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MICROPEDOLOGY OF A SEQUENCE OF SOILS IN THE TURTLE MOUNTAIN AREA

by

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ABSTRACT

Micropedological and some mineralogical studies were conducted on Orthic Dark Gray, Dark Gray Luvisol and Gleyed Gray Luvisol profiles. Descriptions and interpretations are given for the micromorphological features of the various horizons. The rearrangement of plasma constituents has been carried out by pedologic processes (eluviation and illuviation). The rearrangement has resulted in eluviated horizons which are plasma deficient and illuvial horizons which are plasma rich. The degree to which similar horizons in different profiles have developed is believed due to differences in drainage, topography and microclimate.

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TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF PLATES

PLATE PAGE

INTRODUCTION

As a part of general pedology, microscopic investigation of the soil (micropedology), encompasses the study of shape and form (micromorphology), genesis, mineral identification, and general soil dynamics. Every soil feature in its microscopic realm has been a result of the life and environmental conditions of its habitat. It has been observed that soil micromorphology can be extremely varied but it is always typical of a habitat. This means that every soil type has a micromorphology associated with its genesis and that other soil types that happen to be off springs have microscopic fabrics that can be recognized as transformations of the main type (Kubiena, 1970, Chapter II). Thus, micromorphological studies have led to a much better understanding of the soil forming processes.

In the present investigation, micropedological studies were carried out on the various horizons of three soil profiles: Orthic Dark Gray, Dark Gray Luvisol and Gleyed Gray Luvisol. The main objectives of the investigation were:

1. to describe the micromorphological features,
2. to interpret these features with respect to the genesis of the soils, and
3. to give an indication of the weathering of the soil minerals in the various horizons.

LITERATURE REVIEW

The Significance of Micropedological Studies in Soil Science

As soil science has developed, the systematic description of soil profiles in the field and in the laboratory has become progressively more detailed. In the early days, the prime objective was to distinguish different kinds of profiles on the number and arrangement of recognizable horizons, which were described broadly in terms of color and texture. These descriptions were made more complete in later years by including structure, consistence and occurrence of detectable amounts of relatively soluble materials such as carbonates. As descriptions of soils were made more detailed, advancing technology allowed greater detailed descriptions by adapting petrographic geological techniques and methods.

According to Brewer (1960 a), there are four broad phases of pedological studies:

a) Characterization of the soils

Soils are essentially characterized by description and measurement of properties. Deficiencies in accuracy and completeness in descriptions have been shown up by the use of the petrographic approach. This is so because the scale of observation makes it possible to focus attention on the nature and distribution of pedological features, such as cutans, glaebules and pedotubules (defined in Appendix II), which comprise an important record of the genesis and history of soil materials and profiles. For example, clay skins (argillans) have long been observed in hand specimens, and are being used as criterion for classification; however, their internal structure and their relationships with voids and other constituents of the soil material could only be studied microscopically. Other pedological features can also be classified and interpreted on their relationship with voids and other constituents of the soil material. The highly organized, extremely heterogenous nature of the pedological features found in many soils has lead to false measurements. Such is the case where a soil chemist uses the usual methods of grinding and sieving before analysis, which reduces the soil material to a homogenous mass. The analysis on the ground sample averages the data for the whole soil, and provides inadequate information of the internal chemistry of the undisturbed ped interior. Clay mineralogists use the petrographic approach to get away from homogenizing the soil sample. Using this technique an accurate separation of the argillan can be obtained, and the x-ray analysis data can be made more meaningful. This enables the clay mineralogist to determine whether these accumulations are a new clay formation or clay normally found in the s-matrix but translocated in colloidal suspension and deposited elsewhere in the soil.

b) Study of soil genesis

Quantitative evaluations of soil formation can be carried out, providing uniformity of parent material has been established by conducting mineral analysis on the various horizons in a soil profile. The ratio of the percentage of some stable constituent in each horizon to that of the parent material is a measure of the volume change that has occurred in each horizon. Also, qualitative study of weathering can be carried out, but knowledge of properties and conditions of the minerals in the parent material must be known.

This is to be sure the features of weathering observed are due to soil formation. Observed differences in structure and fabric analyses of a horizon and that of its parent material is also a reflection of the effects of soil forming processes.

c) Classification

Structure and fabric descriptions are an integral part of the description and classification of soils. Each horizon within a soil profile has its own characteristic fabric. These fabric arrangements are important characteristics for soil classification, whether it is based on description or genesis.

d) Soil-plant relationships

Structure (size, shape, and arrangement of the constituents and voids) is very important in soil-plant relationships. Since plant roots tend to follow voids, the void pattern and the properties of their surfaces are most important. Clay mineral films may control the environment of plant roots by forming a membrane, coating a porous soil material and thus locking the bulk of the soil material from the activity of plant roots. This type of observations would be of interest to a fertility specialist, in that these coatings control the chemical environment of the roots. Soil physicists have found that these clay films influence such soil characteristics as porosity and water holding capacity.

Terminology

Up to a few years ago, there were only a few terms specific to the science of micropedology. Many observers recorded only those features which they had been trained to recognize and for which adequate terms existed. It was most inconvenient and inefficient to repeat long descriptions for specific features or arrangements.

Kubiena (1938, p. 125-128) made the first attempt to assign names to specific features and arrangements. With the publication of "Fabric and Mineral Analysis of Soils" (Brewer, 1964), additional new terms specific to features were described. This has made the interchange of morphological data among workers more efficient. Both Kubiena and Brewer, in describing and applying specific terms to distinguish micropedological features, drew quite heavily from geological petrographic studies.

Kubiena (1938, p. 129) pointed out that soil constituents can be divided into two broad groups on the basis of their physical and physiochemical properties: "fabric skeleton, of a soil consists mainly of residues of rock minerals and organisms not decomposable or which are only slowly decomposable; and fabric plasma, of a soil is the other group which is more easily moved, changed in composition and shape, and redeposited". The term fabric, which is a result of the dynamics of a soil system, was used to describe the arrangement of the constituents of a soil in relation to each other. Kubiena (1938, p. 129 and 154) also introduced the terms elementary fabric which described arrangement within individual aggregates, while fabric of higher order referred to the arrangement of aggregates. Some of the factors Kubiena (1938, p. 130) attributed to influencing fabric were degree of flocculation of the plasma, work of alkalis and acids, action of eluvial and illuvial processes, and wetting and drying.

Brewer and Sleeman (1960), using essentially the same micromorphological concepts, expanded on Kubiena's work. One of the major additions was the introduction of structure, which they defined as "the physical constitution of a soil material as expressed by the size, shape and arrangement of the solid particles and associated voids, including both the primary particles to form compound particles themselves". Thus, fabric is the element of structure which deals with arrangement.

According to Brewer (1960 a), the skeleton and plasma constituents become organized in various ways during soil formation. This organization can be expressed by the development of (1) peds, (2) pedological features, and (3) matrices, with their associated voids. These terms are defined as follows:

(1) Peds: Within the soil there are units which are referred to as peds. Such units have been described "as an individual natural soil aggregate consisting of a cluster of primary particles, and separated from adjoining peds by surfaces of weakness which are recognizable as natural voids or by the occurrence of cutans" (Sleeman, J.R., 1963). While there are many soils which exhibit peds, there are just as many that do not. Such soils are referred to as being apedal. These soils tend to be very friable and have a strongly interconnected arrangement of vughs.

(2) Pedological features: Within and on peds one finds pedological features which are a result of fractionation and reorganization of the mobile active plasma by soil forming processes. A pedological feature is defined as follows: "recognizable units within a soil material which are distinguishable from the enclosing material for any reason such as origin (deposition as an entity), differences in concentration of some fraction of the plasma (i.e. plasma concentration), or differences in arrangement of the constituents (fabric)",

(Brewer, 1964, p. 142). Pedological features are divided into two groups, orthic and inherited pedological features, the latter being features which are relicts of the parent rock or parent material. Examples of orthic pedological features are cutans, glaebules, and pedotubules which have been defined in Appendix II. The majority of these features are then described according to size, degree of separation and orientation.

(3) S-matrix: "of a soil material is the material within the simplest peds, or composing apedal soil materials, in which the pedological features occur; it consists of plasma, skeleton grains, and voids that do not occur in pedological features other than plasma separations" (Brewer and Sleeman, 1960). This term is also used in sedimentary petrology in the same sense. These features are also described in terms of size and shape in Appendix III.

The majority of the terms used in this study were those proposed by Brewer (1964). A glossary of the terms is found in Appendix II.

Interpretation of Soil Micromorphological Data

The kinds of soil forming processes that have been operative can be inferred directly from structure and fabric analysis, providing one has sufficient background data, and experience in interpreting thin sections. The differences between the structure of the soil material of a particular soil horizon and that of the parent material has been recognized as a reflection of the effect of soil forming processes, and it is a matter of interpreting these observed changes in terms of the processes which caused them. With the aid of micromorphological data, a number of hypotheses have been put forward in recent years concerning the processes involved in formation of various kinds of plasmic fabrics and pedological features. According to Brewer (1960 a), these hypotheses, concerning genesis of profiles and processes of formation of particular fabric features, provide a basis for research projects needed to reproduce the observed phenomena.

A number of papers have been published on interpretations of prepared thin sections, and the following is a summary of the papers reviewed.

Fabrics of humified surface mineral horizons

Kubiena (1953) was one of the first to describe the humified microfabrics of the surface horizons. His descriptions have been widely used and quoted by other investigators. He described a number of different humus forms which occur in mineral surface horizons, three of which are defined as follows:

(1) Mull: "typical spongy fabric, characterized by complete decomposition and humification of the organic substance, lack of recognizable plant remains, good clay formation, and binding of finely dispersed humic substance by the clay substance".

(2) Moder: "loose mixture of broken through plant remains, mineral fragments and arthropod dropping".

(3) Mull-like moder: "loose mixture of mineral rich aggregates. In the aggregates little chemical decomposition of the mineral substance, relatively good humification (the humic substance acts mainly as binding substance), but also existence of slightly decomposed plant fragments with well preserved plant structure".

According to Kubiena the mull humus and mull-like moder humus form were found in the Chernozemic and Chernozemic-like soils. The mull-like moder humus form occurs where there is more pronounced eluviation taking place. The type of fabrics which contained the mull or mull-like moder humus form were referred to as a intertextic fabric and degraded intertextic, respectively; but they were referred to as a chernozemic type when found in a Chernozemic soil. Fabric containing similar humus forms were described by Pettapiece and Zwarich (1970), and St. Arnaud and Whiteside (1964). Dumanski and St. Arnaud (1966) described a fabric containing the mull-like moder humus form which they called a modified intertextic fabric. Barratt (1964, 1969) also devised a classification for humus forms found in organic-rich horizons. The classification was based entirely on micromorphological observations patterned after Kubiena's work.

Fabrics of eluviated mineral surface horizons

Eluviated horizons are found in certain Chernozemic, Solonetzic, Luvisolic, and Gleysolic soils. These horizons, found in the upper portion of a soil profile are characterized by a bleached appearance, low organic matter content, and a platy appearance in thin section. McMillan and Mitchell (1953) studied thin sections from the eluvial horizons, of a degraded Chernozem, a Solonetz, and a Gray Podzol (Gray Luvisol in present classification). Their study revealed a banded fabric in the eluvial horizons, with the presence of invasion amygdali (referred to as nodules in this study). Dumanski and St. Arnaud (1966) in their study of eluvial horizons noted an increasing occurrence of banded fabric, a decreasing occurrence of isoband, and a more pronounced and finer platy structure in soils grading from Chernozemic to Podzolic (Luvisolic in present classification). Banded fabric has been attributed to the physical action of ice lenses

(Pettapiece and Zwarich, 1970, and St. Arnaud and Whiteside, 1964), and to drying of soil from top down (Acton and St. Arnaud, 1963, and Kubiena, 1938, p. 193). Kubiena (1938, p. 192) was the first to describe the banded fabric.

Fabrics of illuvial mineral horizons

Illuvial B horizons are characterized by an accumulation of colloidal plasma which makes for a denser and a more compact fabric. This accumulation modifies the texture and fabric of the natural soil surfaces and gives rise to plasma concentrations (cutans). The degree of anisotropy, and the arrangement of the plasma domains, has been used by Brewer (1964) and others to classify these plasmic fabrics. Early researchers (Buol and Hole, 1959; Nettleton, *et al*., 1969) referred to these accumulations as being clay skins, while other authors referred to them as encrusted clay (Frei and Cline, 1949) or optically oriented clay (Brewer, 1956; Minashina, 1958). From analysis carried out on these coatings by Buol and Hole (1959) and Beke (1964), it was observed that they contained considerable amounts of iron and organic matter in addition to the clay. With this information, plus the realization that these clay coatings could have different genesis and were associated with different soil entities (mineral grains and voids), led Brewer (1960 b) to introduce the term cutan.

In most instances, clay accumulations occur as thin coatings on the surface of mineral grains, around voids, and along conducting channels. These accumulations have been reported in many soils including Chernozemic (Acton and St. Arnaud, 1964; Pettapiece, 1964; Redmond and Omodt, 1964; St. Arnaud and Whiteside, 1964), Solonetzic

(Pawluk, 1969; Yarilova, 1964), Luvisolic (Cline, 1949; Frei and Cline, 1949; McCaleb, 1954; McKeague and Cann, 1969; Pettapiece, 1964; St. Arnaud and Whiteside, 1964; Thorp, et al., 1959), and Gleysolic (Acton and St. Arnaud, 1963; McKeague and Cann, 1969).

Several workers (Brewer, 1956; Frei and Cline, 1949; McCaleb, 1954; Minashina, 1958) have regarded these optically oriented clays as being indicative of the presence of illuvial clay. According to Frei and Cline (1949), the increase in clay content of B horizons could be accounted for in three ways:

(1) Clays may migrate in suspension in percolating water and become oriented by settling out under influence of surface tension.

(2) Synthesis of weathering products from A and B horizons into clay minerals.

(3) Removal of other constituents such as calcium carbonates from a B horizon may concentrate residual clay.

While agreeing with Frei and Cline, Buol and Hole (1959), Brewer (1956), and Minashina (1958) postulated that oriented clay could also be formed by mechanical pressure.

Optically oriented clays have been produced by several workers (Bartelli and Odell, 1960; Brewer and Haldane, 1956; Polyakov and Florinsky, 1968; Thorp, et al., 1957) by passing clay suspensions through columns of sand. The laboratory studies of Brewer and Haldane (1956) showed that the type of cation saturation of clay material did not affect the degree of orientation of the clay particles, but that silt size particles tend to disrupt clay orientation. Thorp, et al. (1957) demonstrated movement of fine clay from leaching columns to effluent water and the deposition of clay in lower layers of the column.

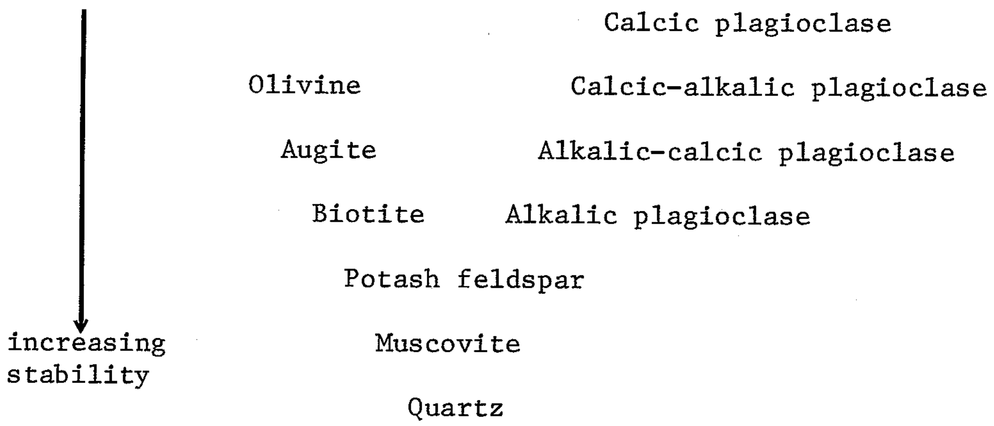
According to Brewer (1960) "the occurrence of cutans will also have a considerable effect on plant growth, not only because of their effect on the course of soil formation, but more immediately because they affect the environments of the plant roots". In studying root soil relationships, one finds that plant roots are frequently confined to ped faces and channels which are coated with thick illuviation cutans composed of clay minerals. Soileau, *et al*. (1964) found that while the cutans tended to stabilize the soil aggregates, they restricted plant growth and potassium uptake.

Mineral Analysis

Minerals at the time of their formation, presumably are at equilibrium with their environment, and therefore stable. When these minerals are disturbed and thrust into a different environment, many of these minerals become unstable and undergo changes. Such changes do occur in soils and sedimentary deposits. Mineral counts have been used to determine amount of weathering that has taken place in a profile and to determine similarity of soil parent materials.

Petrographic mineral analysis of soil materials depend on separation and concentration of mineral species in the medium, fine and very fine sand. In most instances, one separation is made, resulting in two mineral fractions, "light", having a specific gravity less than 2.89, and "heavy", with specific gravity greater than 2.89. The light mineral fraction of soils consists mainly of quartz and feldspars, and accounts for about 95 per cent of the particular size separate. Although the heavy mineral fraction of a soil accounts for only 2 to 3 per cent of the size separate, it contains a wide variety of minerals such as amphiboles, garnets, pyroxenes, iron oxides, zircon epidote, olivine, tourmaline and others. Many of the heavy minerals are very resistant to chemical weathering.

Goldich (Pettijohn, 1957, p. 503), as a result of quantitative studies on several soil profiles, arranged the common rock making minerals into the following mineral stability series:



One can infer from the mineral stability series that the more basic a mineral the more unstable it is. Quartz and potash feldspars would be the most stable, and the alkalic plagioclase such as albite would be moderately stable, whereas the calcic plagioclases, bytownite and labradorite would be relatively unstable. This inference was strengthened by Graham's (1949) study in which he found the more calcic a plagioclase feldspar, the higher its weathering rate. Cann and Whiteside (1955) found that potash feldspars showed a net gain in the profile, while plagioclases showed a net loss, and that plagioclase losses decreased downward in the profile. This suggested that orthoclase feldspars were as resistant to weathering as quartz grains. A study of relative proportions of light or heavy mineral species of different stability could give a qualitative estimation of weathering of surface horizons were compared to the parent material.

The origin of any sedimentary deposit is reflected in the mineral suite present, particularly the heavy mineral suite. The heavy minerals include some species of highly resistant character (Carver, 1971, p. 459; Pettijohn, 1957, p. 504) such as rutile, zircon, tourmaline garnet and others which are capable of surviving more than one cycle of weathering, and therefore, remain in constant proportions in a profile for long periods of time. Since heavy minerals are found in relatively small quantities, variations in species within a certain size separate throughout a profile can be readily ascertained. These variations are used in determining similarity of parent material within a profile and between profiles. Sawhney, _et al_. (1962), Seale (1956), and Yassoglou and Whiteside (1960) used heavy mineral studies to determine similarity of parent materials. A study carried out by Marshall and Haseman (1942) on the total heavy minerals in a Grundy silt loam revealed that mineral breakdown was most severe in upper 20 inches of the profile and fell off with increasing depth.

Technology

Thin section preparation

According to Kubiena (1938, p. 70), as early as 1904 Delage and Lagatu attempted to prepare thin sections of crushed soil by adding hardening substances to the soil. Day (1948) quoted Pigulevsky's study of 1914, in which soil clods were impregnated with paraffin wax and napthalene so that photo-micrographs of soil structures could be made from the thin sections. Kubiena (1938, p. 72), in 1923, developed a method for impregnating friable materials without destroying the natural fabric. He carried out experiments using bakelite, Canada balsam and kollolith, and found kollolith to be the most suitable impregnating material. The main problem encountered using bakelite, Canada balsam, and kollolith was that the procedures required prolonged heating with the danger of boiling the resin and disrupting the specimen. Volk and Harper (1939) found bakelite varnish number 1305 to be the best impregnating agent.

Bourbeau and Berger (1947) introduced the first use of synthetic resin, Castolite, which has since been used by many investigators. Bartelli and Odell (1960), Buol and Fadness (1961), McMillan and Mitchell (1953), and Pettapiece and Zwarich (1970), used Castolite as an impregnating agent quite successfully, but all used differing proportions of Castolite to styrene in their procedures. In all cases where Castolite was used, a hardener, cumene peroxide, was added to aid in polymerization of the Castolite. Curing time for Castolite varies from 12 hours at 100°C (Buol and Fadness, 1961), to five to seven days at room temperature followed by 30 minutes at 82°C (McMillan and Mitchell, 1953).

Yarilova (1963) stated in his paper that Atemueller in Germany had good success using Vestopol H as an impregnating agent. Gile (1967) used Laminac Resin and Lupersol DDM as a hardening agent when impregnating sandy to clayey soils. He concluded that the procedure was successful on calcareous and noncalcareous soils. Innes and Pluth (1969), in their study used Scotchcast No. 3 to get complete impregnation of dense blocks. The advantages in using this resin was its simple preparation, low viscosity, short polymerization period, and high thermal stability. Some studies (Mackenzie and Dawson, 1961) have been carried out using Carbowax to impregnate moist or wet soils. These studies have been successful as far as the impregnation is concerned, because Carbowax melts at 55°C and is readily soluble in water in all proportions. Cutting and grinding of samples impregnated with Carbowax present some problems because of the material's softness.

Many investigators (Buol and Fadness, 1961; Guertin and Bourbeau, 1971; Innes and Pluth, 1970; Pettapiece, 1964) using different resins and procedures, found that impregnation was more complete if the samples were evacuated prior to and during the impregnation procedure.

Mounting and grinding techniques have not changed much over the years and have remained the same essentially. Kerosene has been found to be the best cooling, and lubricating material during the grinding procedure. Water or any other polar liquids tend to disperse and swell clay mineral grains. Some investigators (Brewer, 1962; Guertin and Bourbeau, 1971) have used dry grinding with varying degrees of success.

Sections of appropriate thickness are cut from the impregnated sample and trimmed to fit on a glass slide. In recent years, it has been found that grinding the side of the section to be afixed to the slide resulted in a better bond between the section and the slide. Lakeside 70 and Canada balsam have been used in the past to glue the soil section to the glass slide. More recently, epoxy has been used because of its better bonding properties. Soil sections, once glued to the slide, are then ground using Alundum or Silicon Carbide grinding compounds, to a thickness of 30 to 50 microns as judged by the interference colors of certain minerals. The final grinding using diamond pastes or an oxide is usually done on glass, wood or on a lapidary wheel using different types of cloth or paper. Once the desired soil thickness on the slide is obtained, the complete slide is thoroughly cleaned, and a cover slip is affixed using Canada balsam or Caedax. More recently, Caedax has been used mainly for the reason that it can be redissolved using xylene and also because it does not darken with age as does Canada balsam. Cover slips attached with Caedax may also be removed, and a polished surface can be imparted to the section if microprobe work is required.

Mineral mounts

Petrographic mineral analyses are preceded by specific gravity separations. Specific gravity separations are carried out using either bromoform (specific gravity 2.89), tetrabromethane (specific gravity 2.90), or other heavy liquids, or a mixture of the heavy liquids to arrive at a desired specific gravity. The most common procedures used are those of Jackson (1956, Chapter 10), or Milner (1962, Chapter 3).

A variety of resins are available for permanent light mineral grain mounts. Canada balsam (n 1.54) and Caedax (n 1.55) seem to be the most widely used. Other low index resins are kollolith (n 1.54), lakeside 70 (n 1.54), and permount (n 1.53). For heavy minerals it is generally preferable to use a resin of high refractive index to help facilitate heavy mineral identification. Resins such as piperine (n 1.68), hyrax (1.71), and Aroclor 4456 (n 1.66) have been used for heavy mineral mounts. For temporary mounts of heavy or light minerals, different immersion oils can be used.

Light mineral identification can be carried out by determining refractive indices or by chemical staining. The advantage of chemical staining over the determination by refractive indices is the rapidity of identification and counting. A number of methods (Gross and Moran, 1970; Jackson, 1956, p. 504; Reeder and McAllister, 1957) for chemical staining have been used. Before staining the grains are etched in hydrofluoric acid (Reeder and McAllister, 1957) for two minutes or in its fumes (Gross and Moran, 1970; Jackson, 1956) for ten minutes. After the treatment with hydrofluoric acid, all the investigators immersed the mineral grains in a concentrated sodium cobaltinitrite solution to stain the potash feldspars yellow. Each investigator used a different solution to stain the plagioclase feldspars. Reeder and McAllister (1957) immersed the grains in a buffered hematein solution to stain the plagioclase feldspars purple, while Jackson (1956) immersed the grains in a one percent malachite green dye solution staining the plagioclase feldspars green to greenish-blue, and Gross and Moran (1970) immersed the grains in a one percent solution of amaranth red staining all plagioclase feldspars a bright red. The depth of color of the plagioclase feldspars in all the staining methods became successively lighter with the less calcic feldspars. Quartz remains unchanged.