located in the southwest corner of section 3, T.18 s., R.19 E. on the Mescal 7.5 minute Quadrangle.
WM-11	located on the boundary of sections 1 and 2, T.18 S., R.19 S. on the Benson 7.5 minute Quadrangle 0.97 km (0.6 mi) northeast of Naegle Well.
WM-14	On Haystack Mountain in the Whetstone Mountains in the southeast corner of section 36, T. 17 S., R.18 E. on Mescal 7.5 minute Quadrangle.
WM-16	0.56 km (0.35 mi) north of WM-14.
AR-5	North side of the road leading to the Adams Ranch in the center of section 21, T.16 S., R.22 E. on the Dragoon 7.5 minute Quadrangle.
AR-7	South side of the road leading into the Adams Ranch in the southwest corner of section 21 mentioned above.
PRA-1	In the streambed east of the old railroad tracks in section 28, T.17 S., R.20 E. on the Benson 7.5 minute Quadrangle.
PRA-3	On river bank 0.48 km (0.3 mi) east of PRA-1.
PRA-9	In the hills in the northwest corner of section 27, T.17 S., R.20 E. on the Benson 7.5 minute Quadrangle.
PRA-16	In the streambed 0.32 km (0.2 mi) east of State Route 90 in the northeast corner of section 31, T.17 S., R.20 E. on the Benson 7.5 minute Quadrangle.
AP-3	On the north side of the road passing through the boundary of sections 13 and 14, T.18 S., R.20 E. on the McGrew Spring 7.5 minute Quadrangle.

AP-6 In the wash in the northeast corner of section 12, T.18 S., R.20 E. on the Benson 7.5 minute Quadrangle.

AP-9 Approximately one meter below the surface of the "granite wash"-forming cliff face in the center of section 24, T.18 S., R.20 E. on the McGrew Spring 7.5 minute Quadrangle.

REFERENCES

Allen, B.L. and Hajek, B.F., 1989, Mineral occurrence in soil environments: in Dixon, J.B. and Weed, S.B.,eds., Minerals in Soil Environments, Soil Science Society of America Book Series, Madison, p.199-278.

Bates, Robert L., and Jackson, Julia A., 1980, Glossary of Geology: American Geological Institute, Falls Church, Virginia, 749 p.

Berner, R. A., and Holdren, G.R., 1979, Mechanism of feldspar weathering - II. Observations of feldspar from soils: Geochemica et. Cosmochima Acta, v.43, p.1173-1186.

Blakemore, L.C., Searle, P.L., and Daly, B.K., 1987, Methods For Chemical Analysis of Soils: New Zealand Soil Bureau Scientific Report 80, 103 p.

Boettcher, A.L., 1966, Vermiculite, hydrobiotite, and biotite in Rainy Creek igneous complex near Libby, Montana: Clay Minerals, v.6, p.283-296.

Bohn, H.L., McNeal, B.L.,and O'Connor, G,A, 1985, Soil Chemistry, John Wiley and Sons, New York, 341 p.

Borchardt, Glenn, and Hill, Robert L., 1985, Smectite pedogenesis and late Holocene tectonism along the Raymond Fault, San Marino, California: Geological Society of America Special Paper 203, 150 p.

Brackenridge, Robert G., 1978, Evidence for a cold, dry full-glacial climate in the American Southwest: Quaternary Research, v.9, p.22-40.

Brown, G., and Brindley, G.W., 1980, X-ray diffraction procedures for clay mineral identification: in Brindley, G.W. and Brown, G., editors, Crystal Structures of Clay Minerals and Their X-Ray Identification, Mineralogical Society, London, p.305-360.

Bundy, L.G. and Bremner, J.M., 1972, A simple titrimetric method for the determination of inorganic carbon in soils: Soil Science of America Proceedings, v.36, p.273-275.

Burnette, C.R., 1955, Geology of Middle Canyon, Whetstone Mountains, Cochise County, Arizona: unpublished M.S. thesis, University of Arizona.

Clay Minerals Society (CMS) Nomenclature Committee, 1984, Report for 1982 and 1983: Clay and Clay Minerals, v.32, p.239-240.

Chou, L., and Wollast, R., 1985, Steady state kinetics and dissolution mechanisms of albite: American Journal of Science, v.285, p.963-993.

Cooper, John R., and Silver, Leon T., 1964, Geology and Ore Deposits of the Dragoon Quadrangle Cochise County, Arizona. U.S. Geological Survey Professional Paper 416, 196 p.

Creasey, S.C., 1967, Geologic Map of the Benson Quadrangle Cochise And Pima Counties, Arizona: U.S.G.S. Miscellaneous Geologic Investigations, Map I-470, scale 1:62,500.

Cullers, R., 1988, Mineralogical and chemical changes of soil and stream sediment formed by intense weathering of the Danburg granite, Georgia, U.S.A.: Lithos, v.21, p.301-314.

Damon, P.E., 1959, Geochemical dating of the igneous and metamorphic rocks in Arizona: in Heindl, L.A., ed.,Arizona Geological Society Guidebook II, p.16-20

Dixon, J.B., 1989, Kaolin and serpentine group minerals: in Dixon, J.B. and Weed, S.B., eds., Minerals in Soil Environments, Soil Science Society of America Book Series, Madison, p.467-526.

Drewes, Harald D., 1976, Laramide Tectonics from Paradise to Hells Gate, Southeastern Arizona: Tectonic Digest, Arizona Geological Society Digest, v.10, p.151-168.

Drewes, Harald D., 1981, Tectonics of Southeastern Arizona: U.S. Geological Survey Professional Paper 1144, 96 p.

Eslinger, Eric and Pevear, David, 1988, Clay Minerals for Petroleum Geologists and Engineers: SEPM Short Course Notes No. 22, 356 p.

Fanning, Delvin S., Keramidas, Vissarion Z., and El-Desoky, Mohamed A., 1989, Micas: in Dixon J. and Weed, S.B., eds., Minerals in Soil Environment, Soil Science Society of America, Madison, p.551-634.

Fields, M., and Swindale, L.D., 1954, Chemical weathering of silicates in soil formation: New Zealand Journal of Science and Technology, p.140-154.

Folk, Robert L., 1980, Petrology of Sedimentary Rocks, Hemphill Publishing Company, Austin, 182 p.

Fordham, A.W., 1989, Weathering of biotite into dioctahedral clay minerals: Clay Minerals, v.25, p.51-63.

Foster, M.D., 1963, Interpretation of the composition of vermiculites and hydrobiotites: in Clay and Clay Minerals, 10th National Conference, MacMillan Co., New York, p.71-89.

Galloway, Robert W., 1969, The Full-Glacial Climate in the Southwestern United States: Association of American Geographers, v.60, p.245-256.

Galloway, Robert W.,1983, Full-glacial southwestern United States: mild and wet or cold and dry?: Quaternary Research, v.19, p.236-248.

Giles, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Sciences, v.101, p.347-360.

Giles, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology in the Basin and Range area of Southern New Mexico - Guidebook to the Desert Project: New Mexico Bureau of Mines & Mineral Resources Memoir 39, 222 p.

Gilkes, R.J.,and Suddhiprakarn, Anchalee, 1979, Biotite alteration in deeply weathered granite. I. Morphological, mineralogical, and chemical properties: Clay and Clay Minerals, v.27, p.349-360.

Grant, Willard H., 1963, Weathering of Stone Mountain Granite: Clay and Clay Minerals, v.11, p.65-73.

Gray, Robert S., 1965, Late Cenozoic sediments in the San Pedro Valley near St. David, Arizona: unpublished Doctoral Dissertation, University of Arizona.

Gray, R.S., 1967, Petrography of the upper Cenozoic non-marine sediments in the San Pedro Valley, Arizona: Journal of Sedimentary Petrology, v.37, p.774-789.

Gruner, J.W., 1934, The structure of vermiculites and their collapse by dehydration: American Mineralogist, v.19, p.557-578.

Hendricks, David, 1985, Arizona Soils. University of Arizona, Tucson, 244 p.

Hendricks, David M., 1991, Genesis and Classification of Arid Region Soils: in Skujins, J., ed., Semiarid Lands and Deserts, Marcel Dekker, Inc., New York.

Hendricks, D.M., 1992, Personal Communication: Professor, Department of Soil and Water Science, University of Arizona, Tucson, Arizona.

Hyndman, Donald W., 1985, Petrology of Igneous and Metamorphic Rocks. McGraw-Hill. New York, 786 p.

Jenny H., 1941, Factors of Soil Formation. McGraw-Hill, New York, 281 p.

Lattman, L.H., 1973, Calcium carbonate cementation of alluvial fans in southern Nevada: Geological Society of America Bulletin, v.84, p.3013-3020.

Leonard, R.J., 1927, Pedestal rocks resulting from disintegration: Journal of Geology, v.35., no.5, p.469-474.

McFadden, Leslie D., 1988, Climatic influences on rates and processes of soil development in Quaternary deposits of southern California: United States Geological Society of America Special Paper 216, 150 p.

McFadden, Leslie D., and Hendricks, David M., 1985, Changes in the content and composition of pedogenic iron oxyhydroxides in a chronosequence of soils in southern California: Quaternary Research, v.23,p. 189-204.

McFadden, Leslie D. and Tinsley, John C., 1985, Rate and depth of pedogenic-carbonate accumulation in soils: Formulation and testing of a compartment model: Geological Society of America Special Paper 203, 150 p.

Moore, Duane M., and Reynolds, Robert C., 1989, X-Ray Diffraction and the Identification and Analysis of Clay Minerals. Oxford University Press, Oxford, 332 p.

Nadeau, P.H., Wilson, M.J., McHardy, W.J., and Tait, J.M., 1984, Interparticle diffraction: A new concept for interstratified clays: Clay Minerals, v.19, p.757-769.

Neese, William D., 1986, Introduction to Optical Mineralogy. Oxford University Press, Oxford, 325 p.

Rebertus, R.A., Weed S.B., and Buol, S.W., 1986, Transformation of biotite to kaolinite during saprolite - soil weathering: Soil Science Society of America Journal, v.50, p.810-819.

Retallack, G.J., 1990, Soils of the Past: An introduction to paleopedology. Unwin Hayman Ltd., London, 520 p.

Reynolds, Robert C., and Hower, John, 1970, The nature of interlayering in mixed-layer illite-montmorillonites: Clays and Clay Minerals, v.18, p.25-36.

Ruddiman, W.F. and Wright, H.E., Jr., 1987, Introduction, in Ruddiman, W.F., and Wright, H.E., eds., North America and adjacent oceans during the last deglaciations: Geological Society of America, The Geology of North America, v.K-13, 501 p.

Sawhney, Brij L., 1989, Interstratification in Layer Silicates: in Dixon, J.B. and Weed, S.B., eds., Minerals in Soil Environments, Soil Science Society of America Book Series, Madison, p.789-828.

Schwertmann, U. and Taylor, R.M., 1989, Iron Oxides: in Dixon, J.B. and Weed, S.B., eds., Minerals in Soil Environments, Soil Science Society of America Book Series, Madison, p.379-438.

Sellers, William D., and Hill, Richard H., 1974, Arizona Climate, 1931-1972. University of Arizona Press, Tucson, 616 p.

Sellers, William D., Hill, Richard H., and Sanderson-Rae, Margaret, 1985, Arizona Climate, The First One Hundred Years. University of Arizona Press, Tucson, 143 p.

Silver, L.T., 1956, The structure and petrology of the Johnny Lyon Hills area, Cochise County, Arizona: unpublished Doctoral Dissertation California Institute of Technology.

Smiley, T.L., 1984, Climatic change during landform development, in Smiley, T.L., Nations, J.D., Pewe, T.L., and Schafer, J.P., eds., Landscapes of Arizona, University Press of America, Boston, p.55-78.

Smiley, T.L., Bryson R.A., King, J.E., Kukla, G.J., and Smith G.I., 1991, Quaternary paleoclimates: The Geology of North America, Quaternary nonglacial geology: Conterminous U.S., v.K-2, Geological Society of America.

Srodon, J., 1980, Precise identification of illite/smectite interstratifications by X-ray powder diffraction: Clays and Clay Minerals, v. 28, p.401-411.

Srodon, J., 1981, X-ray Identification of randomly interstratified illite-smectite in mixtures with discrete illite: Clay Minerals, v.16, p. 297-304.

Srodon, J., 1984, X-ray identification of illitic materials: Clays and Clay Minerals, v.32, p. 337-349.

Srodon, J., and Eberl, Dennis D., 1984, Illite: in Bailey, S.W., editor, Micas: Review in Mineralogy, v.13, p.495-543.

Stoch, L., and Sikora, W., 1976, Transformation of micas in the process of kaolinization of granites and gneisses: Clay and Clay Minerals, v.24, p.156-162.

Tyrrell Jr., Willis W., 1957, Geology Of The Whetstone Mountain Area, Cochise And Pima Counties, Arizona: unpublished Ph.D. dissertation, Yale University, 171 p., 64 p. Appendix.

Velbel, Michael A., 1984, Weathering Processes of Rock-Forming Minerals: Mineralogical Association of Canada Short Course Handbook 10, p.67-111.

Wang, C., Ross, G.J., and Rees, H.W., 1981, Characteristics of residual and colluvial soils developed on granite and of the associated pre-Wisconsin landforms in north-central New Brunswick: Canadian Journal of Earth Sciences, v.18, p.487-494.

Wilson, M.J., 1975, Chemical weathering of some primary rock-forming minerals: Science, v.119, p.349-354.