DOCTORAL DISSERTATION SERIES

TITLE MINERALOGY AND PETROLOGY OF THE RESIDUAL KAOLINS OF THE SOUTHERN APPALACHIAN REGION

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UNIVERSITY PENNSYLVANIA STATE COLL. DATE 1952

DEGREE Ph. D. PUBLICATION NO. 4815

UNIVERSITY MICROFILMS
ANN ARBOR - MICHIGAN

THE PENNSYLVANIA STATE COLLEGE

The Graduate School

Department of Earth Science

Division of Mineralogy

MINERALOGY AND PETROLOGY OF THE RESIDUAL KAOLINS OF THE SOUTHERN APPALACHIAN REGION

A Dissertation

by

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Submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

June 1952

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ABSTRACT

An investigation was made of the residual kaolins of the Southern Appalachian region to evaluate conditions giving rise to halloysite and kaolinite.

Samples were taken from weathered granites and pegmatites in the Piedmont provinces of Virginia, North Carolina and Georgia and in the Blue Ridge province of North Carolina.

A new differential thermal analysis technique was developed to determine quantitatively the relative amounts of endellite versus kaolinite and/or halloysite in a sample. This was used along with other analytical methods to make quantitative mineralogical analyses of the residual clays.

The mineralogical analyses and thin section studies formed the basis for determining the sequence of weathering in the granites and pegmatites. Halloysite is formed only from the weathering of feldspars, and under conditions of intense leaching is formed from both the plagioclase and potash feldspars. The primary mica always alters to vermicular kaolinite. Where leaching is less intense, vermicular kaolinite is formed from the potash feldspars through the intermediate stage of secondary mica of the muscovite type and halloysite is formed from the plagioclase feldspars.

Vermicular kaolinite is formed from the weathering of feldspars through the intermediate stage of secondary mica with minor amounts of halloysite froming directly from feldspar where acid leaching conditions obtain but are least intense. The bases are not effectively leached and secondary mica is the first weathering product to be formed from the feldspar. Once secondary mica is formed, vermicular kaolinite is the next weathering product.

The only physiographic region in the Southern Appalachians where halloysite predominates over kaolinite is in the Blue Ridge province of western North Carolina.

INTRODUCTION

Kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), endellite ($Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$) and halloysite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) occur as intimate mixtures in residual clay deposits. Halloysite is known to be the dehydration product of endellite (Alexander, 1943, Hendricks, 1938 and Bates, 1950), but the reason for the simultaneous occurrence of kaolinite and endellite, two varieties of the kaolin group, which are very similar in chemical composition had not been determined. It has been the purpose of this investigation to make a detailed mineralogical analysis of such mixtures and the source material from which they were derived in the hope of obtaining evidence as to the conditions giving rise to these two minerals during the processes of weathering.

The Blue Ridge and Piedmont provinces of the Southern Appalachian region in Virginia, North Carolina and Georgia were selected as the regions of study. Both kaolinite and halloysite occur there as weathered products and particularly good deposits for sampling were afforded by the accessible strip mines producing mica and clay derived from the alteration of the granites and pegmatites in the region. An areal map showing distribution of the areas sampled is shown in Figure 1. Composition of the pegmatites over the entire region is remarkably uniform according to Parker (1950) with the typical rock consisting essentially of plagioclase, perthitic microcline, quartz and muscovite. This uniformity in parent material was of particular advantage in the study. The study was restricted to residual clays in order that climatic control and parent rock or mineralogical control might best be evaluated.

The pegmatites and granites (variety alaskite) are weathered up to depths of one hundred feet with the depth of alteration depending on the

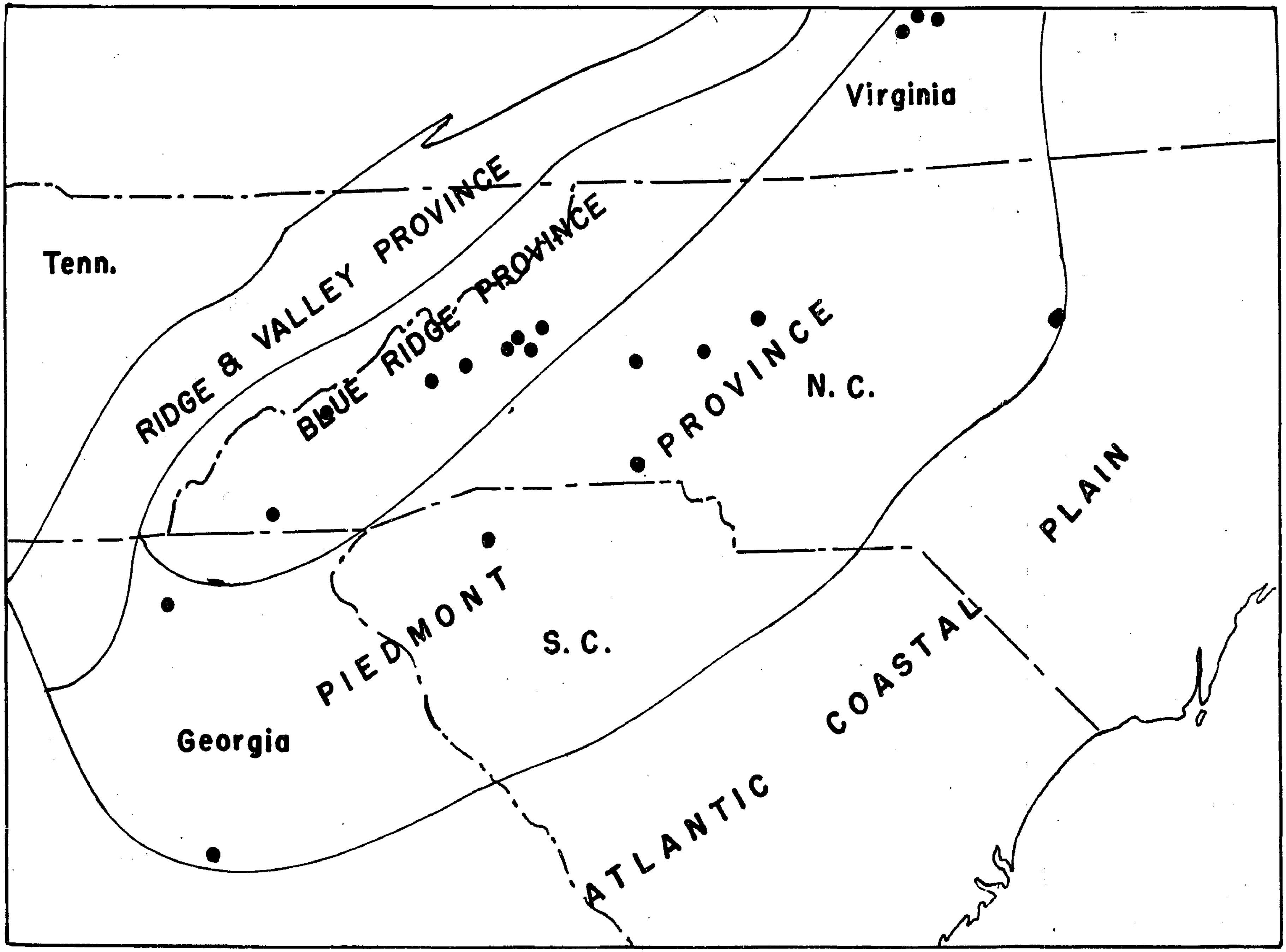


Figure 1. Areal map showing location of deposits in the Southern Appalachian region.

topographic location and degree of fracturing of the intrusive body. The deeply weathered deposits are located on gently sloping strath terraces and it was in these occurrences that transitions from completely altered feldspar grading into the parent material were exposed by the mining operations. According to Parker (1946) the most extensive period of kaoliznization in the Spruce Pine district occurred during the period during which the terraces were being formed. The altitude of these terraces led Bridges (1950) to suggest that they can be considered as intermontane extensions of the Harrisburg peneplane of early Tertiary age. According to Hunter (1940) Edwin C. Eckel was the first to recognize the existence of old river terraces and peneplanes in the Spruce Pine area and called them Tertiary in age. These terraces are covered with deposits up to thirty feet in thickness of poorly sorted river boulders.

Bridges (1950) states that the rocks in the Blue Ridge region were deeply weathered locally during the interval beginning with the uplift of the Schooley or Kittatinny peneplane and throughout the period in which the Harrisburg peneplane was being formed. Hunter and others observed that the depth of alteration coincides with the lowest level at which water freely circulates and the clay deposits occupy such a position relative to the river levels.

Hunter (1940) found no evidence of hydrothermal activity and none was found in the present study, either in the field or as the result of laboratory studies. It seems definitely established that these deposits are residual in nature and effected only by weathering processes.

Samples were collected in sample bags in August 1950 but laboratory work showed the need for preventing the dehyration of endellite and a return trip was made in May 1951 to collect and keep moist samples. The bulk of the samples were taken in the Blue Ridge province of western North Carolina. Profiles were also sampled in the Piedmont provinces of North Carolina, Virginia and Georgia. Sampling was done in open pit or quarry workings and in road cuts.

Analysis of the first suite of samples collected in 1950 disclosed the need for the development of new techniques for making quantitative mineralogical analyses of the clays in order to determine the relative amounts of kaolinite, halloysite and endellite. This was accomplished by development of a differential thermal analysis technique for determining the amount of endellite versus kaolinite and/or halloysite and a base-exchange method for determining the amount of kaolinite versus endellite and/or halloysite.

Mineral composition of the clays was determined in two ways. First, the clay was fractionated and a detailed mineralogical analysis made of each fraction and second, point count analyses were made of thin sections. Analysis by the first method utilized the techniques of x-ray diffraction, differential thermal analysis, and electron microscopy.

Phase equilibria studies were made on endellite to determine the conditions under which this variety is stable. The results of these studies and the data obtained from the mineralogical analyses form the basis for establishing the sequence of formation of kaolinite and endellite in these residual deposits.

NOMENCLATURE

Endellite — this name proposed by Alexander, et al. (1943) is used for the variety containing the monomolecular layer of interlayer water and having the theoretical formula $Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$.

Halloysite — this name is used for the variety resulting from the dehydration of endellite and having the theoretical formula $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. Usually the varietal name of endellite or halloysite is specified for the variety present, but where it is not necessary to distinguish between the two varieties the general term of halloysite is applied as recommended by the International Clay Group (Brindley, 1951).

Primary mica — this term refers to the mica present in the unweathered pegmatite or granite.

Secondary mica — this term refers to the mica formed by decomposition of the feldspar during weathering. It is of the muscovite type.

Alaskite — in the Spruce Pine district the term alaskite is used for the coarse textured granite free from Fe - Mg minerals. Since there is some argument among geologists in the area about the applicability of the term the material will be referred to in this report as granite.

LITERATURE REVIEW

Ross and Kerr (1930, 1934) give excellent reviews of the literature for the origin of kaolinite up to 1930 and for halloysite up to 1934. They state that halloysite is very commonly associated with kaolinite in some kaolinite deposits, especially residual deposits derived from pegmatites. They suggest that the halloysite occurring under such conditions may represent a stage in the eventual crystallization of kaolinite.

Hunter and Hash (1949) on the other hand suggest that in the halloysite deposits of western North Carolina alternate wetting and drying, with the possibility of aeration, may have been influential in the conversion of kaolinite to halloysite.

Ross and Kerr consider weathering to be probably the dominant mode of formation of halloysite, as in the case of kaolinite, but that a considerable proportion of halloysite has been formed in areas where oxidizing sulfides have supplied acids which acted on aluminous materials.

Undoubtedly many of the residual kaolin clays described are in part halloysite and the general evidence cited for the formation of kaolinite probably applied in part to the formation of halloysite.

Bayley (1921) states that the kaolins of North Carolina have without doubt been formed directly or indirectly by the weathering of feldspathic rocks. Surface water percolating through swampy tracts became charged with carbonic and organic acids which not only accelerated the process of weathering but caused removal of some of the iron that was in the parent rock. Bayley (1925) states that the kaolins in the mountain district of North Carolina are residual products resulting from the decay of pegmatite. Concerning the alteration of mica in these deposits, he states that near the surface the mica is altered and loses its characteristic features. Some plates thin enough to be transparent give no axial figure and contain numerous small flakes. He uses the term "hydromica" when referring to the decomposition products embedded in a matrix of unaltered muscovite.

Ries (1911) states that all of the workable kaolin deposits of the United States and probably many of those in central Europe are the work of surface waters whether they entered directly from the surface or filtered through a swamp bed of peat.

Lindgren (1915) states that kaolin is either a product of alteration by descending waters containing sulfuric acid or carbon dioxide, or of alteration by ascending weak carbonated waters close to the surface.

Selle (1876), Hickling (1908) and Galpin (1912) advocate the origin of kaolinite through the weathering of mica as an intermediate product. Galpin states that it is probable that secondary muscovite is directly converted into kaolinite. Secondary muscovite represents the first stage of the process and is the normal product of weathering of feldspars.

In the North Carolina deposits Ross and Kerr (1930) call the intermediate product a muscovite-like kaolin mineral. They say that crystals form vermicular aggregates like those of the kaolinite in the same deposit and many of these groups are partially altered to kaolinite. They present evidence to show that the muscovite of Hickling is not a muscovite but a clay that has about the same proportion of silica and alumina as kaolinite but with some potash and less water.

Denison, Fry and Gile (1929) made a study of alteration of mica in soil profiles and concluded from chemical and optical evidence that the muscovite alters to kaolinite.

Ross (1928) reports phenocrysts of biotite in a bentonite altering to kaolinite.

Cady (1950) reports on two deposits within two miles of each other in the Piedmont province of North Carolina. In a metagabbro he observed feldspar altering to halloysite and in a diorite he listed the formation of gibbsite, chlorite and allophane as the first stage of alteration and vermicular kaolinite as the second stage. He believes that halloysite is formed in regions where weathering is slow and free movement of air and water is restricted.

Shrader (1950) states that more kaolinite is developed in forest soils than in prairie soils.

In discussing the halloysite deposits of North Carolina, Hunter (1940) states that kaolinization takes place best where the topographic features encourage drainage and where alaskite is covered by a dense growth of vegetation such as rhododendron and laurel thickets. He points out that the halloysite deposits in alaskite and pegmatite are on river terraces which are capped with river gravels. This level topography discourages rapid runoff and causes a high percentage of rain water to percolate through the underlying alaskite. He adds that all of the deposits are underlain at some variable depth by partly weathered alaskite at levels where possibly the acidity of the water is partly neutralized and drainage becomes slow.

Takayasu (1950) reports pseudomorphs of kaolinite after biotite in a deposit of halloysite.

METHODS OF INVESTIGATION

Disaggregation and Dispersion Procedure

The samples analyzed were almost all white kaolinitic clays derived from feldspathic and micaceous material. The disaggregation and dispersion procedure is relatively simple. For mineralogical analysis it is required in this particular research that the material be kept wet during fractionation to prevent dehydration of the endellite. A 50 to 100 gram wet sample is mulled in water in a mullite mortar with a rubber pestle. The suspension is brought to pH = 10 by the addition of ammonium hydroxide and stirred in a blender for ten minutes. This gentle treatment allowed clay aggregates to be present in the coarser fractions, but it prevented the books of kaolinite and mica from being broken up and appearing in the finer fractions.

Fractionation Procedure

The suspension is first wet sieved through 60 mesh to remove all particles larger than 250 microns comprising the medium sand fraction. The material on the sieve is reworked in the mortar with the rubber pestle until only clear water passes through the sieve. The sediment then remaining on the sieve is bottled in water and set aside for x-ray and petrographic analysis. The suspension passing through 60 mesh is brought to pH = 10 and stirred again before wet sieving through the 200 mesh sieve. The same procedure as before is used to separate the material belonging to the fine to medium sand size. The sediment on the sieve is bottled wet for future analysis and the suspension again brought to pH = 10 and stirred.

The coarse to fine silts, ranging in size from 7.8 to 74 microns, are separated by gravity sedimentation. Starting with the 5ϕ size fractions are taken off at every intergral phi unit* (Krumbein 1934). The corresponding micron size can be found by referring to the flow sheet in Figure 2. The finest fraction separated by this method is the 6 to 7 phi fraction, and is the first to be taken. The suspension containing less than 200 mesh particles is put into one liter settling tubes and the top ten centimeters decanted after 31 minutes. This is repeated six to eight times until the top 10 cm. is clear. The same procedure applies to the next two coarser fractions.

Sedimentation times are for particles with 2.65 specific gravity and a temperature of 25°C derived from Stokes Law.

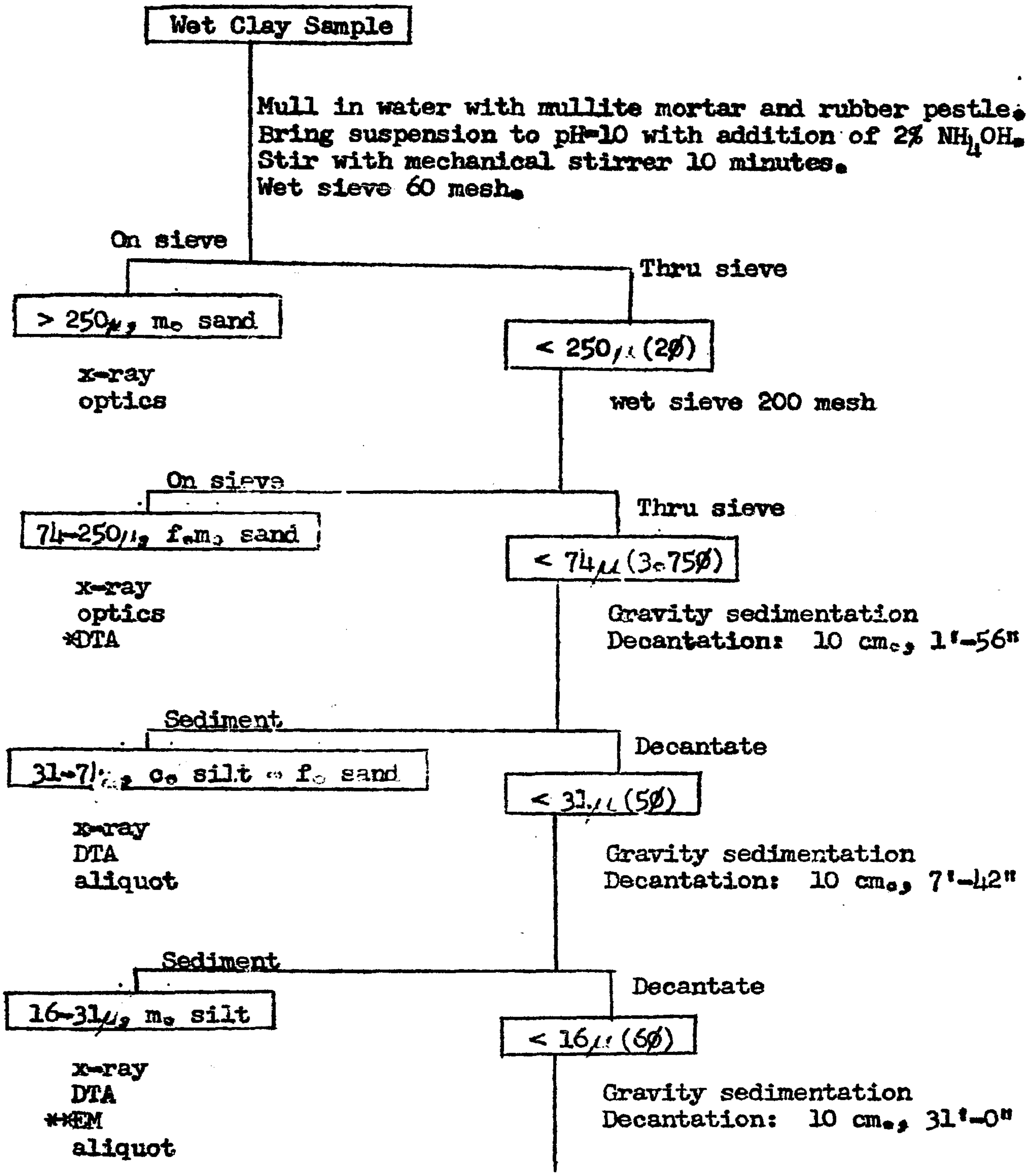
For separating fractions down to 10 phi (1 micron), the International Centrifuge No. 1-SB with No. 242 head and 250 ml. bottles with suspension depth of 10 cm. is used. Times and speeds are given in Figure 2. Centrifuging for each fraction is repeated six times or until the liquid is clear. As is done throughout the fractionation the suspension is kept at pH = 10 and stirred before each step.

The Sharples air-turbine supercentrifuge equipped with clarifer bowl is used for separating the less than 10 phi fractions. The finest fraction is taken off first and then subsequently coarser fractions. Two or three runs for each fraction are usually sufficient. The flow rates and speeds for various particle sizes are given in Table 1, calculated for a temperature of 25 C. An effective bowl volume of 267 ml. (Jackson, et. al., 1950) is used in the calculations.

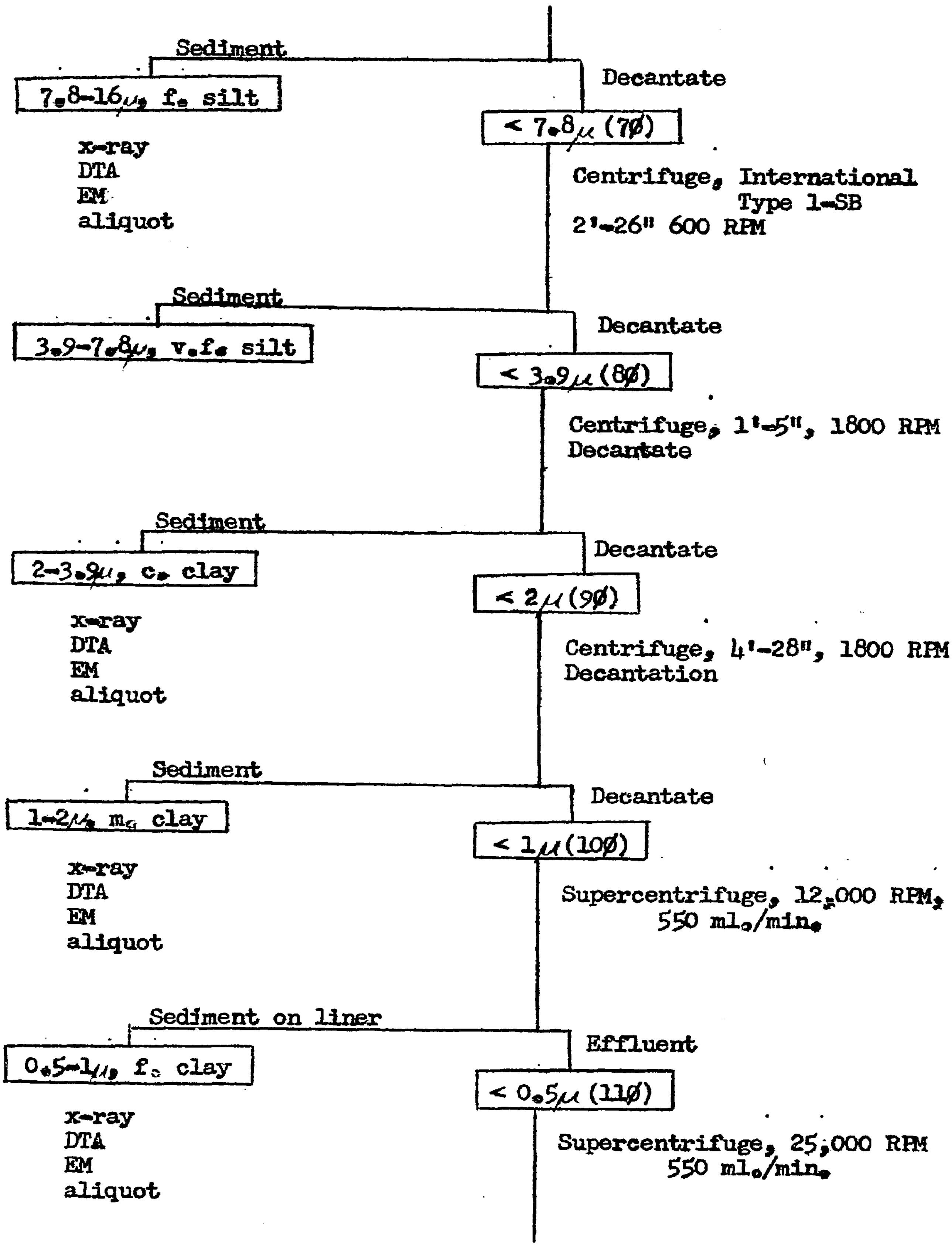
* $\phi = -\log_2$ (diameter in mm.)

Figure 2

Flow Sheet for Fractionation Procedure



*Differential Thermal Analysis
**Electron Microscopy


Sediment
7.8-16μ, f. silt
x-ray
DTA
EM
aliquot
Decantate
< 7.8μ (7Ø)
Centrifuge, International Type 1-SB
2'-26" 600 RPM
Sediment
3.9-7.8μ, v.f. silt
Decantate
< 3.9μ (8Ø)
Centrifuge, 1'-5", 1800 RPM
Decantate
Sediment
2-3.9μ, c. clay
x-ray
DTA
EM
aliquot
Decantate
< 2μ (9Ø)
Centrifuge, 4'-28", 1800 RPM
Decantation
Sediment
1-2μ, m. clay
x-ray
DTA
EM
aliquot
Decantate
< 1μ (10Ø)
Supercentrifuge, 12,000 RPM, 550 ml./min.
Sediment on liner
0.5-1μ, f. clay
x-ray
DTA
EM
aliquot
Effluent
< 0.5μ (11Ø)
Supercentrifuge, 25,000 RPM 550 ml./min.

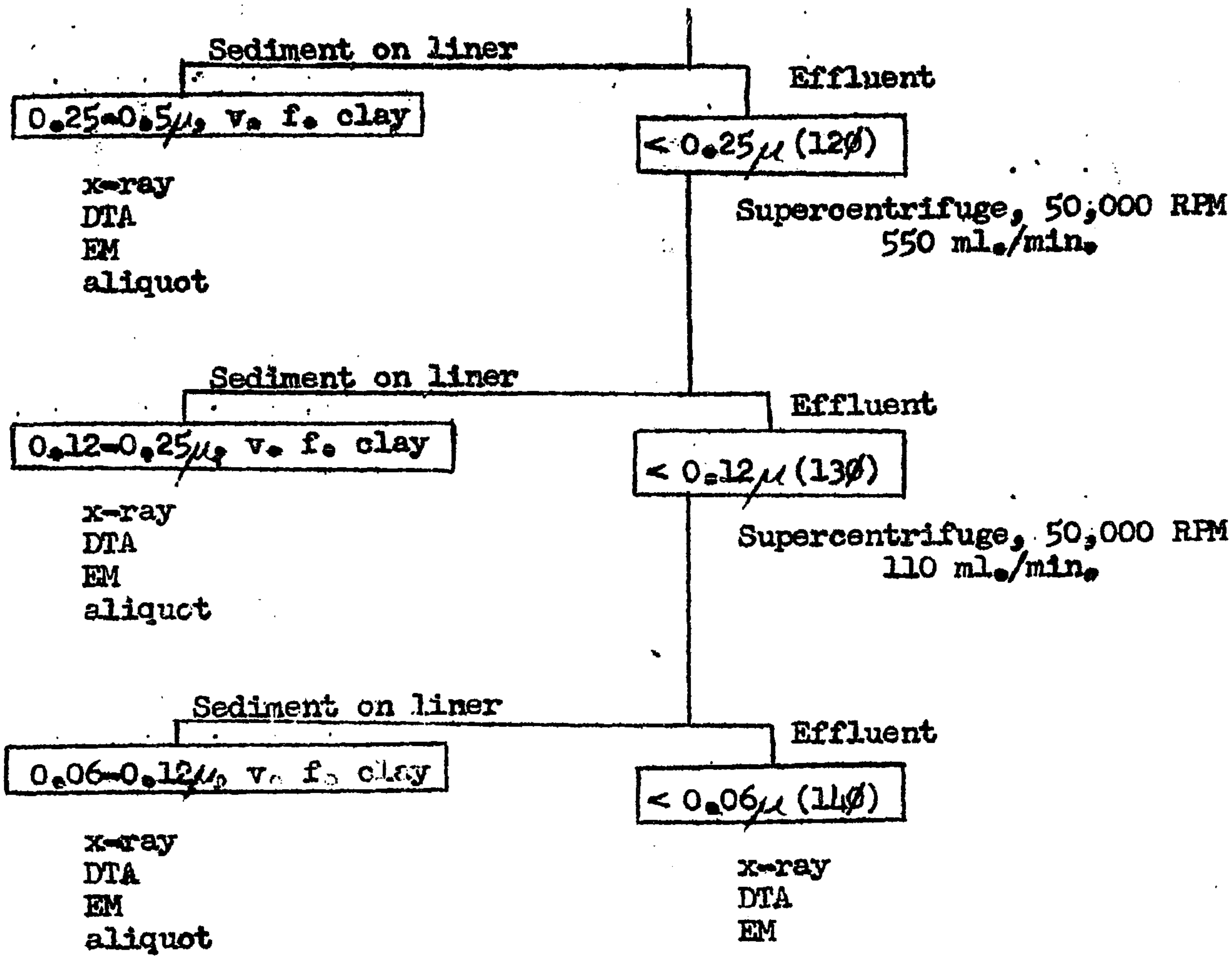

Sediment on liner
Effluent
0.25-0.5μ, v. f. clay
< 0.25μ (12Ø)
x-ray
DTA
EM
aliquot
Supercentrifuge, 50,000 RPM
550 ml./min.
Sediment on liner
Effluent
0.12-0.25μ, v. f. clay
< 0.12μ (13Ø)
x-ray
DTA
EM
aliquot
Supercentrifuge, 50,000 RPM
110 ml./min.
Sediment on liner
Effluent
0.06-0.12μ, v. f. clay
< 0.06μ (14Ø)
x-ray
DTA
EM
aliquot
x-ray
DTA
EM

TABLE 1

Flow Rates and Speeds for Sharples Supercentrifuge

Particle diameter ∅ units	Specific gravity	Speed RPM	Flow Rate ml./min.	Feed Nozzle
10	2.6	6,000	550	large
11	2.6	12,000	550	large
12	2.5	25,000	550	large
13	2.5	50,000	550	large
14	2.2	50,000	110	small

Size Analysis

To determine the size distribution of the clay sample the right side of the flow sheet in Figure 2 is followed all the way down, and a 25 ml. aliquot taken after every step. To check on the efficiency of fractionation an aliquot should also be taken of every fraction obtained and the results compared with the size analysis.

Differential Thermal Analysis

A differential thermal technique was developed which gives the amount of endellite versus kaolinite and/or halloysite in a sample. This new technique was used to determine the amount of endellite in each size fraction and the results are incorporated into the mineralogical analyses.

As Bradley (1946) and MacEwan (1948) have shown, various polar organic liquids have the ability to replace the interlayer water in endellite. When differential thermal analyses were run on certain of these endellite-organic liquid complexes, such as endellite with ethylene glycol, di- and triethylene glycol, and glycerine, the endothermal peak usually occurring at approximately 575°C was lowered to 500°C. Since this did not happen with kaolinite or halloysite, which do not form the complex, it presented itself as a method for determining the amount of endellite versus kaolinite and/or halloysite in a sample.

Endellite from the Dragon Mine, Eureka, Utah and ethylene glycol were used to form the complex by shaking the clay (aggregate size between 80 and 200 mesh) in an excess of the glycol for five minutes. The suspension was centrifuged at 3,000 rpm and the liquid decanted. Excess ethylene glycol was removed by working the complex on the retentive filter paper. Halloysite produced by dehydrating the endellite at 110°C was treated in exactly the same manner so that proportional weights of halloysite and endellite-glycol complex were obtained. (Placing the halloysite and endellite complex in a controlled atmosphere might give better standard mixtures, but the stability of the complexes has not yet been worked out and there is the possibility of some of the endellite changing to halloysite. This remains, however, as a possible future refinement of the method.) Ethylene glycol was added to the weighed mixture which was then worked into the consistency of a thick paste and run on the differential thermal unit.

The apparatus used for obtaining the patterns is shown in Figure 3 and is similar to that described by Kerr and Kulp (1948). The sample holder is a nickel block with a 1/4" dia. x 3/8" hole to contain the sample and covered with a nickel lid. Calcined alumina is used as reference material. The sample block sits on top of a vertically mounted muffle tube over which a furnace is lowered. The rate of heating is 10°C/min. and the differential thermal effect is recorded on an automatically recording Leeds and Northrup Speedomax potentiometer using a

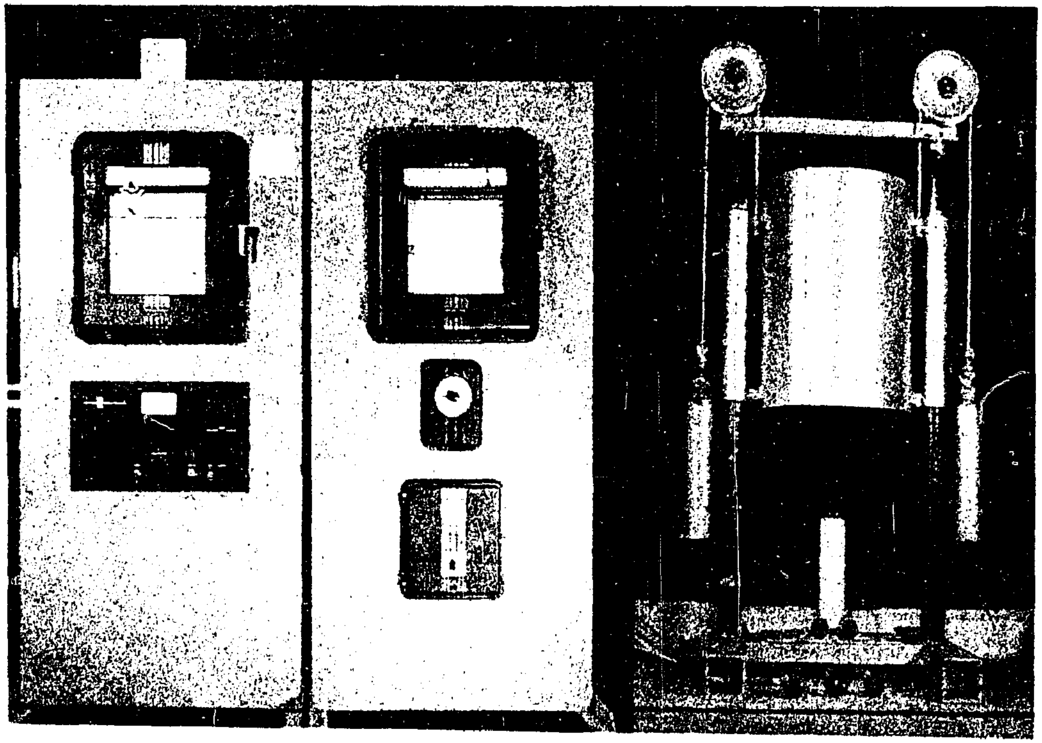


Figure 3. Differential thermal analysis unit.

sensitivity scale on the preamplifier providing a full-scale deflection of 0.6 millivolts on the Speedomax chart for chromel-alumel thermocouples. The chart moves at a rate of 6 inches/hr. to give a temperature interval of 100°C/inch.

A series of twenty-one mixtures at 5% intervals was prepared and run, and the curves in Figure 4 are the endothermal doublets obtained for the standard mixtures. The endothermal peak at 500°C represents the structural water leaving the endellite complex while the 575°C peak represents structural water leaving the halloysite. There is a drift to the exothermal side due to the smaller specific heat capacity of the sample than of the standard used, so the base line is drawn as in Figure 5.

Kaolinite from Langley, South Carolina was substituted for halloysite and mixtures of kaolinite and the endellite complex were also run on the DTA unit. Since it was found that kaolinite gave the same peak intensity as halloysite, this method gives the relative amounts of endellite versus kaolinite and/or halloysite in a sample. Where all three minerals are in a sample other techniques must be used to obtain the proportion of kaolinite and halloysite. If the kaolinite and halloysite particles are approximately the same size a count of plates and tubes can be made from electron micrographs. In special cases where the kaolinite occurs as coarser vermicular crystals, point counts can be made of the thin sections (Chayes, 1949), or the kaolinite crystals may be fractioned off leaving the fine fractions consisting only of halloysite and endellite.

The patterns in Figure 4 are used for direct comparison with those obtained from unknown mixtures and are especially useful in the low and high percentage mixtures.

For the mixtures between 20% and 80% of one component, it is

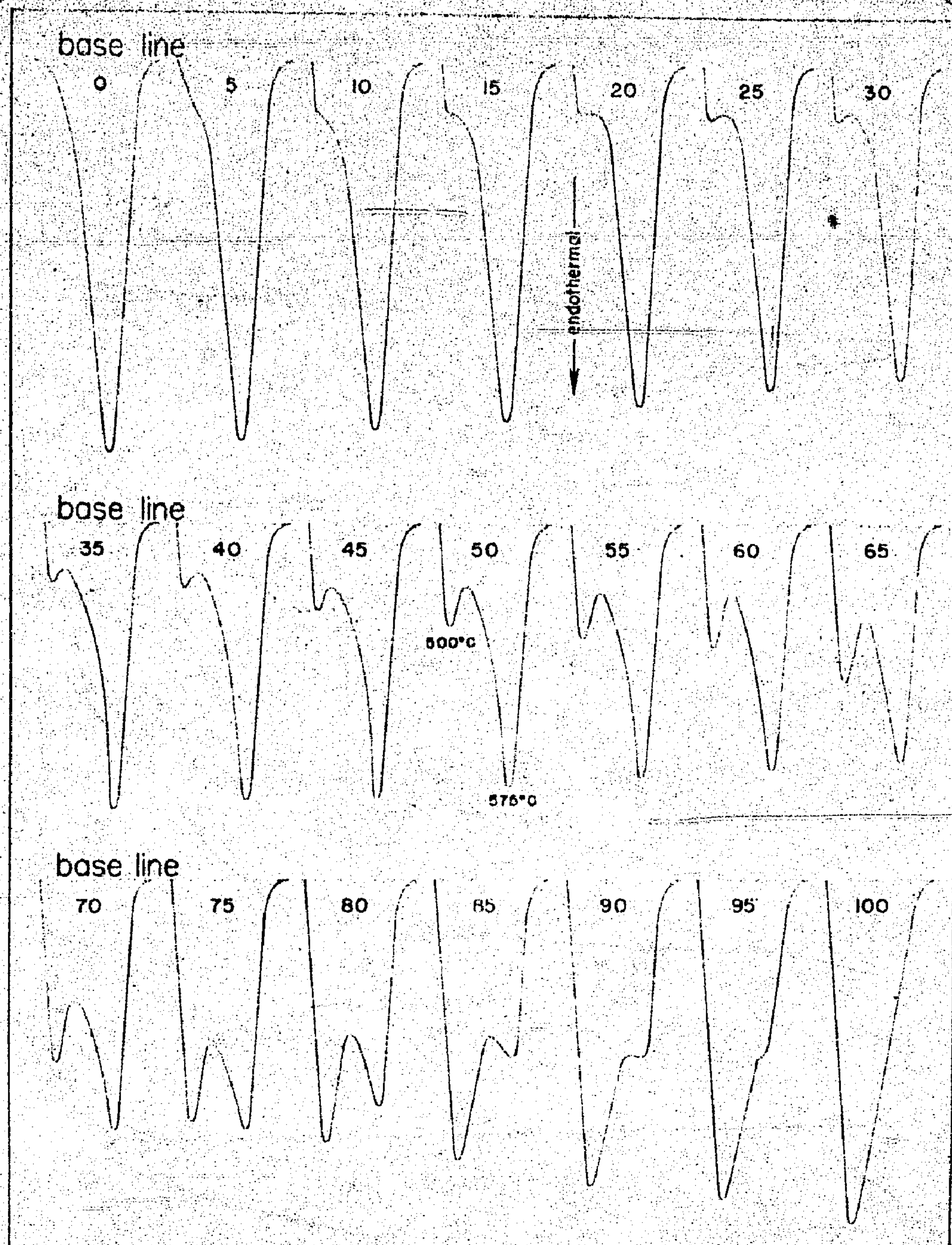


Figure 1. Standard reference patterns of endellite-halloysite mixtures. Percentages are given for endellite content.

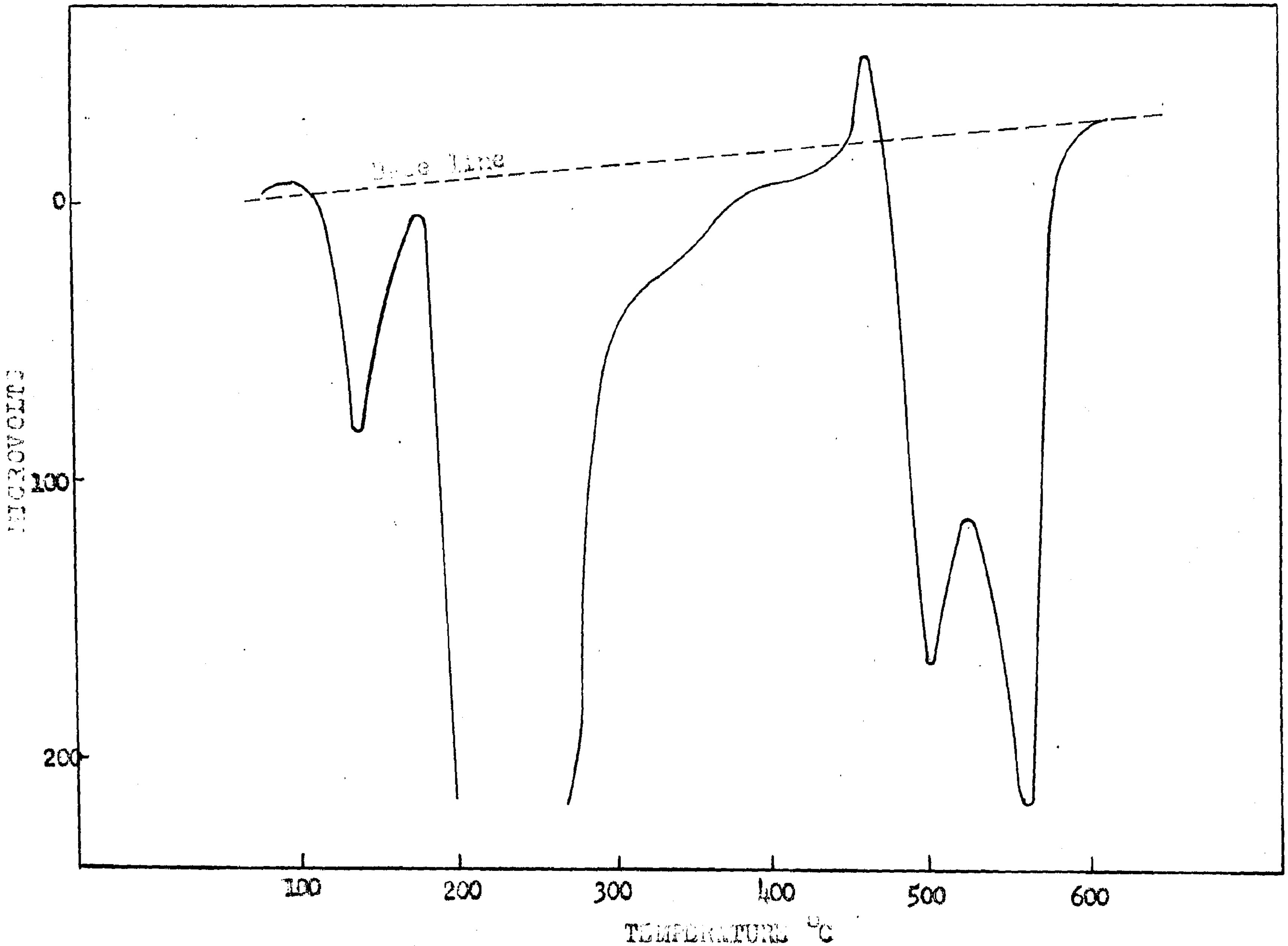


Figure 5. Differential thermal analysis of a mixture of 72% endellite-ethylene glycol complex and halloysite

preferable to use the graph shown in Figure 6. Here the ratio of the height of the 500°C peak from base line (E) to the height of the 575°C peak (H) is plotted along the logarithmic ordinate and the percentage of endellite in the mixture along the abscissa. The ratios as obtained from the standard patterns are as follows:

% Endellite	Ratio: E/H	% Endellite	Ratio: E/H
10	.130	55	.450
15	.138	60	.496
20	.142	65	.660
25	.157	70	.720
30	.172	75	.980
35	.198	80	1.16
40	.226	85	1.60
45	.302	90	1.78

For manually recording potentiometers, where a continuous pattern is not obtained, the graphical solution, which necessitates only the measurement of maximum peak heights, is superior to direct comparison with the reference curves. The overall accuracy of both methods using our apparatus is ± 3% and might be improved by refinement of technique in preparing the standards.

The unknown sample to be analyzed should be mulled in water so the clay aggregate will wet sieve through 80 mesh and be caught on 200 mesh. The clay-water suspension is centrifuged in 15 ml. tubes and the clear water decanted. A large excess of ethylene glycol is added to the wet clay and the tube vigorously shaken until a uniform suspension is obtained. This is centrifuged at 3,000 rpm for about fifteen minutes and the clear ethylene glycol decanted. The resulting clay-glycol suspension is of the right consistency for differential thermal analysis. (If no centrifuge is available the excess glycol may be removed by working the mixture on filter paper.) If the clay aggregate size is below

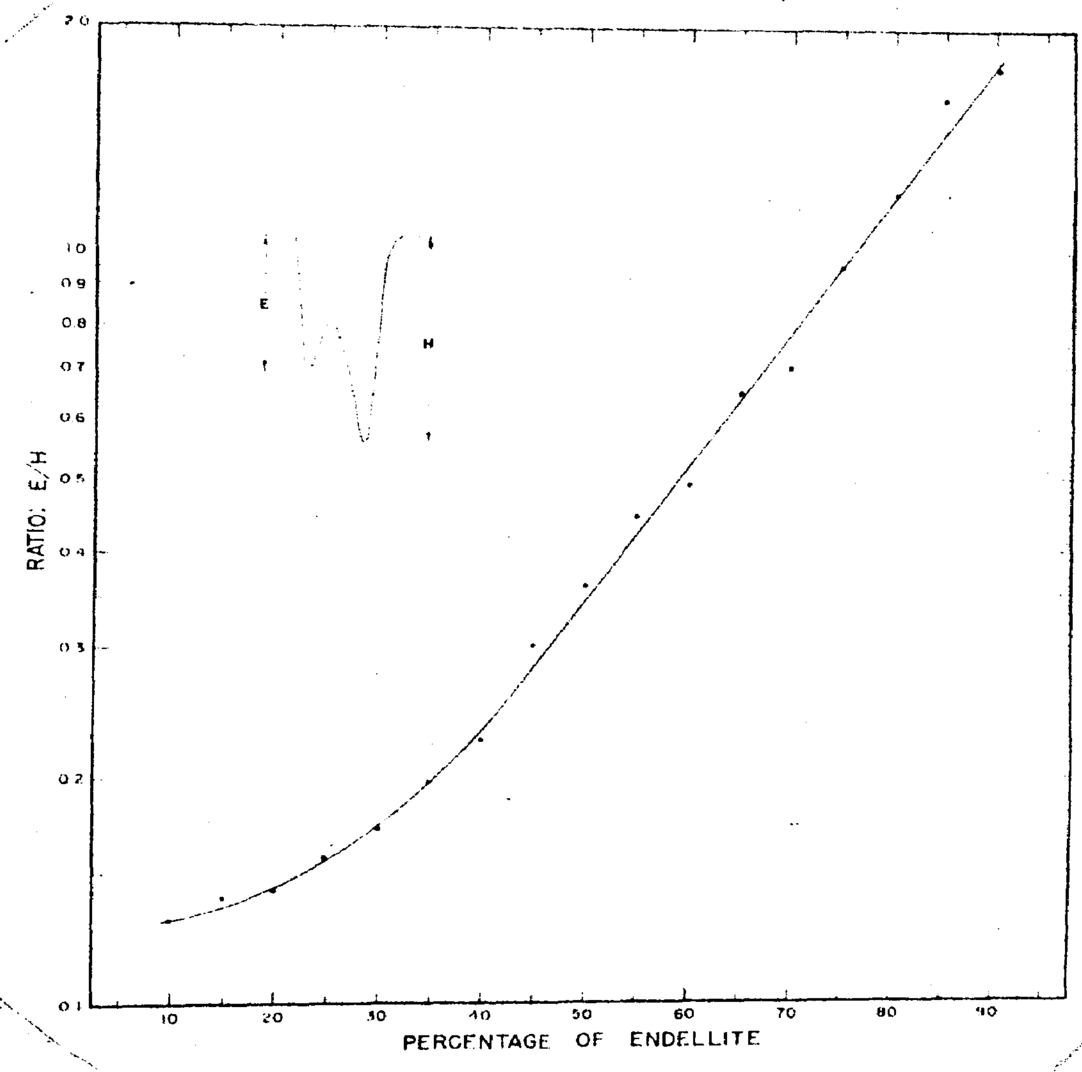


Figure 6. Graphical solution for determining the percentage of endellite in a mixture with halloysite and/or kaolinite.

ten microns, the suspension after centrifugation is not sufficiently compact and the ethylene glycol must be evaporated in an oven until the suspension has the proper consistency.

Since samples to be analyzed for content of the kaolin minerals usually contain other minerals, the effect of impurities on the curves was studied. A mixed layer dioctahedral 2:1 clay, an expanded dioctahedral 2:1 clay, quartz and mica were selected as minerals commonly associated with kaolinite and halloysite, and mixtures of these with the endellite complex were run on the differential thermal analysis unit.

The mixed layer clay was a K-bentonite from Oak Hall, Pennsylvania containing 20% expanded and 80% non-expanded layers. A mixture of 25% of this material and 75% endellite complex yielded a curve (Figure 7a) which is similar to that obtained for 95% endellite and 5% halloysite. A mixture of 50% mixed layer clay and 50% endellite complex gave curve 4b which is similar to 90% endellite and 10% halloysite. A mixture of 50% mixed layer clay, 25% endellite complex, and 25% halloysite gave a curve similar to 42% endellite and 58% halloysite. 10% mixed layer clay in the mixture had no evident effect on the shape of the curve.

The expanded 2:1 clay (montmorillonite from Polkville, Mississippi) had no effect on the curves except to decrease the peak heights.

Vein quartz from Washington, D. C. gave a sharp peak at 573.5°C which was used as the temperature reference. Ground to 200 mesh and mixed with the endellite complex the quartz had the same effect as the mixed layer clay in causing the halloysite peak to be present to a degree equal to about one-fifth the amount of impurity present in the sample. Curves of a series of quartz-endellite complex mixtures are shown in Figure 7c, d, e.

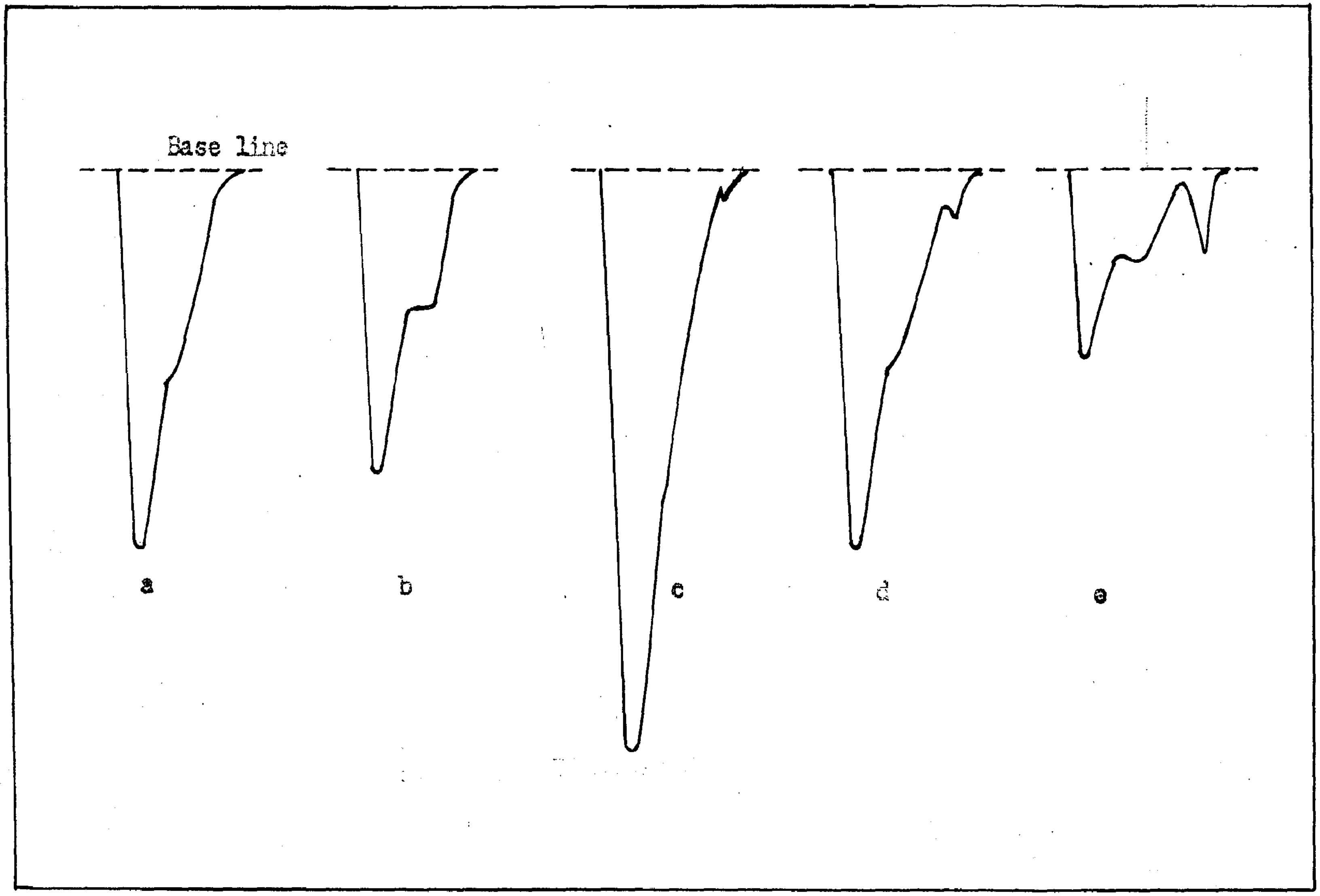


Figure 7 a. 25% illite and 75% endellite-ethylene glycol complex
50% illite and 50% endellite-ethylene glycol complex
10% quartz and 90% endellite-ethylene glycol complex
25% quartz and 75% endellite-ethylene glycol complex
50% quartz and 50% endellite-ethylene glycol complex

Muscovite ground to 200 mesh had the same effect on the curves as the mixed layer clay and quartz.

The effect of impurities, as shown by these curves, is to dampen the peak intensities and produce an erroneous halloysite or kaolinite peak which in magnitude is approximately equal to one-fifth of the amount of impurity present. Less than 10% of impurity in the sample will cause only dampening. Because of its ability to retain the glycol, the expanded 2:1 clay is the only commonly associated mineral which in amounts greater than 10% has no effect on the shape of the curve. The erroneous halloysite or kaolinite peak is produced in the case of the other impurities presumably because there is insufficient glycol retained in the mixture and a small amount of the endellite changes to halloysite. This will also happen if a cover is not placed over the sample, or if the amount of sample is too small or not of the correct consistency.

To test the application of the method using dissimilar differential thermal analysis units, samples were run on Mr. R. M. Gruver's apparatus in the Division of Ceramics and on Dr. C. D. Jeffries' unit in the Department of Agronomy. These units are described in the respective papers by those authors. Mr. Gruver's unit consists of a horizontally mounted furnace and sample holders which are 1.3 ml. platinum crucibles with covers. The rate of heating is automatically controlled and the differential thermal effects automatically recorded on a Brown potentiometer. Dr. Jeffries uses a large nickel block with cover which holds a two gram sample and is placed in a horizontally mounted furnace. The heating rate is maintained by manually increasing the Variac setting while the temperature and differential thermal effect are measured by reading deflections on a Rubicon 3400H galvanometer.

The two units produced curves which gave values to within ± 5% of those obtained on our unit and which were also sensitive to a minimum of 5% of one component. Greater accuracy could be obtained by running a series of standard mixtures on each unit. It seems apparent that almost any type of apparatus may be used providing the following procedures are observed:

1. Not less than 0.6 ml. of sample should be used.
2. The sample should have the consistency of a thick paste.
3. A lid should cover the sample.
4. Rate of heating should approximate 10 °C/min..

X-ray Analysis

The Norelco x-ray spectrometer with Brown recorder was used exclusively for x-ray analysis of samples. Since the samples usually contained only endellite, kaolinite, mica, quartz and feldspar, these were easily differentiated on the spectrometer patterns and the peak intensities obtained directly. CuK_{α} radiation was used. Speed of operation was a great advantage because of the large number of samples and fractions thereof that were analyzed. Forty minutes was the average time for one analysis using the 2 RPM motor. The moist sample was first run through an arc from $2\theta = 14°$ to $2\theta = 3°$ and then dried at 105°C and run from $2\theta = 60°$ to $2\theta = 3°$. This procedure was necessary to resolve the endellite and mica basal reflections which interfere with each other. Upon drying at 105° C the endellite completely dehydrates to halloysite with a shift in the basal spacing from 10.1 Å to 7.25 Å.

In the quantitative mineralogical analysis of the clay sample, the x-ray analyses were used for determination of the amounts of quartz, mica and feldspar in the finer fractions (<32 microns). This was only an estimate based on peak intensities but was found to be satisfactory for obtaining the small percentages of these minerals in these size fractions. In the coarser fractions where these minerals are concentrated, the percentages were obtained accurately by point counts of grain mounts. The data obtained from x-ray analysis are incorporated into the mineralogical analyses. Where kaolinite and halloysite were both present in the finest fractions, the position and sharpness of the basal reflection and the asymmetry of the (020) peak were used as criteria along with differential thermal analysis data and electron micrographs to estimate the mineral composition. Determination of the amounts of halloysite and kaolinite by x-ray analysis was attempted but for several reasons was not found to be satisfactory for more than qualitative evaluation. The tendency for endellite and halloysite to orient causes large variations in peak intensities of subsamples. Also, the peak intensities of the endellite can not be compared with those of kaolinite since the kaolinite is present in two different ways in the samples. Either it is interleaved with the mica from which it is being derived, in which case it orients preferably on the (001) planes, or it occurs as vermicular aggregates which have a preferred orientation on the (010) planes.

There is a possibility that x-ray spectometer analysis might have been used for quantitative analysis for endellite and kaolinite content if the sample had been homogenized to less than one micron to destroy the vermicular habit of the kaolinite and reduce the variability due to difference in orientation. However, a homogenizer was not available for this experiment.

Electron Microscopy

In the initial stages of the investigation it seemed that use of the electron microscope would solve the problem of quantitative analysis of halloysite and kaolinite in these samples by making counts of the platy kaolinite and tubular halloysite in electron micrographs. However, since it was found that the kaolinite occurs in these residual clays as coarse vermicular aggregates and interleaved with the mica, the electron microscope could not be utilized extensively in the quantitative mineralogical analyses. In the few samples where both kaolinite and halloysite were present in the <1 micron fractions, counts of halloysite tubes and kaolinite plates were used in conjunction with differential thermal and x-ray analyses to arrive at the mineral composition. The electron microscope proved an invaluable tool for observing the variations in morphology of the halloysite from different deposits. The table model electron microscope, type EMT, was useful in the reconnaissance of samples before taking the micrographs in the large electron microscope, type EMU.

Thin Section Analysis

The point counter method of Chayes (1949) was used as a method for mineralogical analysis. Since in the samples studied the kaolinite occurs only as vermicular crystals, it was relatively easy to distinguish from halloysite by its habit as well as birefringence. Where the kaolinite was interleaved with the mica from which it was derived, it was sometimes difficult to differentiate between the kaolinite and mica.

The amounts of the other minerals such as quartz, mica and feldspar were also quickly obtained by this method. This technique was used to corroborate the results obtained from mineralogical analysis of the size fractions and was used exclusively for determing the composition of samples which had dehydrated and could not be analyzed by the other method.

A point count employing 1200 counts of a thin section from the 17 acre prospect in the Spruce Pine district was statistically analyzed for precision and the results are tabulated in Table 2.

Table 2.

Bulk Mineral Composition of S-39

	Arith. Mean	Standard Dev. Mean	Coef. of Variation	Confidence Limits
Quartz	3.0%	0.39%	390%	
Halloysite	66.8	1.05	6	63.7-70.0
Kaolinite	13.1	1.16	10	11.0-14.6
Mica	17.1	0.97	15	15.1-19.1
	100.0%			

Two thin sections were made at right angles to each other of another sample ONR 698 from the same deposit to show variation in sub-samples as determined by this method. The two analyses compare well as seen in Table 3.

Table 3.

Bulk Mineral Composition of ONR 698

	698a	698b
Halloysite	85.6%	84.9%
Kaolinite	8.8	8.8
Mica	3.8	6.3
Quartz	1.8	----
	100.0%	100.0%

In order to compare the method of a point count of a thin section with the method of determining the mineral composition by analysis of size fractions, two samples of S-39 analyzed by the latter method are listed together with the mineral composition obtained by point count in Table 4.

Table 4

	Bulk Mineral Composition of S-39 Analysis of Size Fractions		Point Count
	S-39A	S-39B	S-39
Halloysite	64.5%	61.8%	66.8
Kaolinite	13.2	11.1	13.1
Quartz	5.5	8.8	3.0
Mica	16.8	18.2	17.1
	100.0%	99.9%	100.0%

Grain Mounts

Fractions larger than 32 microns were mounted in Canada balsam and point counts made to determine the mineral compositions. These fractions consisted of combinations of quartz, mica and feldspar and of clay aggregates which had not been effectively dispersed.

Base-exchange Capacity Determinations

Base-exchange studies were made on the kaolin clays as well as on artificial mixtures of kaolinite and endellite to determine whether the method would be suitable as an analytical tool. Data obtained from this work was promising and with additional work should form the basis of a method for determining the relative amounts of kaolinite versus halloysite and/or endellite in a kaolin sample. A combination of this method with the differential thermal analysis method which quantitatively determines the relative amounts of endellite versus kaolinite and/or halloysite should provide a complete quantitative picture of the amounts of the three varieties in a sample of kaolin clay. Unfortunately the base-exchange studies were made too late to apply to all the samples. Sampling was carried out so that the majority of the samples analyzed contained only endellite and kaolinite so the method wasn't essential for obtaining the mineralogical compositions.

An accurate and fairly rapid colorimetric method developed by Bower and Truog (1940) was used for the determination of the base-exchange capacities of the residual kaolin clays. This method was selected because of its adaptability for use on small samples. Apparatus in the laboratory of Dr. C. D. Jeffries of the Department of Agronomy was used and the cooperation and assistance of Mr. G. W. Kunze was of great help in analyzing the samples in a minimum of time. Eight samples in duplicate were run simultaneously and required three days for processing. The method involves saturation of approximately 0.1 grams of clay with manganous chloride solution. After displacement with ammonium acetate (pH = 7) the manganese is oxidized to permanganic acid and determined colorimetrically.

The base-exchange capacities were determined for bulk samples (-200 mesh) from each of the deposits under detailed study. The values follow in Table 5 with the base-exchange capacities expressed in milliequivalents per 100 grams of clay.

Two samples were selected to qualitatively measure the effect of kaolinite and endellite content on the base-exchange capacity of the clay. Sample S-16 is predominantly endellite and S-112 is predominantly kaolinite with endellite increasing in quantity in the finer fractions of both samples. The base-exchange capacities for the various size fractions are tabulated in Table 6.

Table 5.

Base-exchange Capacities for Bulk Samples

Sample	Bulk Composition	Base Exchange
S-16, Alexander, N.C.	Endellite, kaolinite, mica, quartz	25.8
S-21, Micaville, N.C.	Mica, endellite, kaolinite, quartz	15.0
S-34, Fluken Ridge deposit, Spruce Pine, N.C.	Endellite, kaolinite, mica, quartz	19.8
S-44, Gusher Knob deposit, Ingalls, N.C.	Endellite, kaolinite, mica, quartz	28.5
S-104, Dry Branch, Ga.	Kaolinite, mica, quartz	17.4
S-39, 17-acre deposit, Spruce Pine, N.C.	Endellite, kaolinite, mica, quartz	18.5
S-112, Hartwell, Ga.	Kaolinite, mica, endellite, quartz	11.3
S-113, Kings Mountain, N.C.	Kaolinite, mica, endellite, quartz	6.1
S-119, Ellerbe, N.C.	Kaolinite, mica, quartz	17.5
S-122, Hayesville, N.C.	Kaolinite, mica, endellite, quartz	15.2
S-123, Roseland, Va.	Kaolinite, mica, quartz, endellite	7.6
ONR 653, Carter Ridge deposit, Spruce Pine, N.C.	Endellite, haolinite, mica, quartz	12.7

Table 6.

Base-exchange Capacities for Size Fractions

	Size Fraction	Base Exchange Capacity
S-16, Alexander, N.C.	bulk	25.8
	32-74 microns	11.0
	16-32 "	9.7
	8-16 "	11.3
	4-8 "	12.2
	2-4 "	17.2
	1-2 "	22.9
	-11 "	27.3
S-112, Hartwell, Ga.	bulk	11.3
	4-8 microns	12.4
	2-4 "	16.1
	1-2 "	17.9
	-1 "	26.6

The values listed in Tables 5 and 6 were obtained from clays containing endellite. To compare the base exchange of halloysite with that of the endellite from which it was derived, three fairly pure endellite samples were dried at 105°C and the base-exchange capacities determined. These results are tabulated in Table 7.

Table 7.

Base-exchange Capacities for Endellite and Halloysite

Sample	Locality	State of Hydration	Base-Exchange
S-16, -1 micron	Alexander, N.C.	endellite	25.8
" "	"	halloysite	27.3
S-39, -1 micron	Spruce Pine, N. C.	endellite	25.0
" "	"	halloysite	26.5
ONR 311, -1 micron	Eureka, Utah	endellite	27.4
" "	"	halloysite	25.3

Ammonium hydroxide had been used to disperse the samples before taking aliquots, and in the first set of eight samples run, washing out the ammonia remaining in the clay after decantation was neglected so manganese hydroxide was precipitated in small amounts to give an erroneous and very high base-exchange value of over a hundred for the endellite. This error in procedure was corrected in subsequent samples by washing with dilute hydrochloric acid before adding the manganous chloride, so that no hydroxide would be present to precipitate manganese.

Since the endellite fractions gave a much higher value than the kaolinite fractions when the manganous hydroxide was precipitated erroneously, it was thought that possibly some of the hydroxide precipitated in the water layers of endellite. If this were the case, the wide range of values that had been obtained in the erroneous determination of from 12 m.e. for kaolinite to 168 m.e. for endellite might be used as the basis for a method for determining the amounts of the two present.

Weighed amounts of Georgia kaolinite (-200 mesh) and aliquots of an Eureka endellite (-200 mesh) suspension were mixed in 0, 25, 50, 75, and 100% mixtures. This was done in triplicate and the base-exchange determinations made on the fifteen samples. Before adding the manganous chloride the mixtures were made up to constant concentration of ammonium hydroxide (15 ml. of 0.5N ammonium hydroxide per gram of clay). These were centrifuged at 3000 rpm for one hour, decanted and inverted to drain for five minutes before the base-exchange determinations were made. The mean values obtained for each mixture are given in Table 8 and plotted in Figure 8 to show the linear relationship. It is apparent from the results that centrifugation and thorough decantation had removed the excess ammonium hydroxide and no manganese hydroxide was precipitated in the water layers of the endellite.

Table 8.

Base-exchange Capacities for Prepared Mixtures of Endellite and Kaolinite

Percent Kaolinite	Percent Endellite	Base-Exchange
0	100	18.3
25	75	15.4
50	50	12.8
75	25	9.8
100	0	7.1

As seen in Table 7 endellite and halloysite derived from the endellite have very similar base-exchange capacities. Values for halloysite samples from different deposits in the North Carolina pegmatite district fall very close to each other. Taking a value of 6.1 m.e. for kaolinite and 27.3 m.e. for halloysite, the graph in figure 9 was constructed and the calculated values in Table 9 obtained from this graph. The percentages of halloysite were obtained from differential thermal

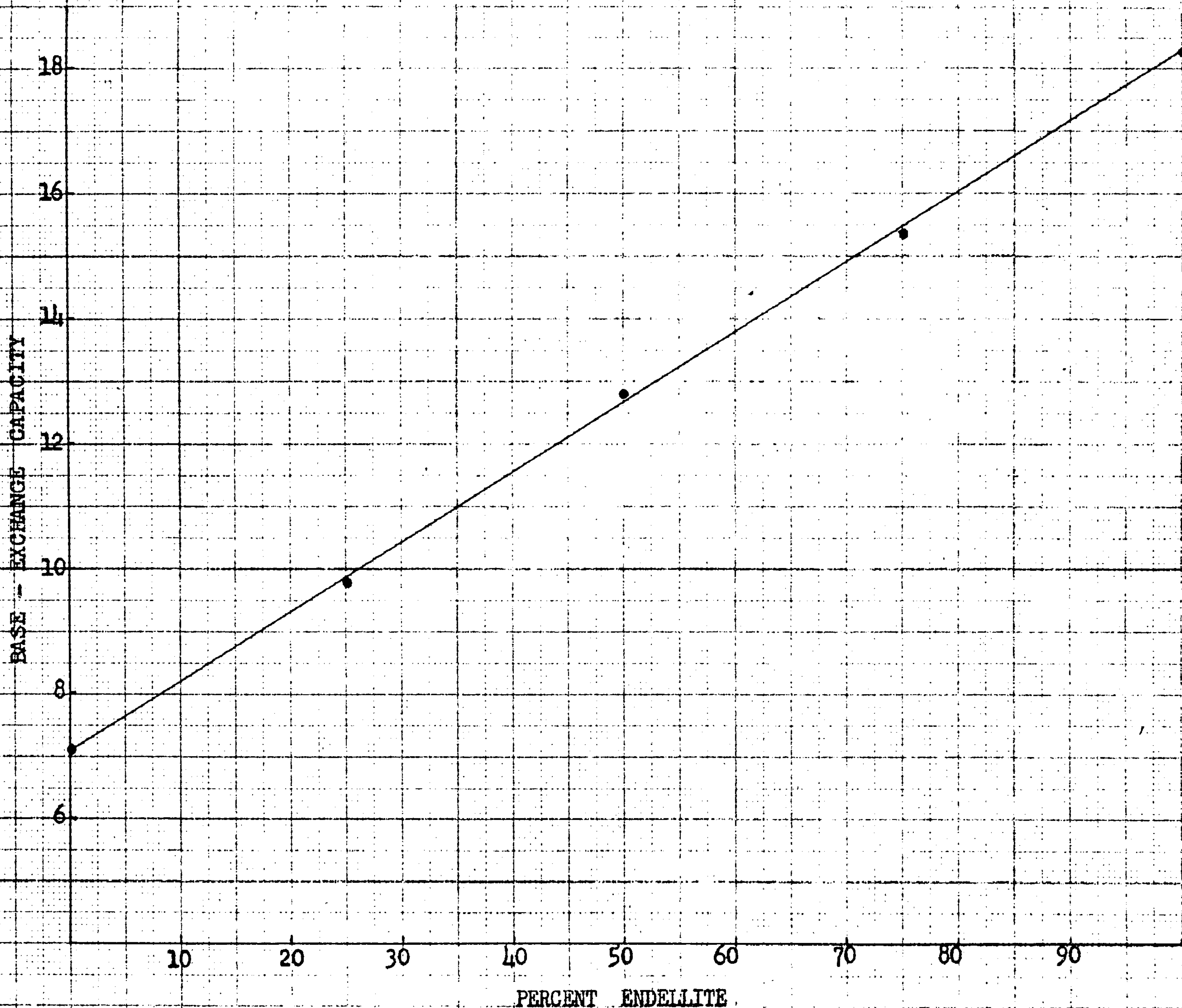
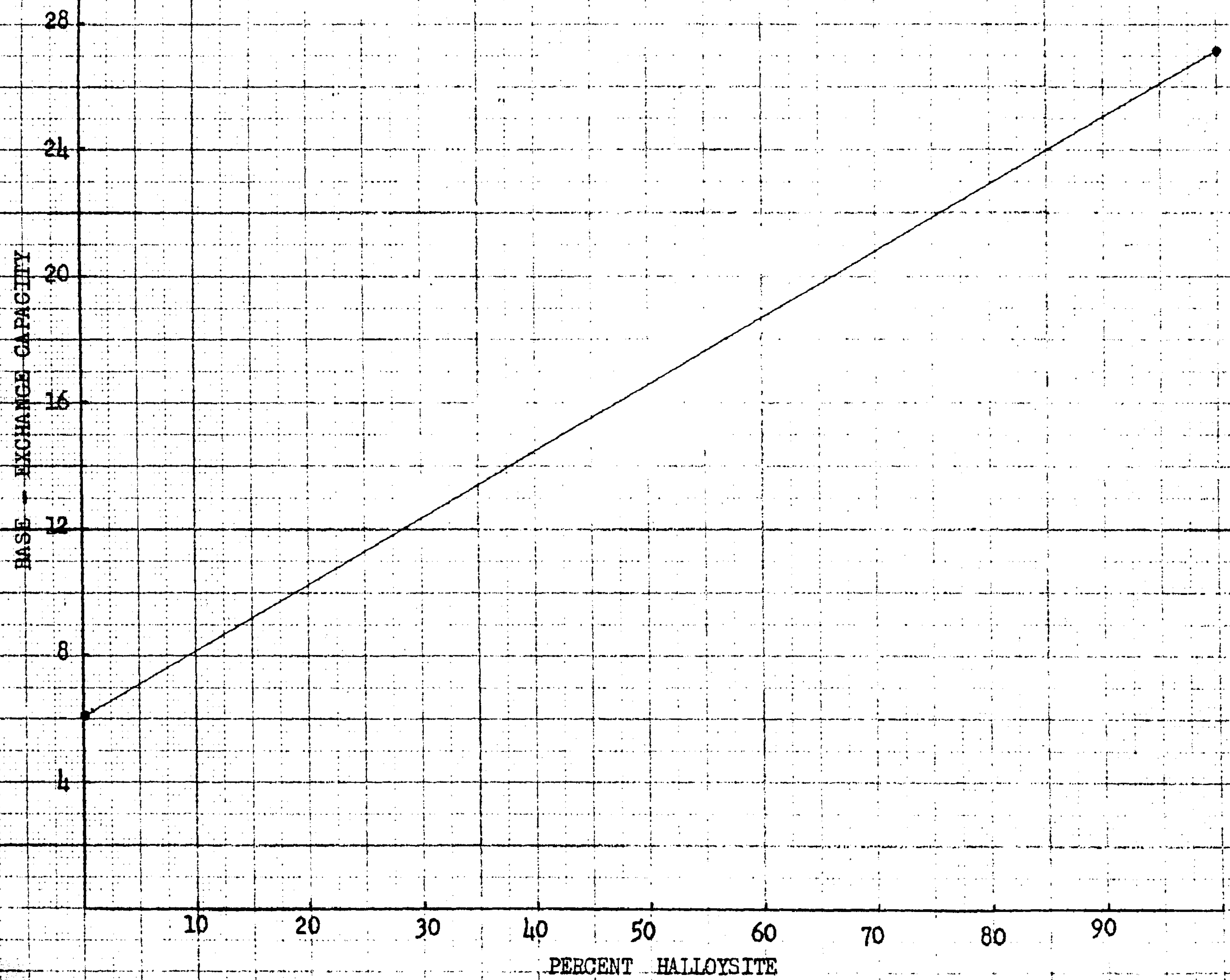

BASE - EXCHANGE CAPACITY
18
16
14
12
10
8
6
10
20
30
40
50
60
70
80
90
PERCENT ENDELLITE

Figure 8



BASE - EXCHANGE CAPACITY
28
24
20
16
12
8
4
10
20
30
40
50
60
70
80
90
PERCENT HALLOYSITE

Figure 9

analysis data and are part of the mineralogical analyses of S-16 and S-112. Particle size undoubtedly has an effect in the increase of base-exchange capacity in the finer fractions, but it is probably secondary as compared to the kaolinite to halloysite ratio. This is substantiated by the correlation between calculated and measured values for the various size fractions of S-16 and S-112. The fractions listed contain only kaolinite and halloysite.

Table 9

Measured and Calculated Base-exchange Capacities for Natural Mixtures of Halloysite and Kaolinite

Size fraction	% Halloysite	Measured b.-e. cap.	Calculated b.-e. cap.
S-16, Alexander, N. C.			
bulk	78.1	25.8	22.7
4-8 microns	36.7	12.2	13.8
2-4 microns	70.0	17.2	20.1
1-2 microns	80.8	22.9	23.2
-1 micron	100.0	27.3	27.3
S-112, Hartwell, Ga.			
bulk	25.4	11.3	11.5
4-8 microns	20.7	12.4	10.5
2-4 microns	53.4	16.1	17.0
1-2 microns	57.3	17.9	18.2
-1 micron	86.9	26.6	24.5

Even with the large error inherent in using aliquots of the endellite suspension to make up the prepared mixtures of endellite and kaolinite and in using bulk samples, fair results were obtained (in Tables 8 and 9 and Figure 8) which indicate the linear relationship between the kaolinite to halloysite and/or endellite ratio and the base-exchange capacity.

Phase Equilibria Studies

Since little has been reported in the literature regarding the stability of endellite at low temperatures, an experiment was set up to determine the vapor pressure-temperature relationship between endellite and halloysite. Brindley and Goodyear (1948) studied the water content of endellite and halloysite at room temperature over a range of humidities as already mentioned, and their results are based on the supposition that endellite and halloysite are in equilibrium at these various humidities. MacEwan (1948) makes the statement that endellite loses its interlayer water at 50°C even when immersed in water at this temperature, but doesn't say how he obtained this figure.

With advice from Dr. E. F. Osborn of the Pennsylvania State College, an attempt was made to obtain this stability information. To furnish a constant temperature, a standard constant-temperature water bath was used which consisted of a 12" pyrex jar, heating element, thermostat and stirrer. This was used in the temperature range of 40-65°C. Because of the limitations of this apparatus, runs were of two days duration although it would have been desirable to make them longer. 1" x 6" test tubes, containing 2" of sulfuric acid-water solutions were immersed in the water bath with a water trap leading from the test tubes to prevent escape of vapors (Stockdale and Tooley, 1950). The sample of endellite was spread thinly on a glass slide, excess water removed by filter paper, and the slide was then placed on a support over the solution after the latter had been allowed to reach the desired temperature.

To obtain data at room temperature, the endellite was placed on a glass slide over these solutions for a period of ten days in sealed bottles.

Since the water bath only reached a temperature of 65° C, an arrangement was needed to give a constant temperature up to an including the boiling point of water. This was satisfactorily obtained by supporting a flask with reflex condenser at various distances over a hot plate.

Sulfuric acid-aqueous solutions were chosen to give the desired vapor pressures because of the wide range of vapor pressures that could be obtained. The differences in vapor pressures are relatively small between various concentrations of solutions at the lower temperatures and consequently concentrations were taken at 10% intervals at these lower temperatures and 5% intervals at higher temperatures.

For determining whether endellite or halloysite was present after equilibrium presumably had been obtained, the sample on the glass slide was wetted immediately and put on the x-ray spectrometer for analysis. In all cases, whether endellite or halloysite, the sample appeared dry and powdery to the touch before wetting. The results of these data are plotted in Figure 10. The boundary curve gets very steep between 80° and 100 C and approaches very closely to the vapor pressure curve of water.

Since endellite-halloysite is a two component system, the only place where the two can co-exist at equilibrium is on the boundary curve. Thus, it is believed that previous weight-loss measurements at various humidities of endellite versus halloysite only measured the rate of dehydration and did not represent equilibrium conditions.

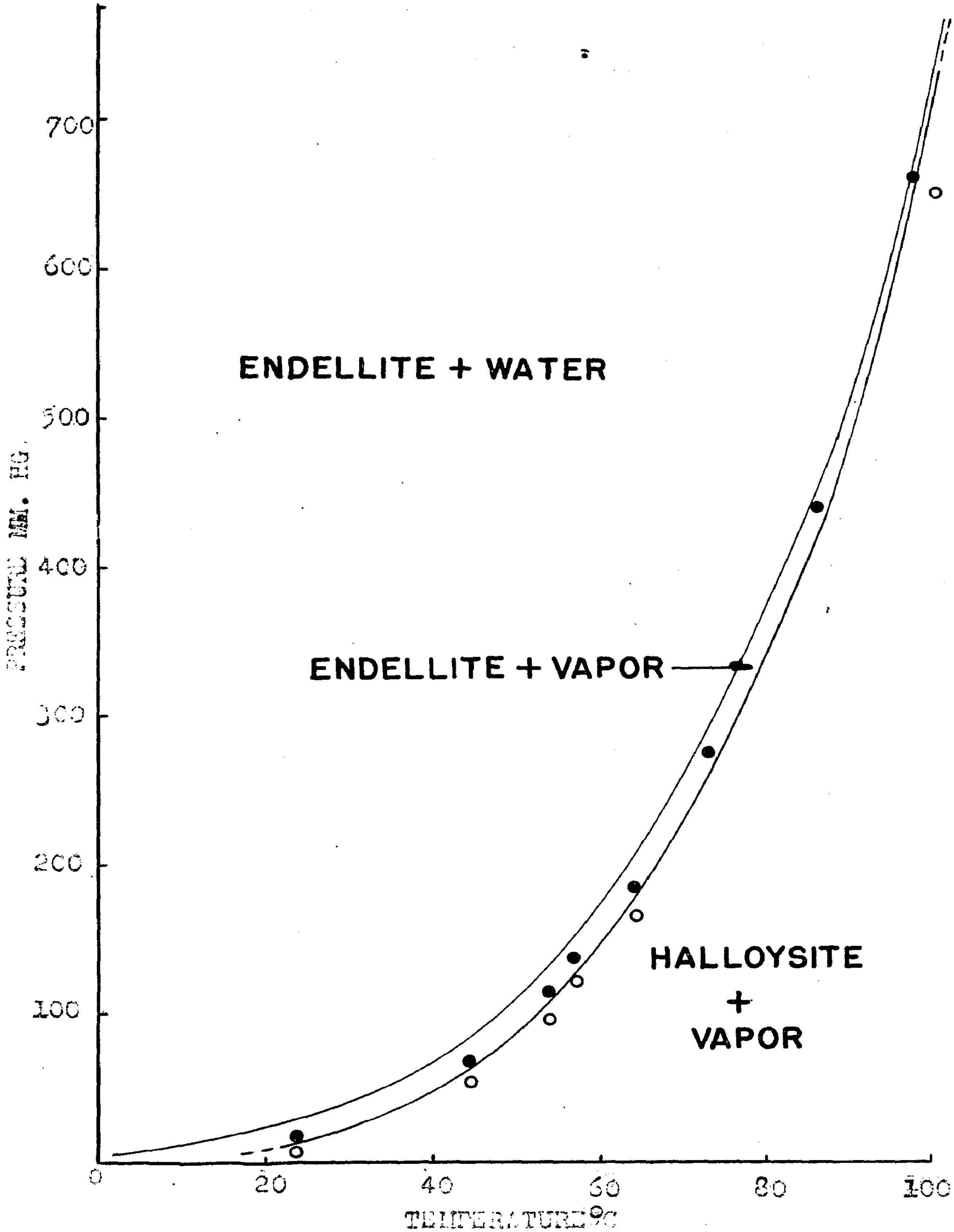


Figure 10. Stability fields for endellite and halloysite.

pH Determinations

pH measurements were made with a Beckman H-2 glass electrode pH meter. 50% suspensions of clay in distilled water (pH = 6.85) were used.

ANALYTICAL DATA OF SAMPLES

The Piedmont Province of Virginia

Morefield Mine, Amelia Court House, Amelia Co., Virginia

A decomposed portion of a large pegmatite dike 1500 feet long and 15 feet wide outcrops on the property of Silas V. Morefield, 4-1/2 miles east of Amelia Court House and 1-1/2 miles southeast of Winterham as shown on Figure 11. The pegmatite is predominantly quartz-microcline with numerous rare minerals as accessories (Pegau, 1933). It strikes N50°E and dips steeply to the northwest. This particular area is in the Piedmont province and has low relief, poor to fair drainage and an average elevation of 300 feet.

The mine is not being worked at the present time and the shaft is completley filled with water. Samples of the decomposed pegmatite were taken in Cut #1 of the mine. This cut is 15 feet deep across the pegmatite dike. The feldspar is altering to secondary mica which in turn is being kaolinized. Very little of the feldspar is altered to halloysite. Electron micrographs of all the samples show well-defined kaolinite plates with a few halloysite tubes averaging 2 microns in length and 0.2 microns in diameter.

American Rutile Mine, Roseland, Nelson Co., Virginia

These open pit workings are located between Virginia state highway 655 and the Tye River in Roseland, Virginia and can be seen from the highway as one enters the community from the south.

This area is close to the Blue Ridge province, has moderate relief

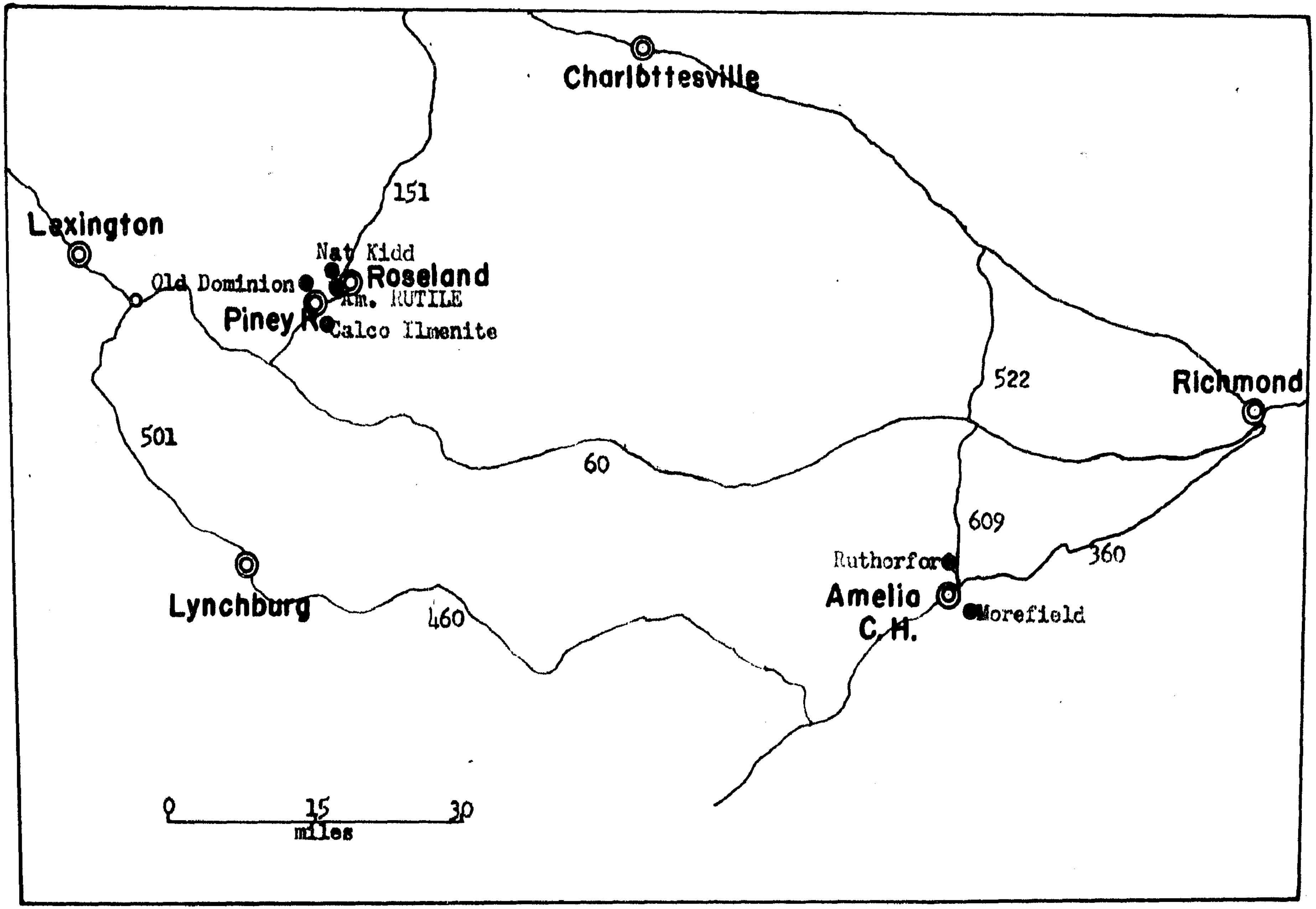


Figure 11. Areal map of the Piedmont province of Virginia.

and good drainage.

The mine is not being worked but overgrowth is negligible and weathering profiles are accessible. The parent rock is a rutile-bearing syenite, locally referred to as nelsonite, with apatite and ilmenite also fairly abundant. The deposit lies 75 feet above the Tye River and the depth of weathering varies from several feet to thirty feet. This variation is due to structural control with the alteration concentrated along fault zones and fractures and most intense at fracture joins. The clay is white with yellow and brown stains from decomposed rutile and ilmenite grains.

Sample ONR 365 was taken at the zone of most intense weathering at a fracture join. Mineralogical analysis of the sample by the thin section method gave the following composition: kaolinite and halloysite 70.0%, mica 29.2% and quartz 0.8%. The feldspar is altering to secondary mica which in turn is being kaolinized to small (.02mm.) vermicular crystals. The vermicular habit is not as well developed as in most deposits of this type. Electron micrographs of the clay show predominantly kaolinite books with a few halloysite tubes.

Nat Kidd Prospect, Roseland, Nelson Co., Virginia

Old kaolin prospects in the weathered nelsonite in the vicinity of Roseland were located but these had been completely filled in and an auger drill is necessary to obtain samples. One moist sample was subsequently obtained in this manner by Mr. Robert Taylor of Roseland from the Nat Kidd kaolin prospect several miles west of Roseland and sent to the author. A mineralogical analysis was made of this sample, S-123. The cumulative size frequency curve is shown in Figure 12.

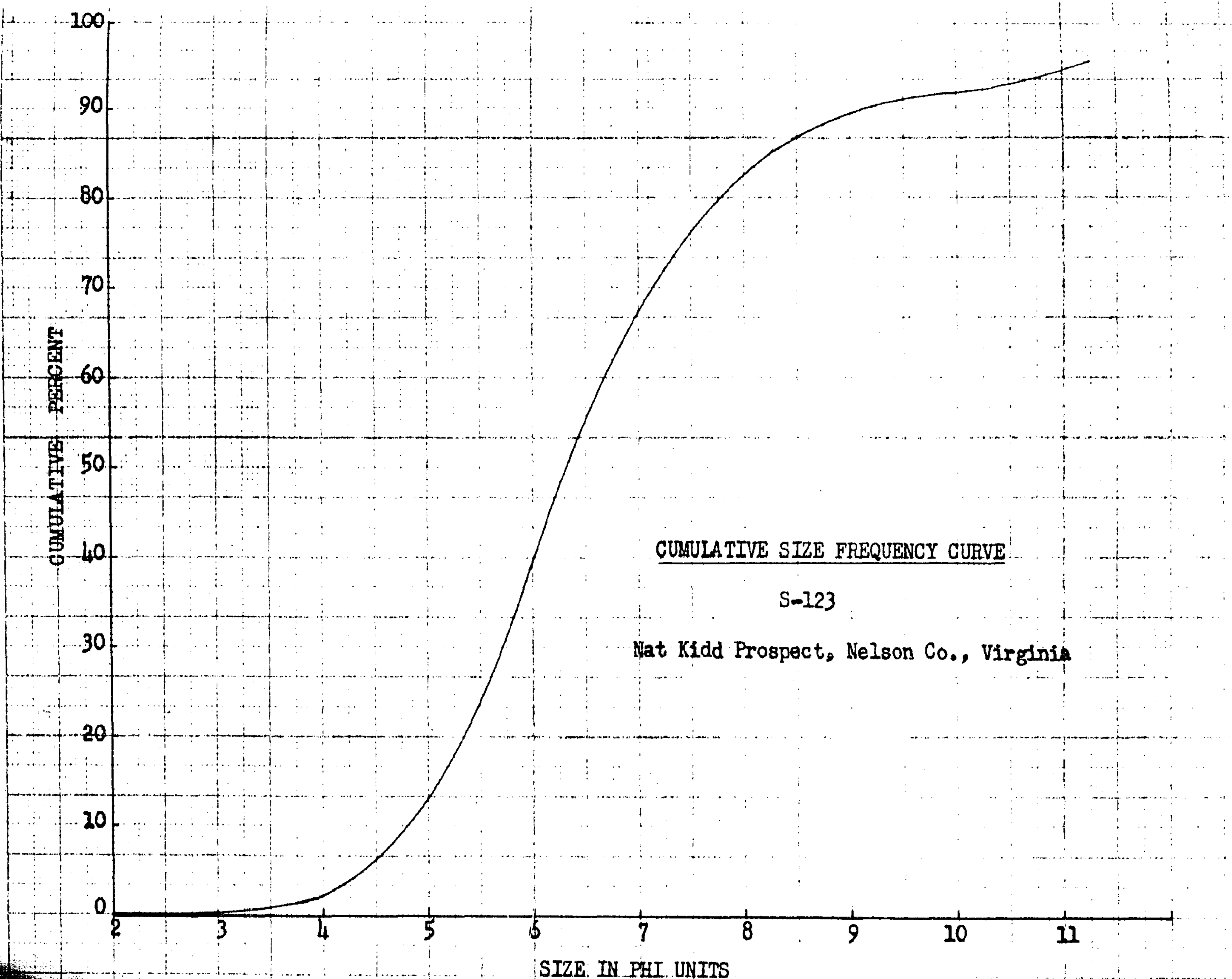

CUMULATIVE SIZE FREQUENCY CURVE
S-123
Nat Kidd Prospect, Nelson Co., Virginia
CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
2
3
4
5
6
7
8
9
10
11
SIZE IN PHI UNITS

Figure 12

Table 10.

S-123, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	tr.	0.2%	tr.		tr.	0.2
2-3.75	0.1	0.3			0.2	0.6
3.75-5		6.1			5.9	12.0
5-6		13.2			13.4	26.6
6-7		8.6			19.0	27.6
7-8		3.1			12.3	15.4
8-9		1.3			7.2	8.5
9-10		tr.		0.1	0.7	0.8
10-11		0.1		0.8	2.1	3.0
-11		0.2		1.4	3.7	5.3
Totals	0.1%	33.1%		2.3%	64.5%	100.0%

The analysis of S-132 shows an halloysite to kaolinite ratio of 1:28. The median size for the kaolinite is 0.02 mm. The analysis corresponds closely with that of ONR 365 obtained from the American Rutile Mine at Roseland.

Electron micrographs of the less than one micron fraction of S-123 show mica and kaolinite flakes with halloysite tubes averaging 3 microns in length and 0.2 microns in diameter (see Plate 1).

The pH measurement on this sample was 5.55.

Calco Ilmenite Mine, Piney River, Amherst Co., Virginia

An ilmenite mine operated by the American Cyanamid Corporation is located at Piney River, Virginia on the Amherst County side of the Piney River. Company offices are on the east side of Virginia state highway 151 and the strip mine is located directly behind these offices. This area is close to the Blue Ridge province and has moderate relief, good drainage and an average elevation of 950 feet.

The ore body consists of a weathered nelsonite with a high content of ilmenite. Alternating bands of feldspar and Fe-Mg minerals are up to 6 inches in width. The ore body is approximately 3000 feet along the strike and 500 feet wide and strikes N75°E and dips 45° southeast. Samples were taken from the feldspathic material for analysis of the clay minerals.

Samples of thoroughly decomposed feldspar from Cut #2 in the foot-wall on the west side contain largely kaolinitic clay with some halloysite tubes averaging 2 microns in length.

Samples from freshly exposed feldspathic material near the south-east hanging wall are predominantly kaolinite with very little halloysite present. The feldspar is being weathered to kaolinite through the intermediate stage of secondary mica. The vermicular kaolinite is especially well developed near fractures in the feldspar and the books range up to .04 mm. in width.

Dominion Minerals Aplite Mine, Piney River, Amherst Co., Virginia

This mine is located west of Virginia 151 across from the Calco ilmenite mine. It is a quarry operation in an anorthosite dike 100 feet above the level of the Piney River. The upper 15 feet of this massive plagioclase is weathered to a white dry clay which is very friable. The clay is stained tan and brown at the subsoil level but is white at the contact with fresh rock.

The feldspar is being altered to mica which in turn is being weathered to vermicular kaolinite. Some feldspar is altering directly to halloysite. Electron micrographs of this clay show kaolinite plates and books with halloysite tubes averaging 1 micron in length and 0.1 micron in diameter. Some mica flakes are also present.

The Piedmont Province of North Carolina

C. R. Boone Quarry, Raleigh, Wake Co., North Carolina

This abandoned quarry is located at the juntion of U.S. 15A and 70 with Oberlin Road in Raleigh, North Carolina. Samples were obtained from the subsoil of a Cecil profile developed from granite gneiss. This is in an area of low relief with an average elevation of 360 feet. The feldspathic material in the gneiss was found to be weathering predominantly to kaolinite with some halloysite. Tubes of the latter average less than 1 micron in length.

North Carolina State College Campus, Raleigh, Wake Co., North Carolina

New construction on the west end of the State College campus afforded excellent fresh soil porofiles. A Cecil soil developed from granite gneiss was sampled 300 feet northwest of the new agronomy building and 100 feet from Hillsboro Road (U.S. 1 and 64). The clay derived from feldspathic material is stained light tan, yellow and red. This is in an area of low relief but fair drainage with an average elevation of 350 feet.

The feldspathic material in the gneiss is being altered to kaolinite but there is no evidence that mica is an intermediate stage. No kaolinite with vermicular habit was observed. Some halloysite is being formed from the feldspar and the tubes are well developed up to 10 microns in length and averaging 0.2 microns in diameter.

Mockville, Davie Co., North Carolina

Weathered gneissoid diorite was sampled in a 12 foot roadcut, 13 miles west of Mockville on U. S. 64 at the juntion with a dirt road leading north to Society Church and south to Griffith's farm. This is an area of low relief with an average elevation of 860 feet.

The feldspar from this gneiss is weathering predominantly to kaolinite with some halloysite.

Catawba, Catawba Co., North Carolina

A Cecil soil profile developed on gneissoid granite was sampled at an exposure by U. S. 64 on the Catawba County bank of the Catawba River. The soil has a uniform dark brown color and has relatively fresh feldspar bands standing out in relief in the cut.

The feldspar is altering to kaolinite but no vermicular aggregates were observed. Electron micrographs of the samples show mostly kaolinite plates with a few halloysite tubes.

Patterson Mica Mine, Kings Mountain, Cleveland Co., North Carolina

This deposit is located one and one-half miles northeast of Kings Mountain. Five samples were taken and detailed analyses made on two of them.

S-113 consists of mica, clay and quartz from thoroughly altered granitic material at the south end of the pit thirty feet below the surface.

The median size of the kaolinite is greater than 0.25 mm. This is not the size of the individual kaolinite crystals, but the interleaving of the kaolinite with the mica causes the kaolinite to appear in the coarsest fractions. Halloysite is present only to the extent of 0.5% of the total sample and the median size is at 2 microns. Electron micrographs of the less than one micron fraction show mica and kaolinite flakes and about one-third of the particles are halloysite tubes 3 microns or less in length with an average diameter of 0.2 microns.

The halloysite to kaolinite ratio is 1: 109.

The cumulative size frequency distribution curve for S-113 is shown in Figure 13.

The pH measurement on this sample was 5.61.

Table 11.

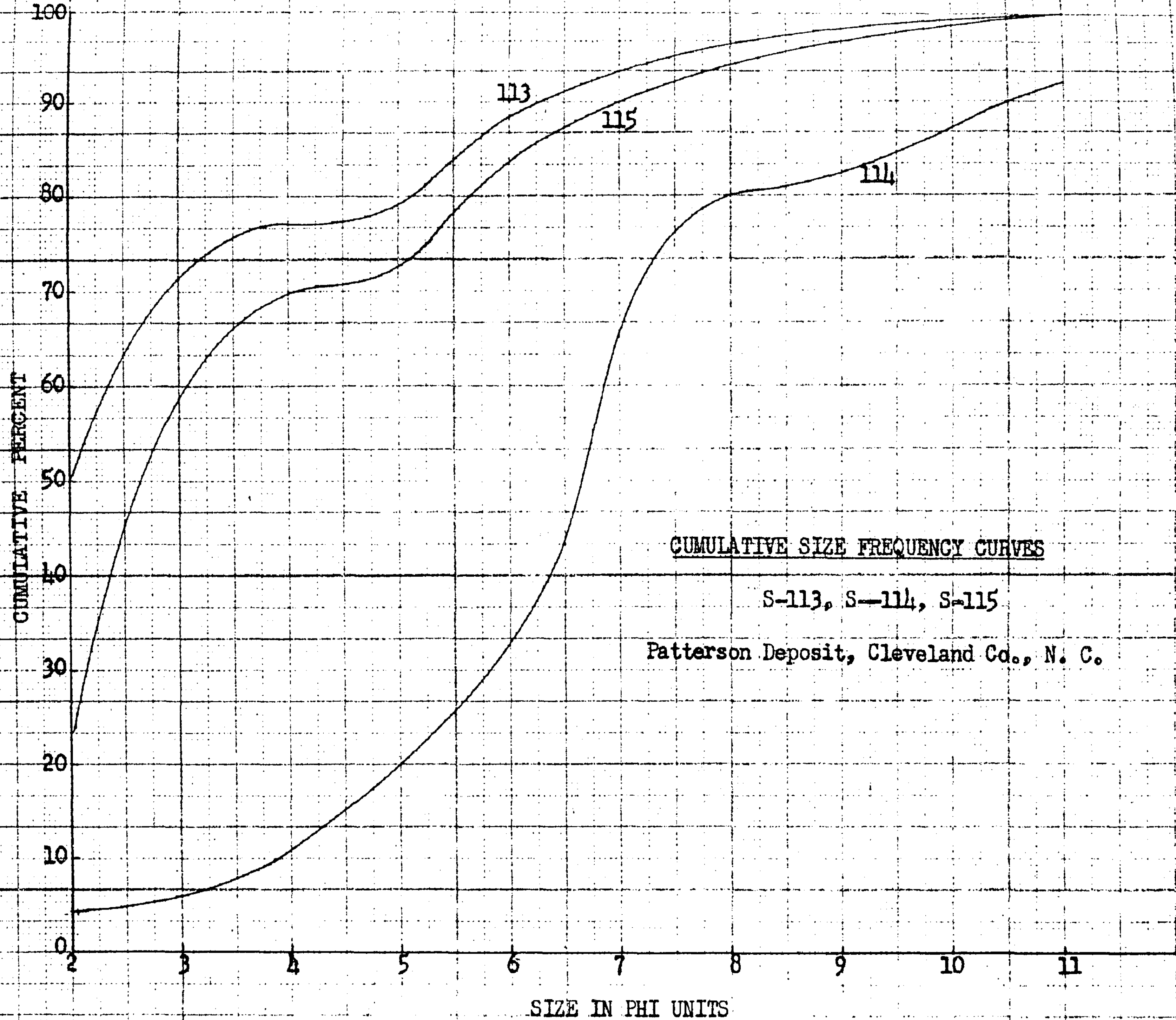
S-113, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ø	5.0%	13.5%		31.7%	50.2%
2-3.75		13.7		12.9	26.6
3.75-5		1.1		1.4	2.5
5-6		3.1		6.4	9.5
6-7		2.0		2.2	4.2
7-8		1.0	tr.	1.4	2.4
8-9		0.5	0.1	1.8	2.4
9-10		0.1	0.1	0.9	1.1
10-11		0.1	0.2	0.5	0.8
-11 ø		tr.	0.1	0.3	0.4
Totals	5.0%	35.1%	0.5%	59.5%	100.1%

Sample S-114 consists of decomposed feldspar from pegmatitic material located in the center of the pit and 50 feet below the surface.

Table 12.

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ø	0.4%	2.3%		1.6%	4.3%
2-3.75	0.2	1.6		2.3	4.1
3.75-5		3.0		9.3	12.3
5-6		2.2	0.2	9.5	11.9
6-7		0.8	8.4	24.6	33.8
7-8		0.7	6.2	7.1	14.0
8-9		tr.	0.9	0.6	1.5
9-10		0.1	2.4	1.6	4.1
10-11		0.1	2.7	2.0	4.8
-11 ø		0.2	6.3	2.7	9.2
Totals	0.6%	11.0%	27.1%	61.3%	100.0%



100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE PERCENT
113
115
114
2
3
4
5
6
7
8
9
10
11
SIZE IN PHI UNITS
CUMULATIVE SIZE FREQUENCY CURVES
S-113, S--114, S-115
Patterson Deposit, Cleveland Co., N. C.

Figure 13

The median size of the kaolinite in S-114 is .025 mm which is considerably smaller than in S-113. The median size of the halloysite is 8 microns. Electron micrographs of the less than one micron fraction show aggregates of kaolinite plates together with halloysite tubes 5 microns or less in length and averaging .02 microns in diameter.

The cumulative size frequency distribution curves are shown in Figure 13.

The halloysite to kaolinite ratio is 1:2.3.

The pH measurement was 5.28.

The Blue Ridge Province of Western North Carolina

Northern Region

The Spruce Pine Pegmatite District

Gusher Knob Deposit, Avery Co., North Carolina

This weathered alaskite deposit is reached by traveling six miles northeast from Spruce Pine on U.S. 19E to Ingalls, turning east on N.C. 194 for 0.9 miles and then north on a gravel road for 0.5 miles (figure 14). The open pit operation is on the southeast side of an old river terrace sloping gently toward Threemile Creek 150 feet below. The elevation is 3000 feet. Although designated a granite body, the granite is cut by numerous pegmatites of varying width up to as much as 70 feet. In the pegmatite are quartz cores up to 5 feet in width and the granite is cut by quartz veins which follow the joint system. These quartz stringers average about 1/4 inch in the main granite body, but they may range up to several inches. Microcline tends to be concentrated along these stringers. The feldspar is conspicuous in the cuts because of its pink color and relatively unaltered condition. Perthite is almost completely altered to halloysite. Mica schist is the country rock and also occurs as xenoliths and horses in the alaskite body. A pegmatite vein commonly is present along the schist contact.

A sample grid was set up in a weathered, fairly uniform friable granite body at the east end of the East pit to evaluate trends in the weathering both vertically and horizontally. The feldspar is either completely altered to endellite or nearly so and the mica is partially altered to kaolinite. An electron micrograph of the -1 micron fraction of a sample from this grid is shown in Plate 1. Twelve samples were

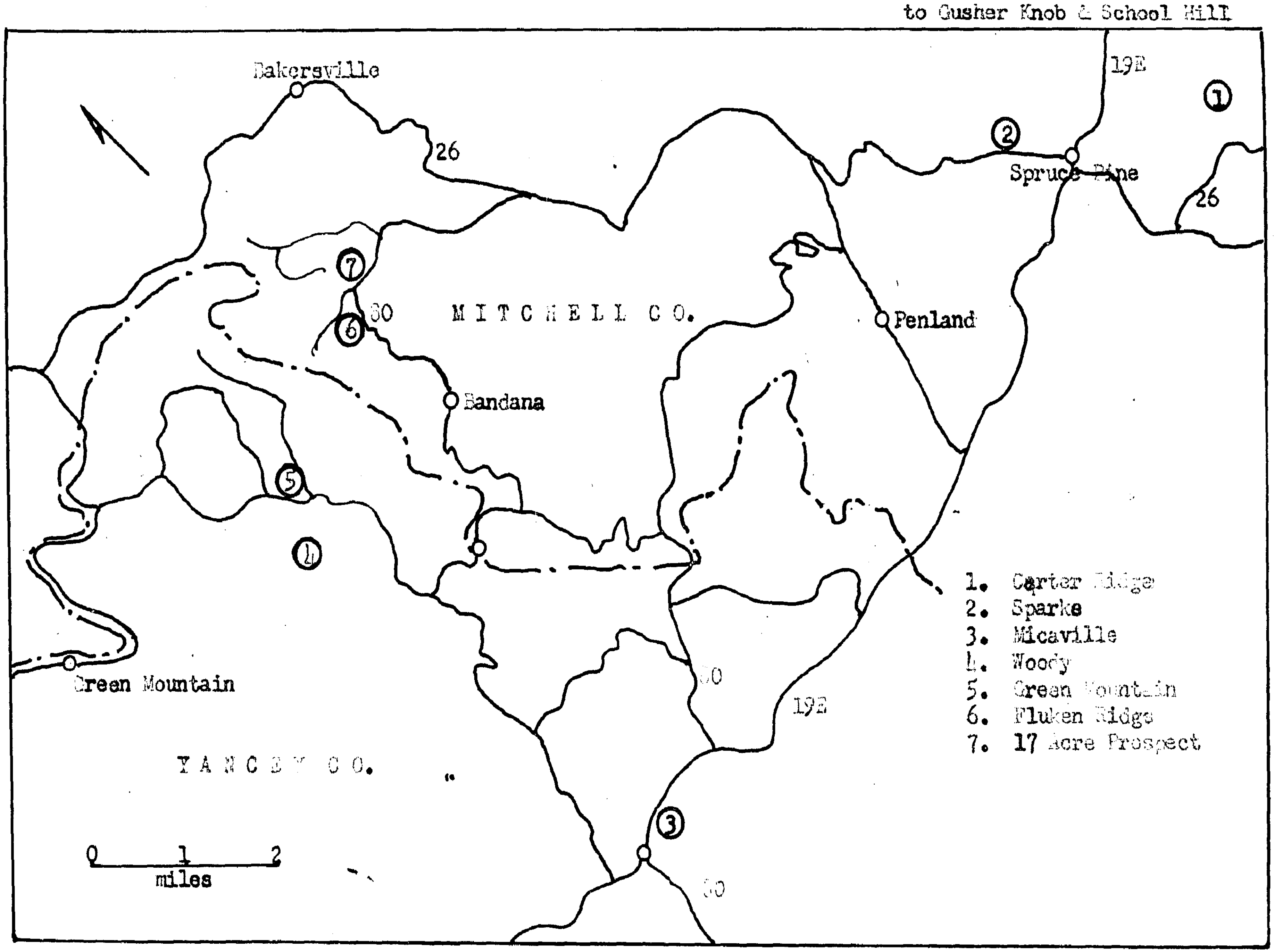


Figure 14. Areal map of the Northern region (Spruce Pine district) of the Blue Ridge Province of western North Carolina.

analyzed in detail. The sequence of the samples is shown in figure 15. The mineralogical analyses follow in sets of three taken in the same vertical profile. The top sample is designated T, the middle sample M and the bottom sample M after the sample number.

Table 13.

S-42B, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ø	0.8%	7.0%	0.7%	7.0%	0.9%	16.4%
2-3.75		5.7		4.0	11.	11.4
3.75-5		1.2		7.5	3.5	12.2
5-6		2.0		7.7	3.6	13.3
6-7		1.2		7.5	3.5	12.2
7-8		tr.		10.1	1.1	11.2
8-9				9.8	0.5	10.3
9-10				3.8	0.2	4.0
10-11				5.2	0.1	5.3
-11				3.6		3.6
Totals	0.8%	17.1%	0.7%	66.2%	15.1%	99.9%

The median size for the kaolinite is .03 mm. and for halloysite 8 microns.

The halloysite to kaolinite ratio is 4.4:1.

The cumulative size frequency distribution curve is shown in Figure 16.

The pH measurement was 5.07.

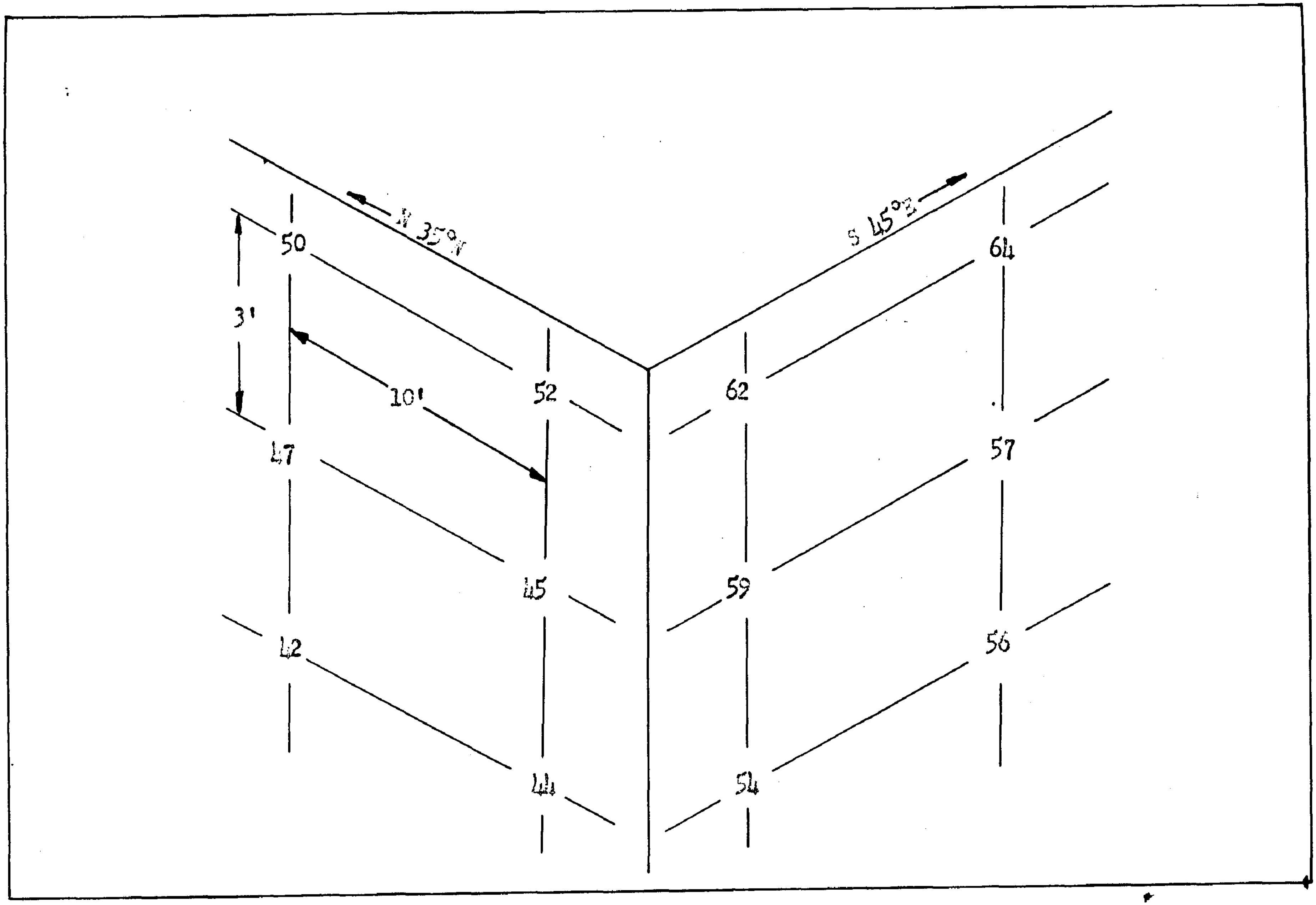
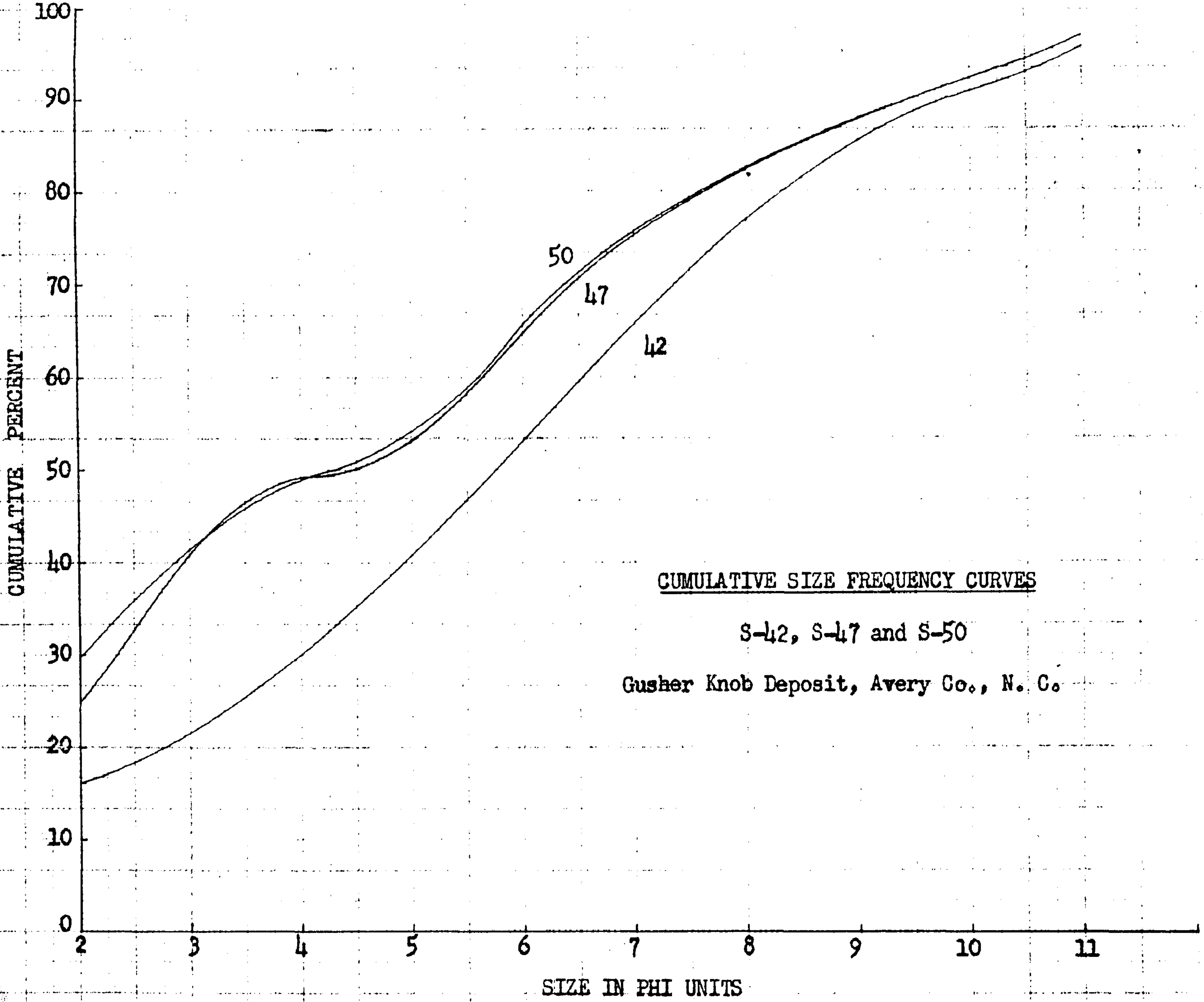


Figure 15. Sample grid at the Gusher Knob Deposit, Avery Co., N. C.



CUMULATIVE SIZE FREQUENCY CURVES

S-42, S-47 and S-50

Gusher Knob Deposit, Avery Co., N. C.

Figure 16

Table 14.

S-47M, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	7.7%	15.2%	2.4%	0.3%	25.6%
2-3.75		15.4	6.9	0.8	23.1
3.75-5		0.2	3.3	0.4	3.9
5-6		1.0	10.2	1.1	12.3
6-7		0.8	8.2	1.2	10.2
7-8		tr.	7.6	0.4	8.0
8-9			5.4	0.1	5.5
9-10			4.3	tr.	4.3
10-11			4.7	tr.	4.7
-11			2.4	tr.	2.4
Totals	7.7%	32.6%	55.4%	4.3%	100.0%

The median size for the kaolinite is 0.02 mm. and for the halloysite 16 microns.

The halloysite to kaolinite ratio is 12.8:1.

The cumulative size frequency distribution curve is shown in Figure 16.

The pH measurement was 5.25.

Table 15.

S-50T, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	8.5%	10.8%	10.2%	0.9%	30.4%
2-3.75	1.7	4.9	9.2	0.8	16.6
3.75-5	0.1	1.0	4.2	0.4	5.7
5-6		1.3	11.5	0.9	13.7
6-7		0.2	9.3	0.6	10.1
7-8		tr.	7.3	0.4	7.7
8-9			4.3	0.1	4.4
9-10			4.2		4.2
10-11			4.4		4.4
-11			2.8		2.8
Totals	10.3%	18.2%	67.4%	4.1%	100.0%

The median size for the kaolinite is 0.03 mm. and for the halloysite is 16 microns.

The halloysite to kaolinite ratio is 16.4:1.

The cumulative size frequency distribution curve is shown in Figure 16.

The pH measurement was 5.12.

Table 16.

S-44B, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	19.2%	17.3%	2.3%	5.3%	1.5%	45.6%
2-3.75	4.1	3.5	1.6	5.6	1.6	16.4
3.75-5		0.6		1.5	0.4	2.5
5-6		1.2		5.7	1.3	8.2
6-7		0.6		4.5	1.1	6.2
7-8		0.8		4.2	0.8	5.8
8-9		0.2		3.9	0.2	4.3
9-10		0.1		4.7	0.1	4.9
10-11		tr.		3.9	tr.	3.9
-11		tr.		2.0		2.0
Totals	23.3%	24.3%	3.9%	41.3%	7.0%	98.8%

The median size for the kaolinite is 0.05 mm. and for the halloysite is 16 microns.

The halloysite to kaolinite ratio is 5.9:1.

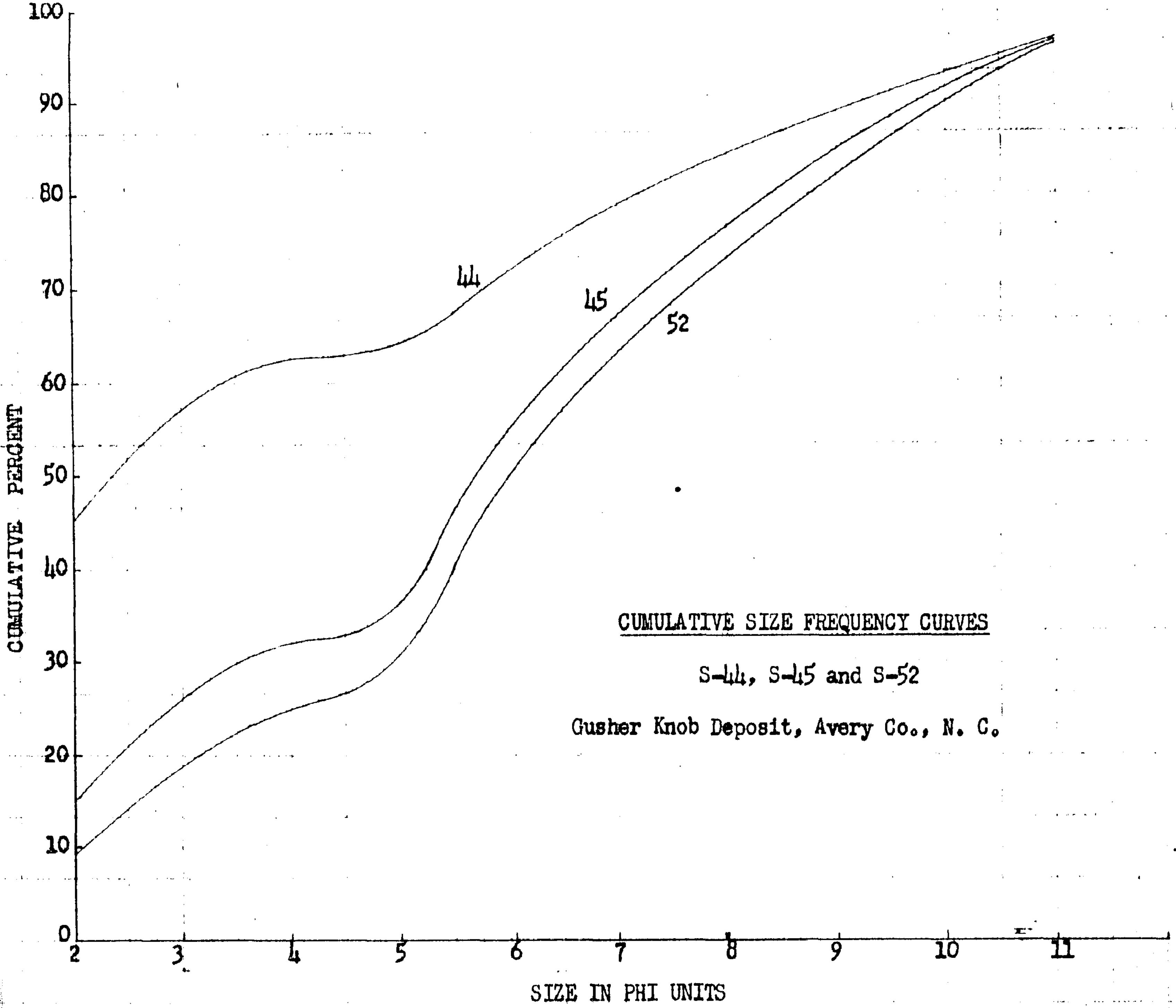
The cumulative size frequency distribution curve is shown in Figure 17.

The pH measurement was 5.10.

Table 17.

S-45M, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	12.5%	1.6%	0.8%	0.6%	0.2%	15.7%
2-3.75	4.0	4.1		5.9	2.2	16.2
3.75-5	0.1	1.8	0.1	1.8	0.5	4.3
5-6		3.5		12.0	3.9	19.4
6-7		2.2		7.8	2.4	12.4
7-8		1.0		6.8	1.9	9.7
8-9		0.5		7.2	0.8	8.5
9-10		0.1		5.4	0.2	5.7
10-11		tr.		5.4	tr.	5.4
-11				2.8	tr.	2.8
Totals	16.6%	14.8%	0.9%	55.7%	12.1%	100.1%



CUMULATIVE SIZE FREQUENCY CURVES

S-44, S-45 and S-52

Gusher Knob Deposit, Avery Co., N. C.

Figure 17

The median size for the kaolinite is 0.05 mm. and for the halloysite 12 microns.

The halloysite to kaolinite ratio is 4.6:1.

The cumulative size frequency distribution curve is shown in Figure 17.

The pH measurement was 5.05.

Table 18.

S-52T, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	11.0%	1.5%	----	1.1%	0.4%	13.0%
2-3.75	4.6	2.3		3.5	1.2	11.3
3.75-5	0.2	1.0		3.7	1.3	6.2
5-6		2.6		11.5	3.6	19.7
6-7		0.3		10.0	2.6	12.9
7-8		0.2		9.5	1.2	10.9
8-9		0.2		7.8	1.0	9.0
9-10		0.1		5.9	0.8	6.8
10-11		0.2		7.8	0.2	8.2
-11		0.0		1.7		1.7
	15.8%	8.4%		62.5%	12.3%	100.0%

The median size for the kaolinite is 0.02 mm. and for the halloysite is 10 microns.

The halloysite to kaolinite ratio is 5.1:1.

The cumulative size frequency distribution curve is shown in Figure 17.

The pH measurement was 5.12.

Table 19.

S-54B, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	43.8%	8.4%		3.8%	55.0%
2-3.75	1.2	4.8	4.3	2.4	12.7
3.75-5		0.3	1.7	0.7	2.7
5-6		0.9	5.2	2.3	8.4
6-7		0.5	4.4	1.5	6.4
7-8		0.2	3.6	0.7	4.5
8-9		0.1	3.1	0.3	3.5
9-10		tr.	3.0	0.1	3.1
10-11			1.0	tr.	1.0
-11			2.7		2.7
Totals	45.0%	15.2%	29.0%	11.8%	100.0%

The median size for the kaolinite is 0.2 mm. and for halloysite 10 microns.

The halloysite to kaolinite ratio is 2.5:1.

The cumulative size frequency distribution curve is shown in Figure 18.

The pH measurement was 5.13.

Table 20.

S-59M, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	34.3%	8.2%	1.2%	5.1%	48.8%
2-3.75	3.2	5.7	1.4	5.6	15.9
3.75-5		0.2	0.5	2.2	2.9
5-6		1.3	2.4	5.2	8.9
6-7		0.9	2.7	2.9	6.5
7-8		0.1	2.8	1.8	4.7
8-9		tr.	3.7	1.2	4.9
9-10			2.6	0.6	3.2
10-11			2.9	0.1	3.0
-11			1.3		1.3
Totals	37.5%	16.4%	21.5%	24.7%	100.1%

The median size for the kaolinite is 0.03 mm. and for the halloysite 4 microns.

The halloysite to kaolinite ratio is 1:1.1.

The cumulative size frequency distribution curve is shown in Figure 18.

The pH measurement was 5.51.

Table 21.

S-62T, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	27.4%	3.8%	5.6%	2.9%	59.7%
2-3.75	2.7	5.7	3.0	1.5	12.9
3.75-5	0.1	0.8	3.9	2.0	6.8
5-6		0.3	7.2	3.7	11.2
6-7		0.2	5.6	2.4	8.2
7-8		tr.	4.8	1.8	6.6
8-9			4.2	1.3	5.5
9-10			3.8	0.5	4.3
10-11			3.0	0.3	3.3
-11			1.5	0.1	1.6
Totals	30.2%	10.8%	42.6%	16.5%	100.1%

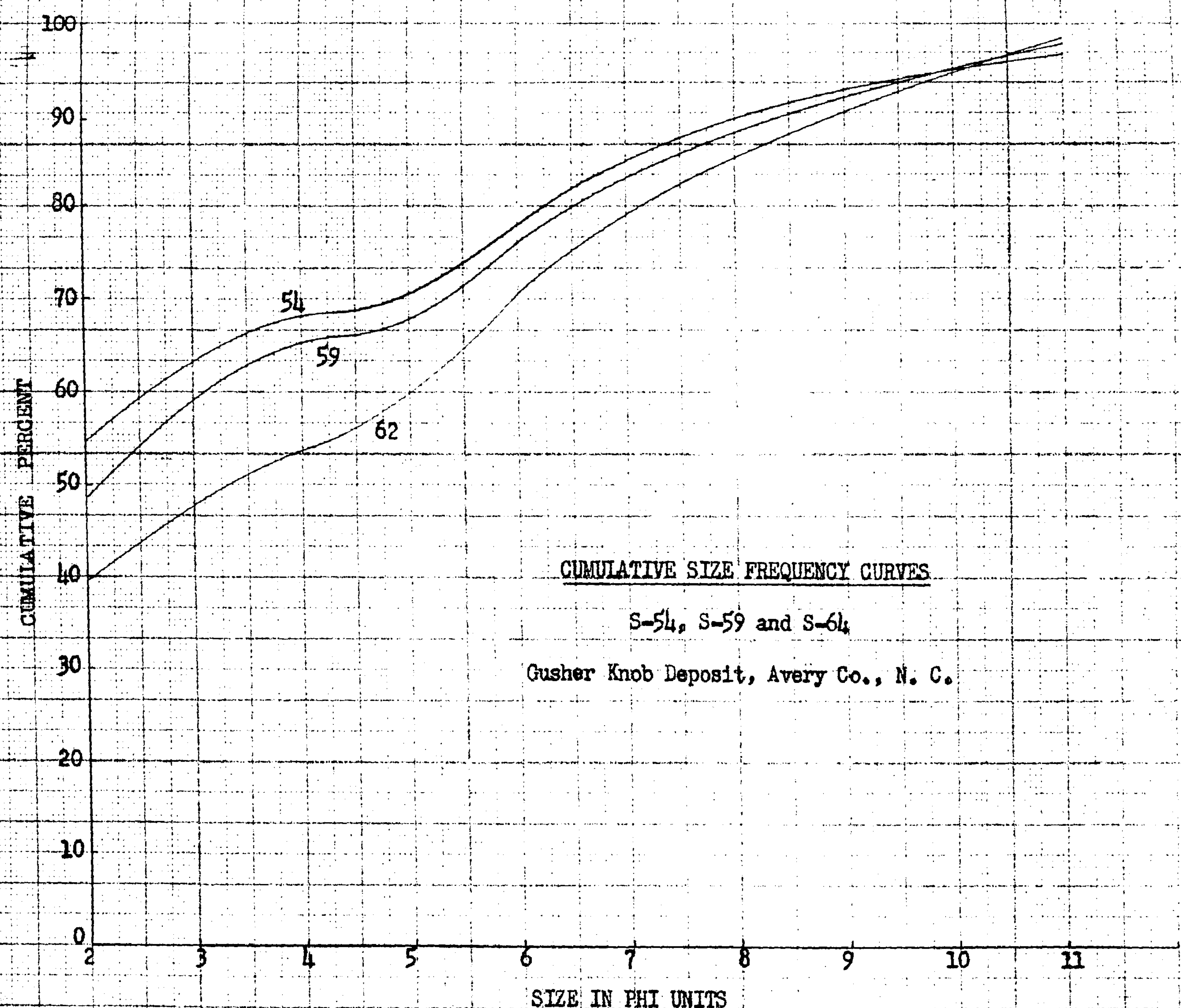

CUMULATIVE SIZE FREQUENCY CURVES
S-54, S-59 and S-64
Gusher Knob Deposit, Avery Co., N. C.
CUMULATIVE PERCENT
SIZE IN PHI UNITS
54
59
62
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11

Figure 18

The median size for kaolinite is 0.03 mm. and for halloysite 16 microns.

The halloysite to kaolinite ratio is 2.6:1.

The cumulative size frequency distribution curve is shown in Figure 18.

The pH measurement was 5.20.

Table 22.

S-56B, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
- 2 ∅	28.1%	6.2%		5.8%	40.1%
2-3.75	4.2	3.2	10.7	3.0	21.1
3.75-5		0.3	1.8	0.5	2.6
5-6		1.8	8.3	2.3	12.4
6-7		0.3	4.6	0.9	5.8
7-8		0.2	5.2	0.5	5.9
8-9		0.1	4.4	0.2	4.7
9-10		tr.	2.8	tr.	2.8
10-11			2.9		2.9
-11			1.8		1.8
Totals	32.3%	12.1%	42.5%	13.2%	100.1%

The median size for kaolinite is 0.3 mm. and for halloysite 16 microns.

The halloysite to kaolinite ratio is 3.2:1.

The cumulative size frequency distribution curve is shown in Figure 19.

The pH measurement was 5.03.

Table 23

S-57M, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
- 2 ∅	30.8%	6.2%	1.0%	3.1%	41.1%
2-3.75		10.2	8.0	7.1	25.3
3.75-5		0.1	0.9	0.8	1.8
5-6		0.8	4.7	3.4	8.9
6-7		0.3	3.6	2.1	6.0
7-8		0.1	3.4	1.3	4.8
8-9		tr.	2.9	0.9	3.8
9-10			3.1	0.7	3.8
10-11			2.7	0.3	3.0
-11			1.4	0.1	1.5
Totals	30.8%	17.7%	31.7%	19.8%	100.0%

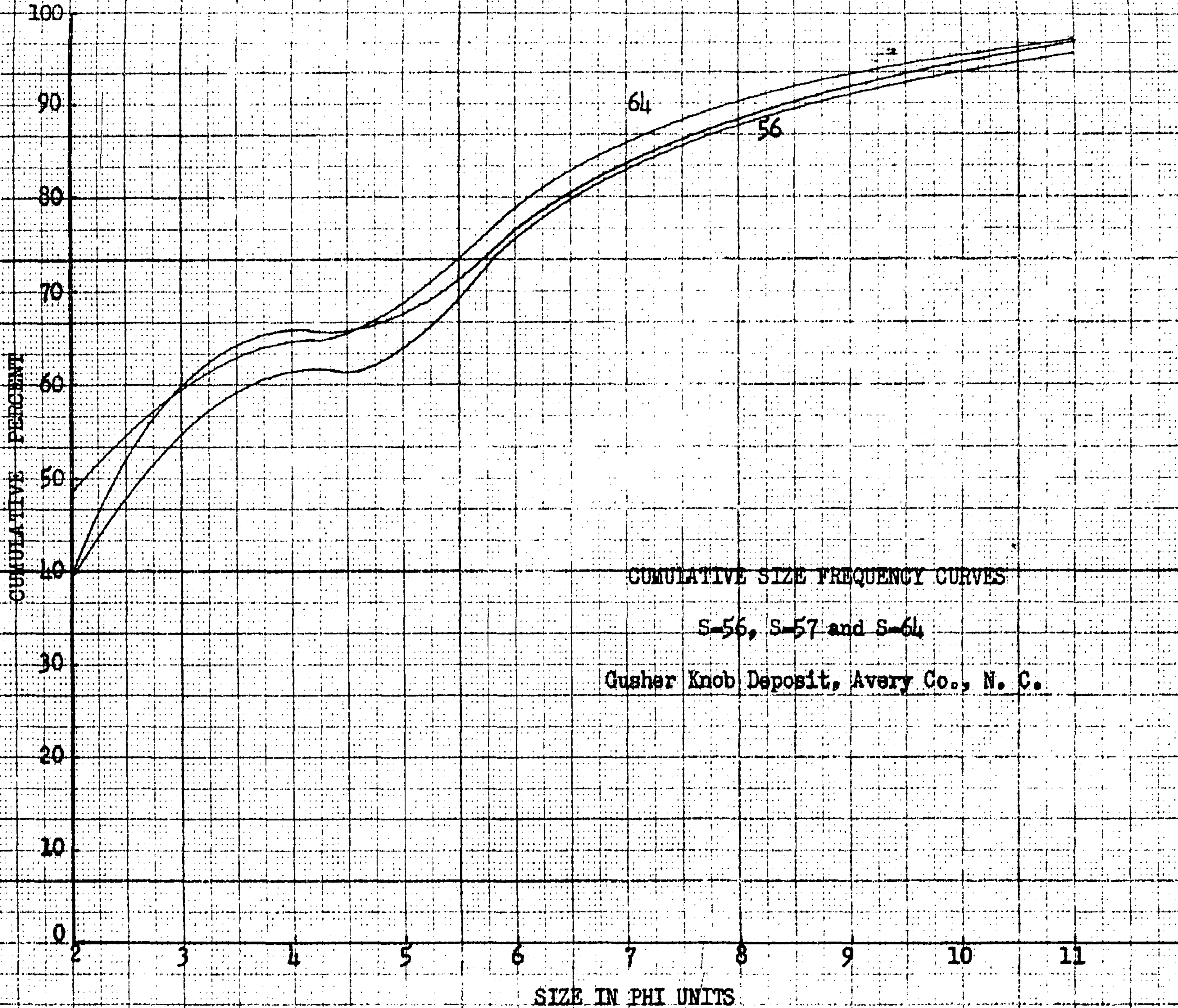

CUMULATIVE SIZE FREQUENCY CURVES
S-56, S-57 and S-64
Gusher Knob Deposit, Avery Co., N. C.
CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11
64
56
SIZE IN PHI UNITS

Figure 19

The median size for kaolinite is 1.0mm. and for halloysite 16 microns.

The halloysite to kaolinite ratio is 1.6:1.

The cumulative size frequency distribution curve is shown in Figure 19.

The pH measurement was 5.40.

Table 24.

S-64T, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
-2 ∅	34.5%	3.1%	8.9%	2.9%	49.4%
2-3.75	3.9	6.5	3.3	1.1	14.8
3.75-5	0.1	0.6	2.9	1.0	4.6
5-6	tr.	0.7	9.6	1.6	11.9
6-7		0.3	4.6	0.7	5.6
7-8		tr.	3.5	0.4	3.9
8-9			3.4	0.2	3.6
9-10			2.5	0.1	2.6
10-11			2.4		2.4
-11			1.2		1.2
Totals	38.5%	11.2%	42.3%	8.0%	100.0%

The median size for the kaolinite is 0.1mm. and for halloysite 0.03 mm.

The halloysite to kaolinite ratio is 5.3:1.

The cumulative size frequency distribution curve is shown in Figure 19.

The pH measurement was 5.03.

School Hill Deposit, Avery Co., North Carolina

This deposit is located a half mile east of the Kamec mine on Brushy Creek. Sample S-69 was selected for detailed analysis because of its high content of quartz to see if the friable texture had any effect on determining the clay mineral.

Table 25.

S-69, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	39.4%	0.6%	2.9%	1.0%	43.9%
2-3.75	18.8	0.4	3.2	1.1	23.5
3.75-5		0.1	2.2	0.3	2.6
5-6		0.4	7.4	1.0	8.8
6-7		0.3	4.8	0.5	5.6
7-8		tr.	4.3	0.5	4.8
8-9		tr.	3.9	0.4	4.3
9-10			3.1	0.1	3.2
10-11			2.5		2.5
-11			0.9		0.9
Totals	58.2%	1.8%	35.2%	4.9%	100.1%

The median sizes for the clay minerals are .05 mm. for kaolinite and .016 mm. for halloysite. The halloysite ocurring in the coarser fractions is in the form of aggregates and is the result of the gentle disaggregation procedure. Electron micrographs of the less than one micron fraction show stubby tubes of halloysite averaging 1.5 microns in length and 0.4 microns in diameter.

Mica is present only in traces in the less than 8 micron size fractions indicating that alteration of the mica to kaolinite is fairly complete.

The halloysite to kaolinite ratio is 7.2:1.

The cumulative size frequency distribution curve is shown in Figure 20.

The pH measurement was 5.33.

Carter Ridge Mine, Mitchell Co., North Carolina

The Carter Ridge deposit is reached by traveling 1.5 miles south of Spruce Pine on N.C. 26 and turning left on the dirt road across from the recreation pool and following it for a mile.

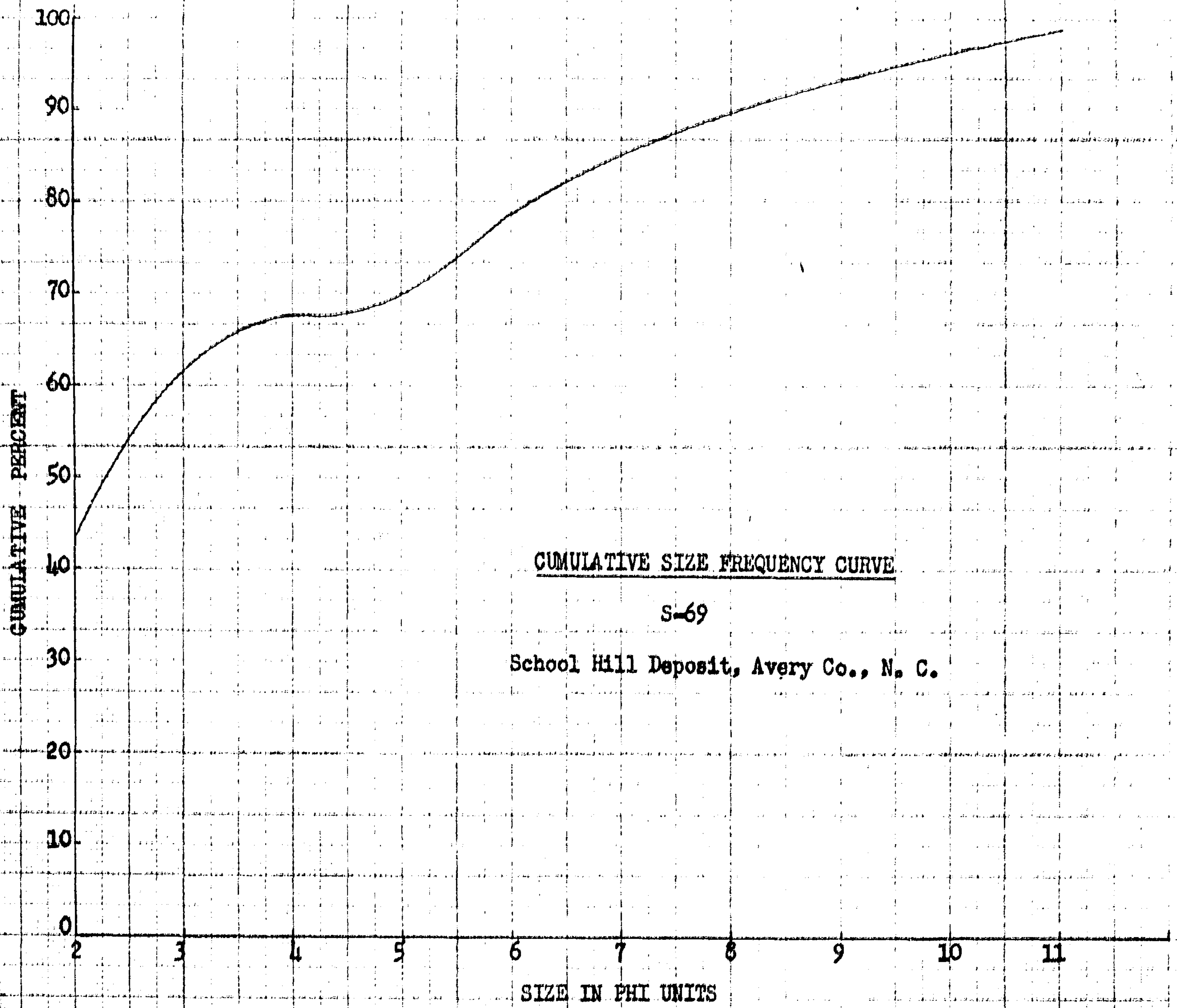

CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE SIZE FREQUENCY CURVE
S-69
School Hill Deposit, Avery Co., N. C.
2
3
4
5
6
7
8
9
10
11
SIZE IN PHI UNITS

Figure 20

A 15 foot quartz core is exposed as well as contacts of the pegmatite with gneiss and schist. The pegmatite contains numerous schist inclusions near which the clay is badly stained yellow and red.

Sample ONR 653 was obtained 10 feet from the surface in the southwest wall and five feet from the quartz core. It consists of thoroughly decomposed feldspar stained yellow from schist inclusions and contains small angular quartz grains less than 2 mm. in size. Mineralogical analysis by the thin section method gave the following composition: halloysite 84.3%, kaolinite 12.8%, and mica 2.9%. The halloysite to kaolinite ratio is 6.6:1.

The feldspar is altered to halloysite and much disseminated mica less than 0.1 mm. in size is partially or completely altered to vermicular kaolinite. The halloysite tubes average 2 microns in length and 0.1 micron in diameter.

The cumulative size frequency distribution curves for ONR 653 is shown in Figure 21.

Sparks Mine, Mitchell Co., North Carolina

This mine is a large abandoned open pit operation located on the east side of N.C. 26 two miles northwest of Spruce Pine. The mine was worked until hard rock was encountered at about 80 feet, but water now fills the pit to about 40 feet of the original surface. The pegmatite vein strikes north for about 1000 feet and is approximately 100 feet wide. Exposed at the present time is only the weathered quartz-mica-feldspar pegmatite which reaches the surface in places but in general is covered by six to ten feet of overburden. The deposit is on the slope of a hill 200 feet above the Toe River. The clay weathered from

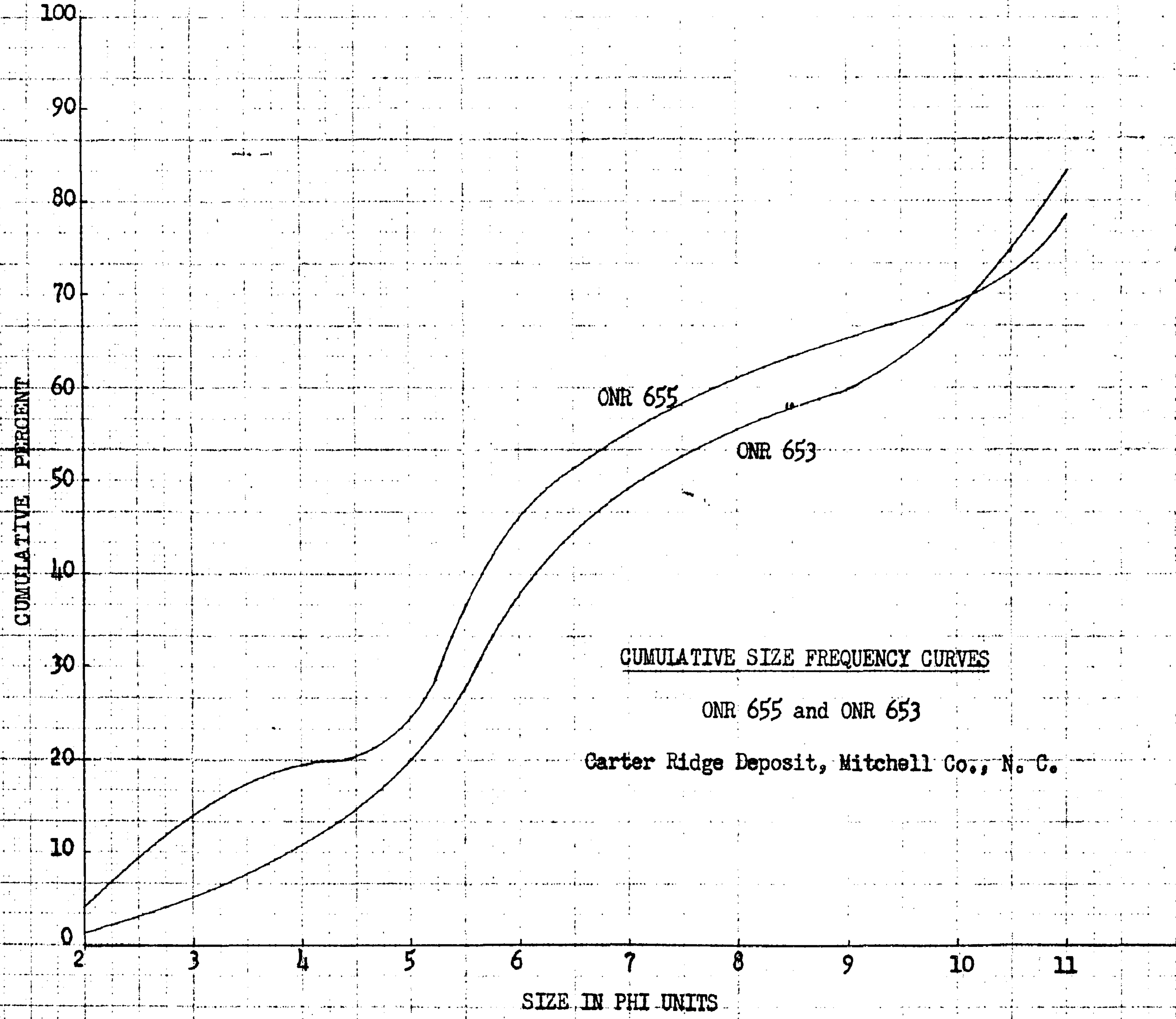

CUMULATIVE SIZE FREQUENCY CURVES
ONR 655 and ONR 653
Carter Ridge Deposit, Mitchell Co., N. C.
CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11
SIZE IN PHI UNITS
ONR 655
ONR 653

Figure 21

large feldspar crystals up to one foot in diameter and is very white and free from stain. While most of the clay is derived from pegmatite, there are remnants of granite bodies and samples were also taken from these pockets with granitic texture.

Sample ONR 560 was taken 40 feet from the surface on the west wall. It consists of granite with partially altered feldspar. Electron micrographs of the clay derived from this material show short and stubby halloysite tubes averaging 1.5 microns in length and 0.3 microns in diameter.

Sample ONR 562 was taken from a pegmatite vein directly above sample ONR 560. It consists of microcline which is 20% altered to halloysite along the fractures. These alteration zones along the fractures are up to 0.3 mm. in width and contain fragments of the microcline. The fracture system runs obliquely to the twinning planes (see Plate 1). Small phenocrysts of plagioclase feldspar up to 1 mm. in length are altered almost completely to halloysite. Angular quartz inclusions in the phenocrysts are not affected. The mica disseminated through the feldspar is only slightly altered on the edges. This shows that the sequence of weathering of the minerals is plagioclase feldspar, potash feldspar, muscovite and quartz. This is the sequence given by Goldich (1938).

Sample ONR 564 was taken 35 feet from the surface on the west wall. It is a perthite crystal almost completely altered to halloysite with the included mica partially altered to kaolinite. The mica shows a parting perpendicular to the basal cleavage when it alters to kaolinite to give vermicular kaolinite aggregates varying in width up to a maximum of 0.04 mm. This causes the kaolinite to concentrate in this size fraction.

Yellow-stained halloysite, presumably introduced from above, fills fractures developed after the weathering of the feldspar.

Fluken Ridge Mine, Mitchell Co., North Carolina

This deposit consists of granite and intruded pegmatite. It is reached by traveling 1.5 miles north from Bandana on N.C. 80. The deposit is located on the summit of Fluken Ridge on the property of W. A. Howell. It is being mined at the present time for feldspar and clay in an irregular open cut and in numerous drifts and shafts. Samples were obtained here of thoroughly altered granite and pegmatite and of transitions from weathered to fresh rock.

Sample ONR 631 was taken 25 feet from the surface on the south wall in granite. It is a very white clay containing graphic quartz and disseminated mica. Mineralogical analysis of the sample by the thin section method gave the bulk composition shown in Table 26.

Table 26.

ONR 631 Bulk Mineral Composition

Halloysite	73.7%
Kaolinite	2.8
Mica	0.3
Quartz	22.4
Feldspar	0.8
Total	100.0%

The halloysite to kaolinite ratio is 26.3:1.

The perthite is almost completely altered to halloysite. The primary mica is in various stages of alteration to vermicular kaolinite.

Electron micrographs of this sample show halloysite tubes varying in length from 2 to 10 microns and averaging 0.2 microns in diameter.

Sample ONR 635 was taken 25 feet from the surface on the west wall in pegmatite. The sample consists of a partially decomposed microcline crystal. Alteration was effected only along the fractures where the microcline is altered to halloysite. The primary mica is unaltered.

Sample ONR 636 was taken 30 feet from the surface on the east wall 2 feet from the contact with schist. The sample consists of massive white clay derived from a microcline crystal. The mineralogical analysis as obtained by thin section methods is given in Table 27.

Table 27.

ONR 636 Bulk Mineral Composition

Halloysite	90.8%
Kaolinite	7.2
Mica	1.3
Quartz	0.4
Feldspar	0.3
Total	100.0%

The halloysite to kaolinite ratio is 12.6:1.

The microcline is altered almost completely to halloysite and the mica partially to almost completely altered to vermicular kaolinite. The vermicular aggregates are as large as 3 mm. by 0.4 mm. with the average width being 0.2 mm. Some large books of mica are partially altered to kaolinite.

Sample ONR 638 is a sample of altered perthite obtained 50 feet from the surface on the west wall. The perthite is preferentially altered along the plagioclase bands with the microcline only partially altered. The mica is also only partially altered to kaolinite.

Sample ONR 639 was obtained 50 feet from the surface on the west wall. The microcline is only slightly decomposed and is altering to halloysite along fractures and separated cleavage planes. The mica is not altered.

Sample S-34 is a moist sample of microcline obtained from the south wall of the east workings 2 feet under the schist contact.

Table 28.

S-34, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Halloysite	Kaolinite	Size Analysis
2 ø	0.7%		4.7%	0.4%	tr.	0.1%	5.9%
2-3.75		1.4		4.2	0.1	1.3	7.0
3.75-5		5.0		16.1	0.3	3.7	25.1
5-6		0.6		6.2	0.1	1.7	8.6
6-7				8.4	0.2	2.2	10.8
7-8				7.7	0.2	1.9	9.8
8-9				8.1	0.2	1.8	10.1
9-10				3.1	tr.	0.4	3.5
10-11				9.8	0.2		10.0
-11				8.9	0.2		9.1
Totals	0.7%	7.0%	4.7%	72.9%	1.5%	13.1%	99.9%

The median sizes for the clay minerals are 0.03 mm. for the kaolinite and 16 microns for the halloysite.

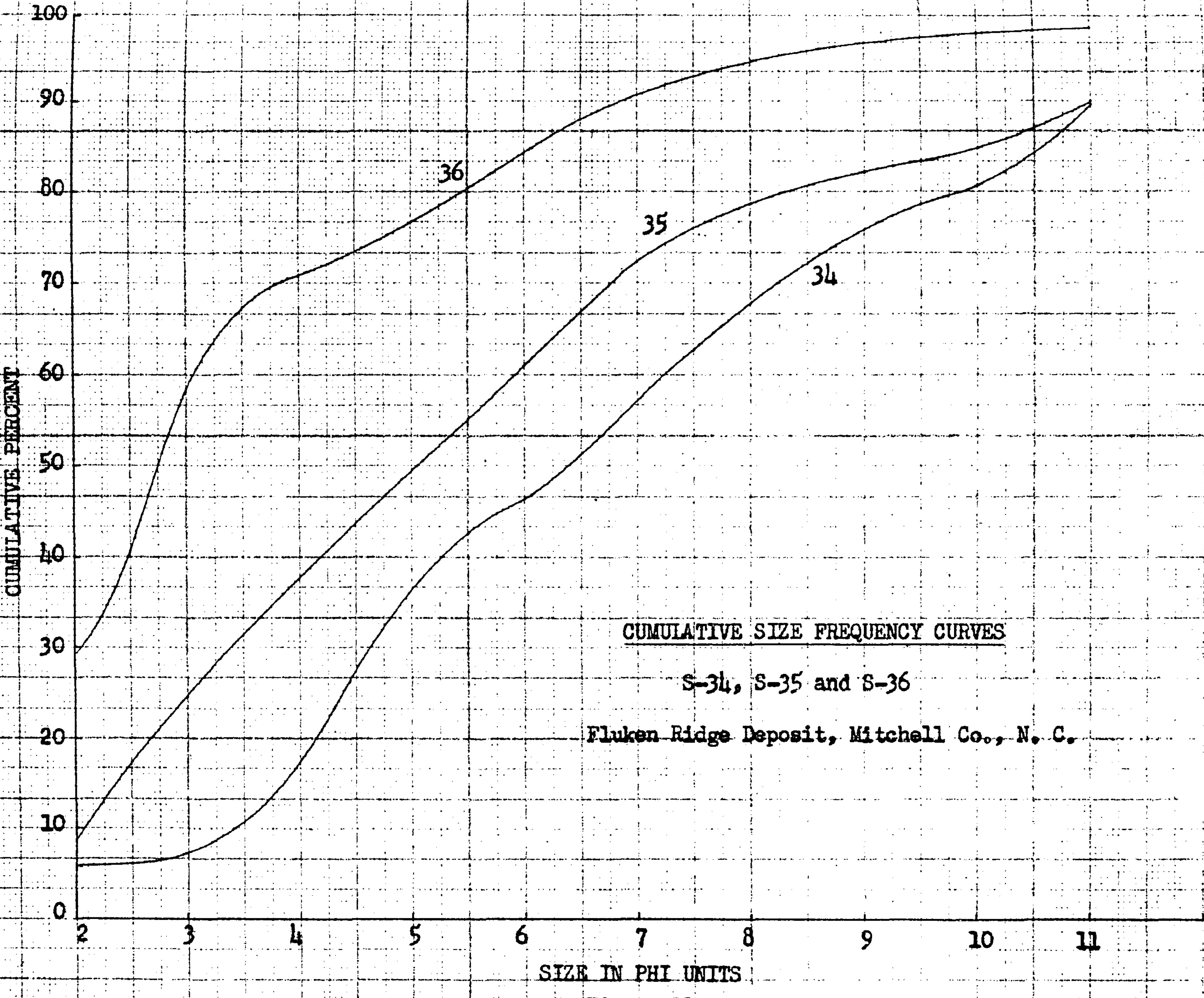
The halloysite to kaolinite ratio is 4.9:1.

The cumulative size frequency distribution curve is shown in Figure 22.

Electron micrographs of the less than one micron fraction contain some very thin halloysite tubes measuring 5 microns in length and 0.05 microns in diameter. Most of the halloysite measures 2 microns in length and 0.1 micron in diameter.

The pH measurement was 5.25.

Sample S-35 is a moist sample of perthitic microcline obtained from the east wall of the east workings 3 feet above unaltered feldspar.



CUMULATIVE SIZE FREQUENCY CURVES

S-34, S-35 and S-36

Fluken Ridge Deposit, Mitchell Co., N. C.

Figure 22

Table 29

S-35, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	tr.	0.9%	8.2%			9.1%
2-3.75		2.7	21.3	2.6	0.1	26.7
3.75-5		1.5	10.2	2.1	0.1	13.9
5-6		0.6		11.0	0.6	12.2
6-7		0.4		10.1	0.5	11.0
7-8		0.2		5.4	0.3	5.9
8-9		tr.		3.6	0.1	3.7
9-10		tr.		2.8	tr.	2.8
10-11		0.1		4.9		5.0
-11		tr.		9.7		9.7
Totals	tr.	6.4%	39.7%	52.2%	1.7%	100.0%

The halloysite to kaolinite ratio is 30.8:1.

The median sizes for the clay minerals are 0.025 mm. for the kaolinite and 8 microns for the halloysite.

The cumulative size frequency distribution curve is shown in Figure 22.

Electron micrographs of the less than 1 micron fraction show halloysite tubes varying from 1 to 2 microns in length and measuring 0.2 microns in diameter.

The pH measurement was 4.82.

Sample S-36 is a moist sample of partially decomposed perthitic microcline obtained 6 feet from the surface near the east wall of the east wall of the east workings and about ten feet distant from S-35.

Table 30

S-36, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	4.6%	1.4%	23.7%			29.7%
2-3.75		tr.	40.3			40.3
3.75-5		0.7	6.6			7.3
5-6		tr.	2.4	4.4	0.6	7.4
6-7			1.3	5.0	0.5	6.8
7-8			0.7	2.5	0.3	3.5
8-9			0.5	2.1	tr.	2.6
9-10			0.1	0.5		0.6
10-11				0.8		0.8
-11				1.0		1.0
Totals	4.6%	2.1%	75.6%	16.3%	1.4%	100.0%

The median sizes for the clay minerals are 0.02 mm. for the kaolinite and 16 microns for the halloysite.

The halloysite to kaolinite ratio is 11.6:1.

The cumulative size frequency distribution curve is shown in Figure 22.

Electron micrographs of the less than 1 micron fraction contain a few long thin halloysite tubes 3 microns in length and 0.1 micron in diameter, but most of the halloysite is stubby and measures 1 micron in length and 0.4 microns in diameter.

The pH measurement was 5.33.

17 Acre Prospect, Harris Clay Company, Mitchell Co., North Carolina

This clay prospect occurs on the summit of a hill in an area of high relief. It can be reached by following N.C. 80 to the spot marked on location map, figure 14. The prospect can be seen clearly from the road. This deposit has not been extensively exploited as yet and the exploratory tunnels afforded opportunity to collect fresh samples. Samples were obtained from a 50 foot drift trending across the N15°E strike.

Sample S-39 is a moist sample obtained from large crystals of decomposed feldspar in the drift wall. Two mineralogical analyses were obtained by analyzing the size fractions and one mineralogical analysis made by the thin section point counter method.

Table 31.

S-39A, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	3.2%	1.3%			4.5%
2-3.75	2.3	6.3	10.9	1.5	21.0
3.75-5		5.0	15.4	4.4	24.8
5-6		2.0	15.3	2.5	19.8
6-7		1.3	9.8	1.6	12.7
7-8		0.7	4.7	1.0	6.4
8-9		0.2	1.4	0.6	2.2
9-10		---	---	---	---
10-11			3.9	0.9	4.8
-11			3.1	0.7	3.8
Totals	5.5%	16.8%	64.5%	13.2%	100.0%

The median sizes for the clay minerals are 0.03 mm. for the kaolinite and 16 microns for the halloysite.

The halloysite to kaolinite ratio is 4.9:1.

The cumulative size frequency distribution curve is shown in Figure 23.

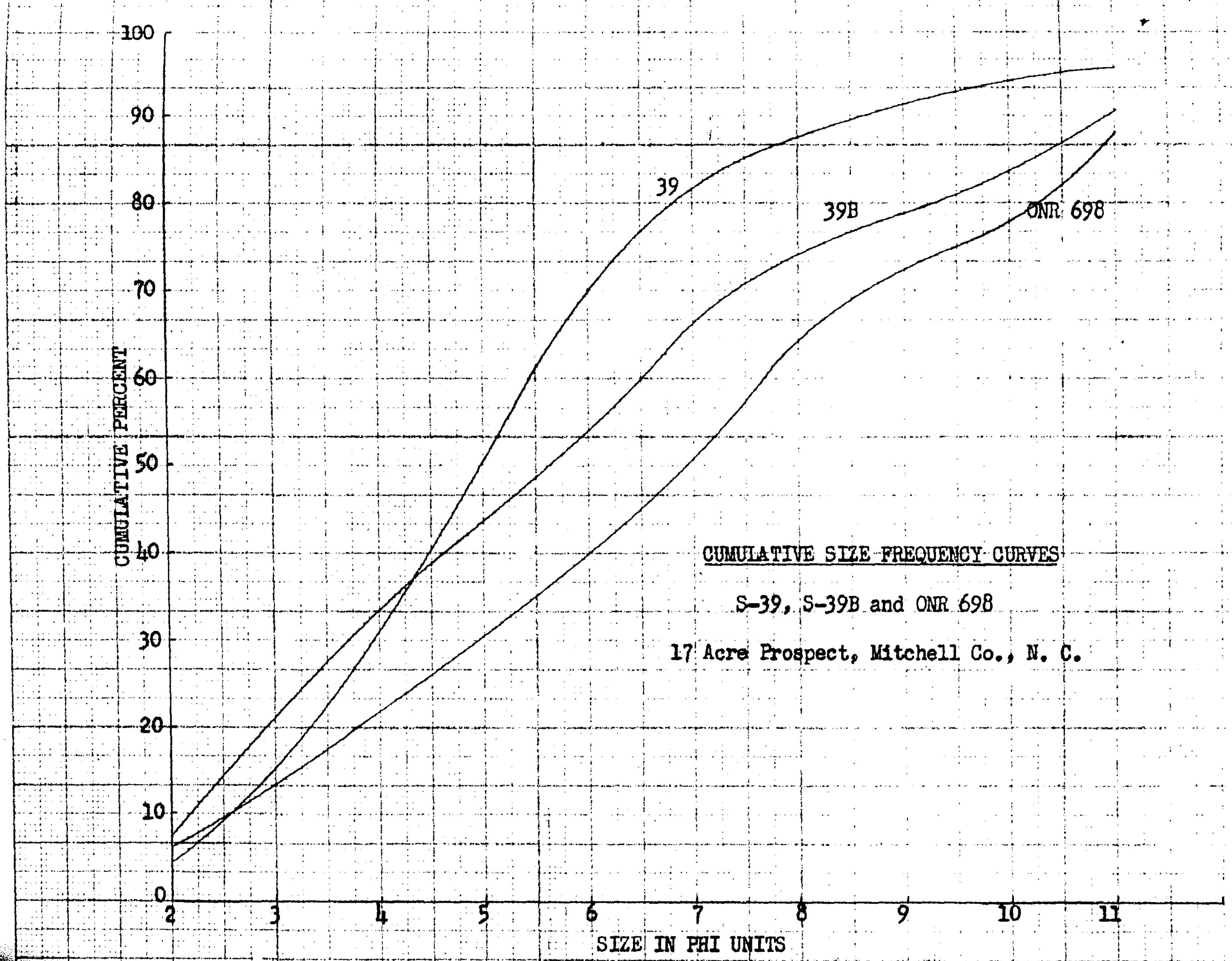
The pH measurement was 5.25.

Table 32.

S-39B, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	6.1%	1.5%			7.6%
2-3.75	2.4	11.8	7.8	1.7	23.7
3.75-5	0.1	2.8	2.2	0.5	5.6
5-6	0.2	1.9	13.2	3.3	18.6
6-7		0.2	9.7	2.4	12.3
7-8			5.6	1.4	7.0
8-9			3.6	0.8	4.4
9-10			4.2	1.0	5.2
10-11			7.0	tr.	7.0
-11			8.5		8.5
Totals	8.8%	18.2%	61.8%	11.1%	99.9%

The median sizes for the clay minerals are 0.025 mm. for the kaolinite and 16 microns for the halloysite.



CUMULATIVE SIZE FREQUENCY CURVES

S-39, S-39B and ONR 698

17 Acre Prospect, Mitchell Co., N. C.

Figure 23

The halloysite to kaolinite ratio is 5.6:1.

Electron micrographs contain stubby halloysite tubes averaging 1.5 microns in length and 0.2-0.3 microns in diameter.

The cumulative size frequency distribution curve is shown in Figure 23.

The pH measurement was 5.50.

The point count of the thin section of S-39 gave the mineral composition in Table 33.

Table 33.

S-39, Bulk Mineral Composition

	Arith. Mean	Std. Dev. Mean	C/e of Variation	95% Confidence
Quartz	3.0%	0.39%	390%	
Halloysite	66.8	1.05	6	63.7-70.0
Kaolinite	13.1	1.16	10	11.0-14.6
Mica	17.1	0.97	15	15.1-19.1

The halloysite to kaolinite ratio is 5.1:1.

Sample ONR 698 was obtained from this deposit and sent by Mr. Lee White of Ingalls, N.C. The sample became partially dehydrated during shipment and this shows up in the analysis as halloysite.

Table 34.

ONR 698, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Halloysite	Kaolinite	Size Analysis
2 ∅	2.4%	1.2%	1.8%	0.4%	0.7%	6.5%
2-3.75	1.0	2.6	5.0	2.5	2.0	13.1
3.75-5		1.5	5.9	1.0	1.8	10.2
5-6		1.5	5.9	1.1	1.9	10.4
6-7		0.6	8.3	1.5	2.6	13.0
7-8		0.5	7.2	1.3	2.2	11.2
8-9		0.3	5.6	1.0	1.7	8.6
9-10		0.1	4.3	0.8		5.2
10-11		tr.	9.1	1.6		10.7
-11		tr.	9.5	1.7		11.2
Totals	3.4%	8.3%	62.6%	12.9%	12.9%	100.1%

The median sizes for the clay minerals are 0.03 mm. for the kaolinite and 4 microns for the halloysite.

The halloysite to kaolinite ratio is 5.8:1.

The cumulative size frequency distribution curve is shown in Figure 23.

The pH measurement was 5.73.

Two thin sections were made at right angles to each other of the same subsample of ONR 698 (from this deposit) and the mineral composition as determined by the point counter method follows in Table 35.

Table 35.

ONR 698, Bulk Mineral Composition

	698a	698b
Halloysite	85.6%	84.9%
Kaolinite	8.8	8.8
Mica	3.8	6.3
Quartz	1.8	----
	100.0%	100.0%

The halloysite to kaolinite ratio for 698a is 9.7:1 and for 698b is 9.6:1. Electron micrographs from this sample show halloysite tubes of unifrom size which measure 0.15 microns in diameter and 1 micron in length.

The feldspar in the samples taken from this deposit is completely decomposed to halloysite. There is much disseminated mica in 0.2 mm. books that is partially or completely altered to vermicular kaolinite.

Micaville Mica Mine, Micaville, Yancey Co., North Carolina

This mica mine is located south of U.S. 19E one-half mile east of Micaville. It consists of a weathered granite body cut by numerous pegmatite veins.

Sample ONR 567 was taken from the north end of the pit 50 feet from the surface. It has a granitic texture and contains disintegrating plagioclase and potash feldspar with mica and quartz. Electron micrographs show 0.5 to 5 micron tubes averaging 0.2 microns in diameter and scattered kaolinite plates.

Sample ONR 569 was taken from a granite pocket in a pegmatite vein. Electron micrographs taken of clay from this sample show particles similar to those seen in micrographs of ONR 567.

Sample S-21 was obtained from the southwestern end of the pit at the top of the hill directly under the schist and 15 feet from the surface. The sample was taken from a perthite crystal in an altered pegmatite vein which contained biotite books up to 6 inches in thickness. The pegmatite contained numberous quartz stringers up to one inch in thickness.

Table 36.

S-21, Mineralogical Analysis of Size Fractions

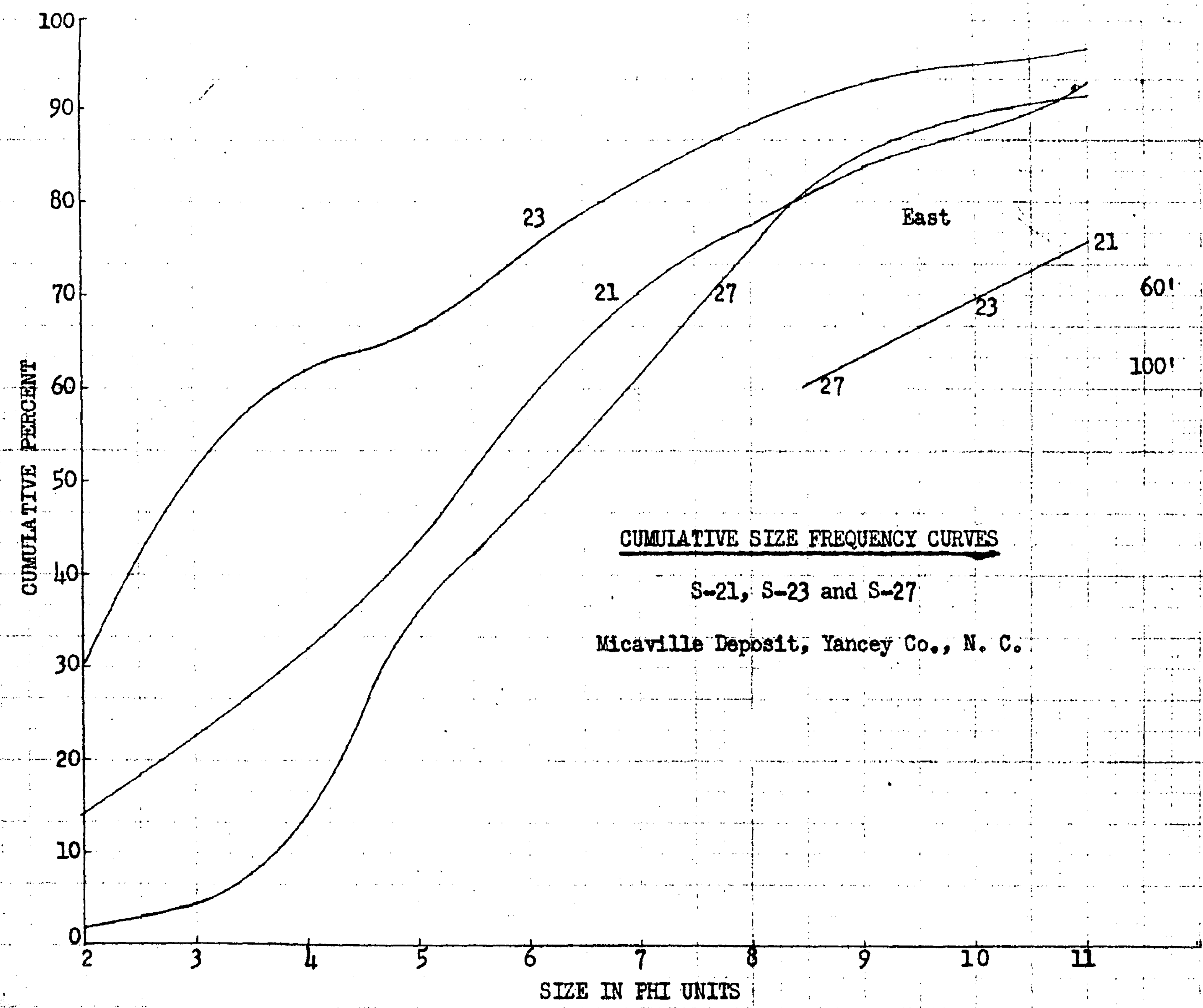
Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 Ø	0.4%	6.4%	6.9%	0.3%	14.0%
2-3.75	0.5	5.1	10.8	0.5	16.9
3.75-5	1.0	1.1	9.8	0.4	12.3
5-6	1.6	1.4	12.5	0.7	16.2
6-7	0.9	0.5	9.6	0.5	11.5
7-8		0.2	6.8	0.2	7.2
8-9		0.1	6.5	0.1	6.7
9-10			3.2	tr.	3.2
10-11			5.2		5.2
-11			6.7		6.7
Totals	4.4%	14.8%	78.0%	2.7%	99.9%

The median sizes for the clay minerals are 0.04 mm. for the kaolinite and 16 microns for the halloysite.

The halloysite to kaolinite ratio is 29:1.

The cumulative size frequency distribution curve is shown in Figure 24.

The pH measurement was 4.50.



100
90
80
70
60
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CUMULATIVE PERCENT
2
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7
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SIZE IN PHI UNITS
23
21
27
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60'
23
100'
27
CUMULATIVE SIZE FREQUENCY CURVES
S-21, S-23 and S-27
Micaville Deposit, Yancey Co., N. C.

Figure 24

Mica does not appear in the size fractions below 2 microns. The perthite is completely altered to halloysite and the mica only partially altered to kaolinite. Electron micrographs of this sample show mostly stubby halloysite tubes averaging 1 micron in length and 0.3 microns in diameter. A few flakes of mica are usually present in the micrographs.

Sample S-23 was obtained of a friable clay containing much quartz located 60 feet below and 100 feet north down the slope from S-21.

Table 37.

S-23, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ø	24.8%	6.2%				31.0%
2-3.75	2.9	23.4	0.5	2.2	0.5	29.5
3.75-5	0.5	3.6	0.2	1.4	0.3	6.0
5-6	0.8	3.1		3.4	0.9	8.2
6-7	0.8	2.2		3.8	1.7	8.5
7-8	0.1	0.5		4.0	0.6	5.2
8-9		0.3		4.0	0.5	4.8
9-10		0.2		1.7	0.1	2.0
10-11		0.1		2.0	0.1	2.2
-11		tr.		2.6		2.6
Totals	29.9%	39.7%	0.7%	25.1%	4.7%	100.0%

The median sizes for the clay minerals are 0.012 mm. for the kaolinite and 8 microns for the halloysite.

The halloysite to kaolinite ratio is 5.3:1.

The cumulative size frequency distribution curve is shown in Figure 24.

The pH measurement was 5.35.

Mica is present in the less than 0.5 micron size fraction. This indicates that alteration of the mica to kaolinite has not been extensive. Electron micrographs of the less than one micron fraction show halloysite tubes averaging 3 microns in length and 0.3 microns in diameter and ill-defined mica or kaolinite flakes.

Sample S-27 is located 85 feet from the surface and 300 feet north of S-23 down slope. The sample was taken from an altered feldspar crystal. The hand speciment was gritty from microcline fragments.

Table 38.

S-27, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	0.2%	0.4%	1.1%			1.7%
2-3.75	0.6	0.7	3.7		0.4	5.4
3.75-5	3.0	10.6	15.2		1.2	30.0
5-6	0.8	2.6	2.6	5.4	2.1	11.5
6-7	0.9	2.9	0.8	6.9	2.8	14.3
7-8	0.2	1.1	0.2	9.3	2.0	12.8
8-9	tr.	0.5		8.1	1.7	10.3
9-10		0.2		3.4	tr.	3.6
10-11		0.1		2.6		2.7
-11		0.3		7.4		7.7
Totals	5.7%	19.4%	21.6%	43.1%	10.2%	100.0%

The median sizes of the clay minerals are 0.01 mm. for the kaolinite and 4 microns for the halloysite.

The halloysite to kaolinite ratio is 4:1.

The cumulative size frequency distribution curve is shown in Figure 24.

The pH measurement was 6.31.

Electron micrographs of the less than one micron fraction are similar to those obtained of S-23. Mica is present in sizable amount in the less than one micron fractions.

S-21 was near the surface and located high up on the terrace so had undergone weathering for the longest period of time. This is indicated by the absence of feldspar and mica in less than 2 micron size fractions. S-23 is farther down the terrace slope than S-21 as well as farther from the surface and has been exposed to conditions of weathering for a shorter period of time. This is indicated by the presence of feldspar and mica in the less than 0.5 micron fractions. S-27 which is located still farther down the terrace slope and farther from the surface than S-23 is the youngest sample in terms of duration of weathering. This is shown by the high percentage of feldspar still present in the sample and the large amount of unaltered mica present in the less than 0.5 micron fraction. The amount of unaltered primary mica present in the finest fractions can be taken as a criterion for the duration or intensity of weathering. An additional criterion is the size of the finest fraction in which the mica appears. This is indicated clearly by the mineralogical analyses of these three samples.

Green Mountain Deposit, Yancey Co., North Carolina

This deposit is reached by traveling north 8.7 miles on Double Island Road from its junction with U. S. 19E to the Pleasant Grove Baptist Church. The clay pit is 500 feet behind the church. The clay has weathered from a 30 foot pegmatite dike which is bordered on the north by mica schist and on the south by a weathered dunite dike.

Sample ONR 478 was taken from a three inch vertical vein of white clay in the schist. Electron micrographs of this sample show halloysite tubes averaging 2 microns in length and 0.2 microns in diameter. Tubes of this shape are typical of the Spruce Pine district.

Sample ONR 480 was obtained from tan stained, thoroughly decomposed feldspar with clusters of green mica up to one centimeter in diameter. This sample was taken directly at the contact of the pegmatite with the mica schist. Electron micrographs show halloysite tubes up to 5 microns in length and 0.1 to 0.2 microns in diameter.

Woody Deposit, Yancey Co., North Carolina

This unworked clay pit is reached by taking the dirt road directly south of the Pleasant Grove Baptist Church and traveling 0.7 miles before turning left to the Woody farm on which the deposit is located.

Although the property hasn't been worked for some time, there are good exposures of decomposed pegmatite and its contacts with mica schist and altered dunite dikes. The weathered pegmatite extends to the surface. The plagioclase has altered to a clear white clay containing quartz relicts while the tan-stained potash feldspar is only partially altered and stands out in relief in the mine faces. Clusters of biotite books up to 2 inches in diameter occur in the weathered pegmatite and are concentrated near the contacts mentioned above.

Samples were taken of the potash and plagioclase feldspars within the pegmatite body and near the contacts. Electron micrographs of all the samples show halloysite tubes very similar in size except of those samples located directly on the contacts which show small stubby tubes of halloysite averaging 1 micron in length and 0.3 microns in diameter.

Sample ONR 482 was taken at the contact with the altered dunite dike. The feldspar is completely altered to halloysite and the sample contains a large amount of primary mica which is partially altered to vermicular kaolinite. A small amount of the feldspar is altering to kaolinite through the intermediate stage of secondary mica.

The biotite alters to vermiculite in this deposit as elsewhere in the district.

The Blue Ridge Province of Western North Carolina

Central Region

Arrowood Deposit, Democrat, Buncombe Co., North Carolina

The clay deposit is located one mile southwest of Democrat and immediately east of N.C. 197 (figure 25). The pegmatite is exposed for several hundred feet and averages about 60 feet in width. Only the southern end had been mined by open pit stripping. A 40 foot shaft has been sunk 40 feet north of the cut. The pegmatite contains a quartz core and is bounded by serpentinized dunite. Talc and vermiculite veins undulate through the pegmatite body.

Sample ONR 599 was obtained from the portal of the right tunnel in the face of the cut 20 feet from the surface. It come from a hard crystal of microcline standing out in relief in decomposed plagioclase feldspar. The microcline is only partially altered to halloysite in veins and fractures and especially along the contacts with quartz veins. Fragments of feldspar remain in the matrix of halloysite. Phenocrysts of plagioclase feldspar are half altered to halloysite. The mica is relatively unaltered except where it occurs near fractures where it is partially altered to kaolinite.

Sample ONR 600 was obtained next to ONR 599 and consists of decomposed perthite which is considerably altered to halloysite. Many small fragments of feldspar are left in a matrix of halloysite. These fragments vary in size from 0.02 mm. to 2 mm. The primary mica has altered almost completely to kaolinite. Some very fine vermicular kaolinite less than 0.01 mm. in size is derived from feldspar along fractures. Electron micrographs of this sample show long halloysite tubes

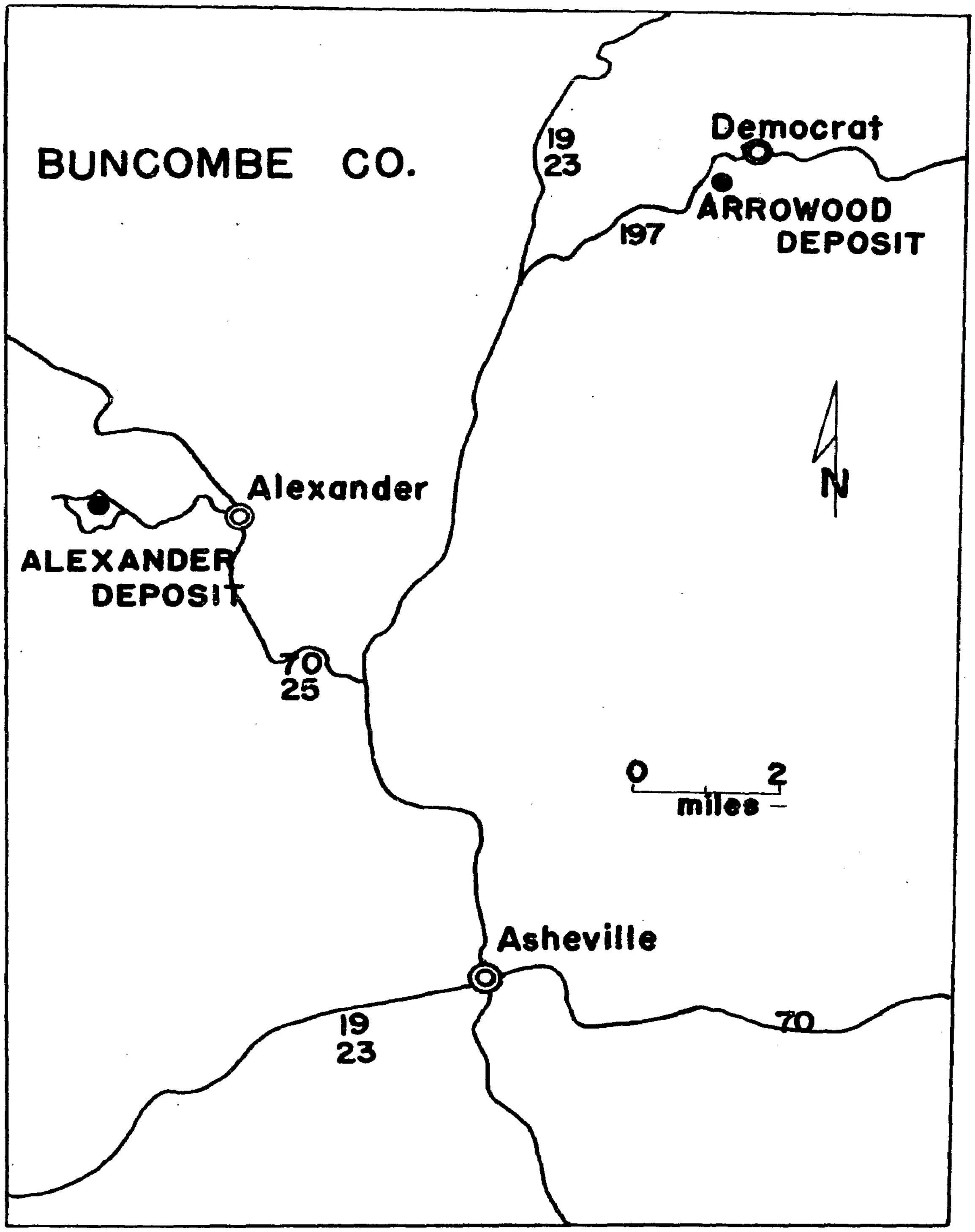


Figure 25. Areal map of the Central region of the Blue Ridge province of western North Carolina.

averaging 8 microns in length and 0.1 microns in diameter. The mineralogical analysis obtained from point count of the thin section is shown in Table 39.

Table 39.

ONR 600, Bulk Mineral Composition

Halloysite	75.1%
Kaolinite	10.4
Mica	0.6
Feldspar	13.9
Total	100.0%

The halloysite to kaolinite ratio is 7.5:1.

Sample S-20 is a moist sample obtained from a large crystal of perthite taken from the left tunnel in the cut 25 feet from the surface.

Table 40.

S-20, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Halloysite	Kaolinite	Size Analysis
2 ∅	0.7%	2.6%	0.4%				3.7%
2-3.75	0.5	1.3	7.1	5.1	0.9	3.0	14.9
3.75-5				6.9	0.9	6.1	13.9
5-6				6.1	0.9	4.6	11.6
6-7				5.7	1.0	2.8	9.5
7-8				4.1	0.5	3.1	7.7
8-9				4.8	0.6	1.6	7.0
9-10				5.5	1.4		6.9
10-11				14.9	1.1		16.0
-11				8.2	0.6		8.8
Totals	1.2%	3.9%	7.5%	61.3%	7.9%	21.2%	100.0%

The median sizes for the clay minerals are .04 mm. for the kaolinite and 4 microns for the halloysite.

The halloysite to kaolinite ratio is 3.2:1.

The cumulative size frequency distribution curve is shown in Figure 26.

Electron micrographs of the less than one micron fraction of this sample show halloysite tubes 1 to 4 microns in length and averaging 0.1 micron in diameter (see Plate 1).

The pH measurement was 5.58.

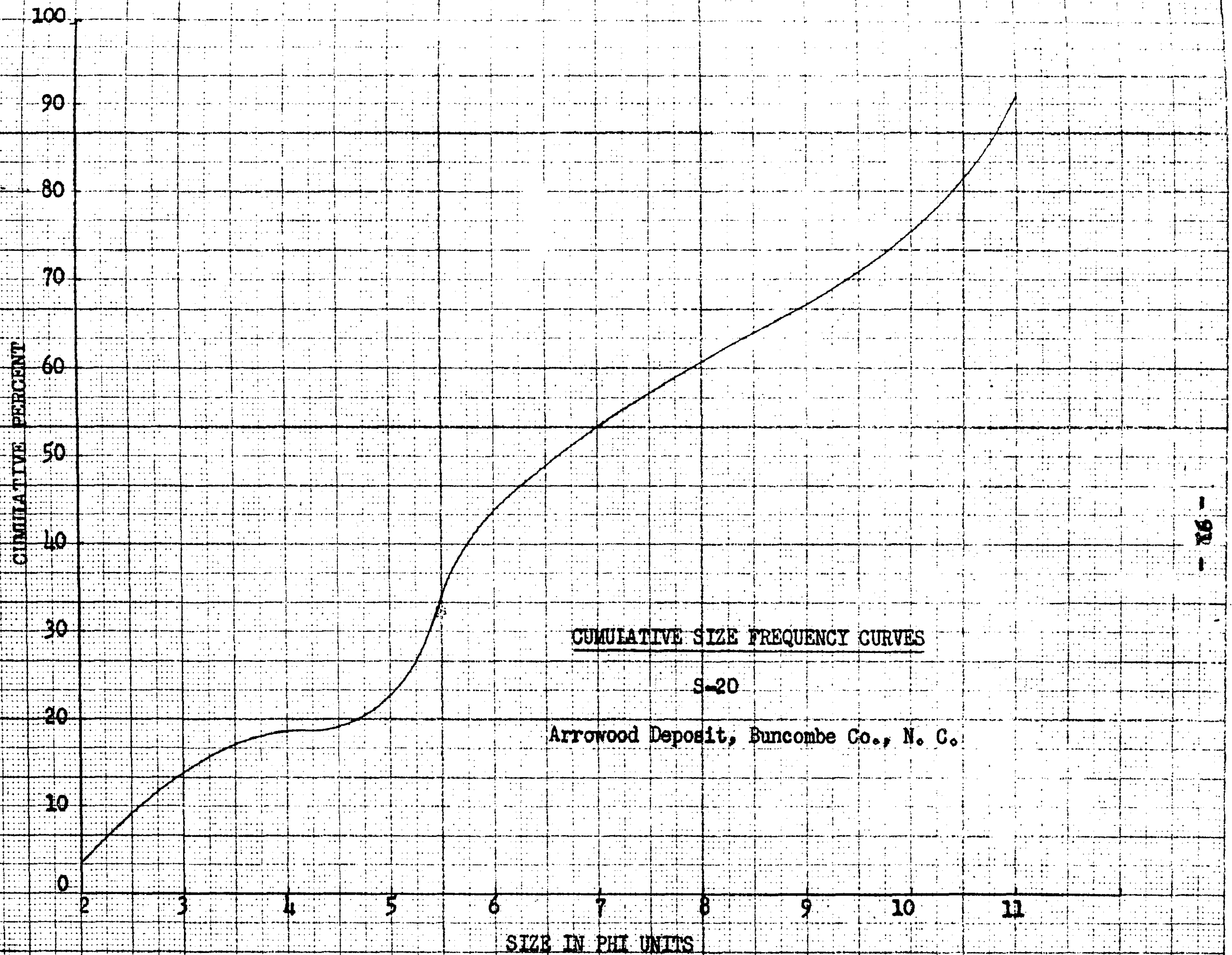

CUMULATIVE SIZE FREQUENCY CURVES
S-20
Arrowood Deposit, Buncombe Co., N. C.
CUMULATIVE PERCENT
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11
SIZE IN PHI UNITS

Figure 26

Alexander Deposit, Alexander, Buncombe Co., North Carolina

This clay deposit is reached by traveling three miles east from Alexander on U.S. 25 and 70 (figure 25). The deposit is worked by several cuts and shafts. Relatively unaltered microcline is concentrated near the core of the pegmatite. Schist inclusions in the pegmatite are numerous.

Sample ONR 580 is a decomposed perthite crystal obtained on the south wall of the north pit 10 feet from the surface. The perthite is altered almost completely to halloysite and most of the mica is altered to vermicular kaolinite. When altered to kaolinite the mica books part perpendicular to the basal cleavage to give a maximum width of 0.04 mm. for the kaolinite books. The average width of the vermicular kaolinite is .02 mm. The mineral composition of the sample as obtained from the thin section is given in Table 41.

Table 41.

ONR 580, Bulk Mineral Composition

Halloysite	87.5%
Kaolinite	10.7
Mica	1.6
Feldspar	0.2
Total	100.0%

The halloysite to kaolinite ratio is 8.2:1.

Sample ONR 582 is a decomposed perthite crystal obtained from the North pit in a tunnel 10 feet from the surface and 15 feet north from ONR 580. Quartz stringers cut through the large feldspar crystal. The mineral composition of this sample as determined by a thin section point count follows in Table 42.

Table 42.

ONR 582, Bulk Mineral Composition

Halloysite	86.8%
Kaolinite	10.5
Mica	2.7
Total	100.0%

The halloysite to kaolinite ratio is 8.3:1.

Sample ONR 583 is a hard, only partially altered microcline crystal taken 12' from the surface in the south pit. Only 10% of the microcline had weathered to halloysite along fractures. The mica is unaltered.

Sample ONR 584 is a perthite sample taken next to ONR 583 and is almost completely weathered in contrast to the slightly weathered microcline. The mica is largely altered to kaolinite. Veins of yellow-stained halloysite apparently introduced from above fill fractures formed in the halloysite developed in situ. The mineral composition as determined by thin section analysis follows in Table 43.

Table 43.

ONR 584, Bulk Mineral Composition

Halloysite	91.8%
Kaolinite	7.6
Mica	0.4
Feldspar	0.2
Total	100.0%

The halloysite to kaolinite ratio is 12:1.

Sample S-6 is a moist, decomposed perthite crystal taken from the north wall of the North pit 40 feet from the surface.

Table 44.

S-6, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Halloysite	Kaolinite	Size Analysis
2 ∅	0.3%	0.5%	0.2%	1.8%	0.1%	0.1%	3.0%
2-3.75	0.2	4.2	0.4	12.7	1.3	2.3	21.1
3.75-5	0.2	1.1		14.8	1.0	4.9	22.0
5-6	0.1	1.4		9.0	0.6	2.4	13.5
6-7	0.1	0.1		4.2	0.3	2.3	7.0
7-8	tr.	tr.		2.2	0.3	1.6	4.1
8-9				1.2	0.1	1.0	2.3
9-10				3.2	0.2	1.5	4.9
10-11				8.5	0.4		8.9
-11				12.6	0.5		13.1
Totals	0.9%	7.3%	0.6%	70.2%	4.8%	16.1%	99.9%

The median sizes for the clay minerals are 0.03 mm. for the kaolinite and 0.03 mm. (30 microns) for the halloysite. The larger median size for the halloysite than usual is due to the partially dehydrated nature of the endellite which caused disaggregation to be less effective with the technique used.

The halloysite to kaolinite ratio for S-6 is 4.7:1.

The cumulative size frequency distribution curve is shown in Figure 27.

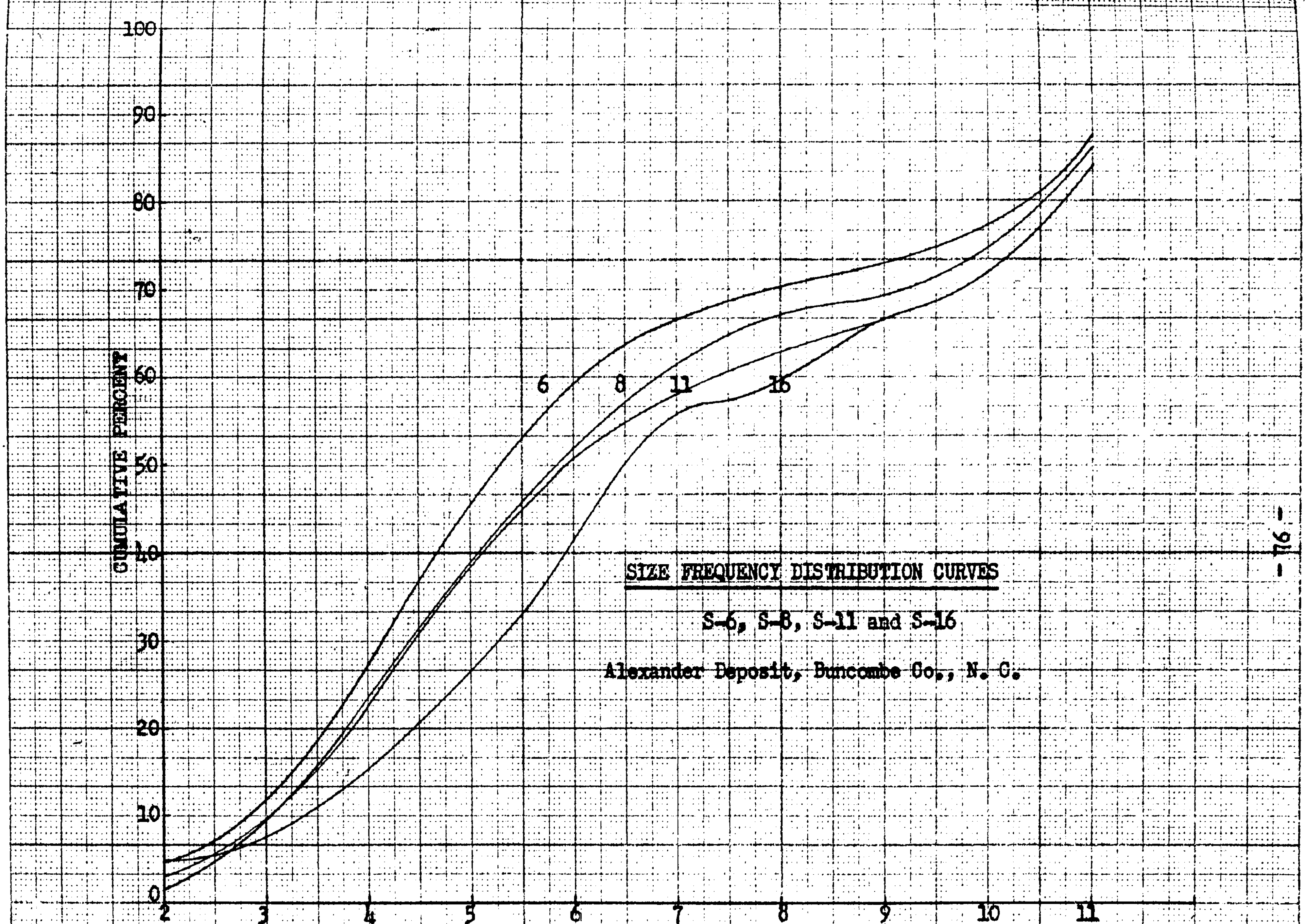
The pH measurement was 5.60.

Sample S-8 is a moist clay derived from perthite containing some schist inclusions. It was obtained 5 feet above S-6.

Table 45.

S-8, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ∅	1.0%	0.5%		0.1%	1.6%
2-3.75		3.7	10.2	4.6	18.5
3.75-5	0.9	3.9	10.6	4.8	20.2
5-6	1.2	0.2	8.5	2.9	12.8
6-7	0.1		5.5	2.9	8.5
7-8	0.1		3.8	1.7	5.6
8-9		0.1	1.1	0.3	1.5
9-10		0.3	6.4	0.7	7.4
10-11			9.8		9.8
-11			14.1		14.1
Totals	3.3%	8.8%	70.0%	17.9%	100.0%


CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
2
3
4
5
6
7
8
9
10
11
6
8
11
16
SIZE FREQUENCY DISTRIBUTION CURVES
S-6, S-8, S-11 and S-16
Alexander Deposit, Buncombe Co., N. C.
SIZE IN PHI UNITS
Figure 27

The median sizes for the clay minerals are 0.07 mm. for the kaolinite and 8 microns for the halloysite.

The halloysite to kaolinite ratio is 3.9:1.

The cumulative size frequency distribution curve is shown in Figure 27.

The pH measurement was 5.67.

Sample S-11 is a moist clay derived from a one foot crystal of perthite located directly below a schist inclusion 7 feet above and 6 feet east of S-8. The perthite is completely weathered to halloysite and the mica partially altered to kaolinite. Introduced stained halloysite occurs in fracture-filled veins.

Mineral composition of a subsample of S-6 obtained by point count analysis of a thin section follows in Table 46.

Table 46.

S-6, Bulk Mineral Composition

Halloysite	74.3%
Kaolinite	16.7
Mica	6.3
Quartz	0.9
Feldspar	0.8
Total	100.0%

The halloysite to kaolinite ratio is 4.4:1.

Table 47.

S-11, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Halloysite	Kaolinite	Size Analysis
2 ∅	0.1%	0.4%		-	tr.	0.5%
2-3.75	0.2	16.6	1.0	0.3	0.4	18.4
3.75-5	0.1	1.8	13.2	2.2	3.2	20.5
5-6	0.1	1.0	7.2	1.2	1.8	11.3
6-7	0.1	0.7	5.1	0.9	1.2	8.0
7-8	tr.		3.0	0.8	0.7	4.6
8-9			2.1	0.8	0.2	3.1
9-10			4.0	1.1	0.3	5.4
10-11			9.2	2.7		11.9
-11			12.5	3.7		16.2
Totals	0.6%	20.5%	57.3%	13.7%	7.8%	99.9%

The median sizes for the clay minerals are 0.07 mm. for the kaolinite and 8 microns for the halloysite.

The halloysite to kaolinite ratio is 9.1:1.

The cumulative size frequency distribution curve is shown in Figure 27.

The pH measurement was 5.62.

Electron micrographs of the -1 micron fraction contain halloysite tubes 4 microns in length and 0.1 microns in diameter. Mineral composition of S-11 obtained by point count from a thin section follows in Table 48.

Table 48.

S-11, Bulk Mineral Composition

Halloysite	88.9%
Kaolinite	5.6
Mica	4.6
Total	100.0%

The halloysite to kaolinite ratio of this subsample is 16:1.

Sample S-16 is a moist clay derived from a plagioclase crystal taken 15 feet below the surface in the South pit. This is about 15 feet above S-11 and 250 feet south.

Table 49.

S-16, Mineralogical Analysis of Size Fractions

Size Fraction	Mica	Endellite	Kaolinite	Size Analysis
2 Ø	5.1%	0.1%	0.1%	5.3%
2-3.75	7.6	0.2	0.2	8.0
3.75-5	0.7	10.2	2.6	13.5
5-6		8.5	5.9	14.4
6-7		9.0	5.0	14.9
7-8		1.1	1.9	3.0
8-9		5.6	2.4	8.0
9-10		3.8	0.9	4.7
10-11		12.4		12.4
-11		15.7		15.7
Totals	13.4%	67.6%	18.9%	99.9%

The median sizes for the clay minerals are .03 mm. for the kaolinite and 4 microns for the halloysite.

The halloysite to kaolinite ratio is 3.6:1.

The cumulative size frequency distribution curve is shown in Figure 27.

The pH measurement was 5.25.

The Blue Ridge Province of Western North Carolina

Southern Region

Bethel Deposit, Bethel, Haywood Co., North Carolina

This deposit is located 1.5 miles south east of Bethel on the property of Marvin Long and is reached by taking N.C. 110 south from Canton or U.S. 276 east from Waynesville (figure 28).

This mine was abandoned in 1918 and is considerably overgrown and all shafts filled, but walls in the open cut have exposures of weathered pegmatite. The deposit is well up the slope of a hill in an area of moderate relief at an elevation of 3400 feet and lies 600 feet above the East Fork Pigeon River. The cut made in the pegmatite dike is 600 feet along the N26°E strike and several hundred feet wide. The dike dips 75°E at its contact with gneiss. The dike is not uniformly weathered and is thoroughly decomposed in places and only partially altered in others. The clay is very white and contains much fine-grained quartz. Mica books 2" in diameter occur.

Sample ONR 659 was obtained from the northwest wall 12 feet from the surface. Most of the feldspar is altered to halloysite but a considerable amount is altered to vermicular kaolinite through the intermediate stage of secondary mica. A photomicrograph of this vermicular kaolinite being derived from secondary mica is shown in Plate 1. The small amount of primary mica disseminated through the halloysite is partially altered to kaolinite.

The mineralogical analysis was obtained by thin section methods and is as follows: halloysite 76.5%, kaolinite 21.8%, mica 1.6%. The halloysite to kaolinite ratio is 3.5:1.

Electron micrographs of the less than one micron fraction show stubby

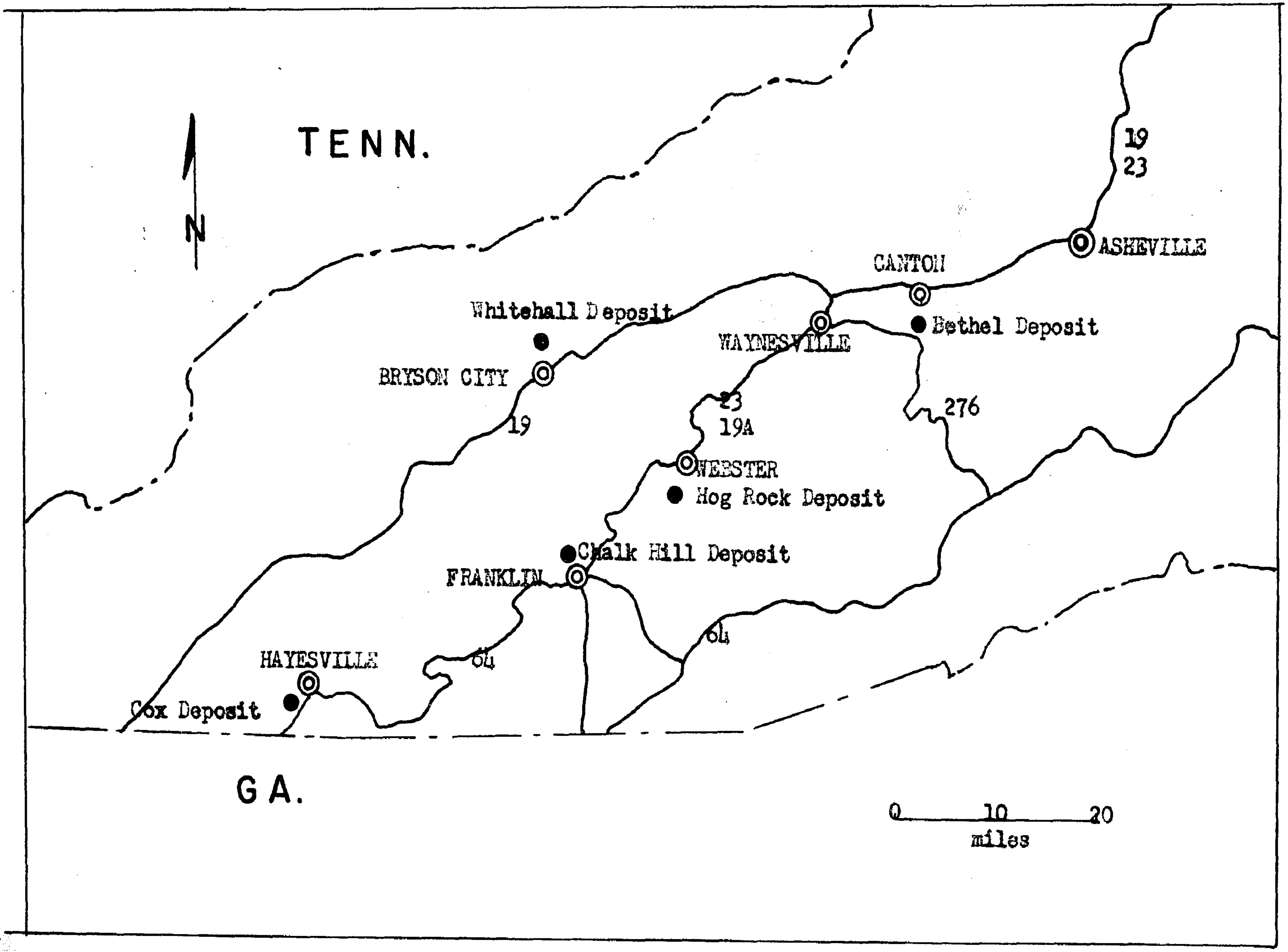


Figure 28. Arealmap of the Southern region of the Blue Ridge province of western North Carolina.

tubes of halloysite averaging 1 micron in length and 0.3 microns in diameter.

Whitehall Deposit, Bryson City, Swain Co., North Carolina

This deposit is located 1-1/2 miles north of Bryson City (figure 28). Feldspar is being mined from this large pegmatite and the cuts provide profiles for sampling the transition from clay to fresh rock. Weathering is pronounced along the contacts with large quartz veins and in finely fractured quartz zones. Depth of weathering varies from several feet to 60 feet.

Sample ONR 695 was taken 25 feet from the surface directly above a quartz ledge. It consisted of thoroughly decomposed perthite disseminated with fine-grained muscovite and milky quartz grains less than 0.5 cm. in size.

The plagioclase feldspar is altering to halloysite and the potash feldspar to vermicular kaolinite through an intermediate stage of secondary mica.

Mineralogical analysis by thin section methods follows in Table 50.

Table 50.

ONR 695, Bulk Mineral Composition

Halloysite	71.2%
Kaolinite	8.4
Mica	20.0
Feldspar	0.4
Total	100.0%

The halloysite to kaolinite and secondary mica ratio is 2.9:1.

Hog Rock Mine, Jackson Co., North Carolina

This mine is now an abandoned deposit. It was the first clay mine in the state and was mined by open cuts and shafts which penetrated to a maximum depth of 125 feet. The workings are now caved and overgrown. The mine is located 2 miles southwest of Webster on the top of a hill 300 feet above Little Savannah Creek. The only samples that were obtained were of weathered pegmatite exposed on the surface.

Sample ONR 664 was taken from the surface 55 feet from the summit. The potash feldspar is altered to both halloysite and kaolinite. The primary mica is partially altered to kaolinite. The kaolinite formed from weathering of the feldspar is derived from the secondary mica formed during the first stages of weathering of the feldspar.

Chalk Hill Deposit, Iotla, Macon Co., North Carolina

This deposit is located 3 miles southwest of Iotla on the side of a gently sloping hill 80 feet above Iotla Creek. The mine is in disuse and the shafts are filled with water, but the open cuts and several prospect pits provide good exposures for sampling. Samples were taken across the strike of a three foot vertical dike.

Sample ONR 672 was obtained near the contact of the pegmatite with schist. Almost all of the feldspar is altered to secondary mica which is being kaolinized. The primary mica has been altered almost completely to kaolinite. There is some halloysite being derived from the feldspar. Electron micrographs of the less than one micron fraction show halloysite tubes 1 to 2 microns in length together with kaolinite plates.

Sample ONR 673 was taken near the center of the dike. The feldspar is altering mostly to halloysite but near fractures around quartz grains some feldspar has altered to secondary mica which is partially altered to vermicular kaolinite. Electron micrographs of this sample show uniform size halloysite tubes averaging 1.5 microns in length and a few well-defined kaolinite plates.

Cox Deposit, Hayesville, Clay Co., North Carolina

One representative sample (S-122) was obtained from this deposit from Mr. Lee White of the Harris Clay Company. The deposit is located near Hayesville several miles from the Georgia border near the southern end of the Appalachian chain.

In the hand specimen the sample is very friable and contains much quartz and mica.

Table 51.

S-122, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	17.8%	8.2%	3.2%		5.4%	34.0%
2-3.75	4.4	9.8	1.2		6.5	21.9
3.75-5		4.2			3.9	8.1
5-6		5.9			6.9	12.8
6-7		2.5			7.5	10.0
7-8		1.2		0.6%	4.8	6.6
8-9		0.9		0.2	3.3	4.4
9-10		0.2		0.2	0.8	1.2
10-11		tr.		0.4	0.2	0.6
-11		tr.		0.3	0.1	0.4
Totals	22.2%	32.9%	4.8%	1.7%	39.4%	100.0%

The median size of the kaolinite is .02 mm. and that of the halloysite 2 microns.

The ratio of halloysite to kaolinite is 1:23.

The cumulative curve for this sample is shown in Figure 29.

The pH measurement was 5.90.

Halloysite isn't present in the larger than 8 micron fractions but

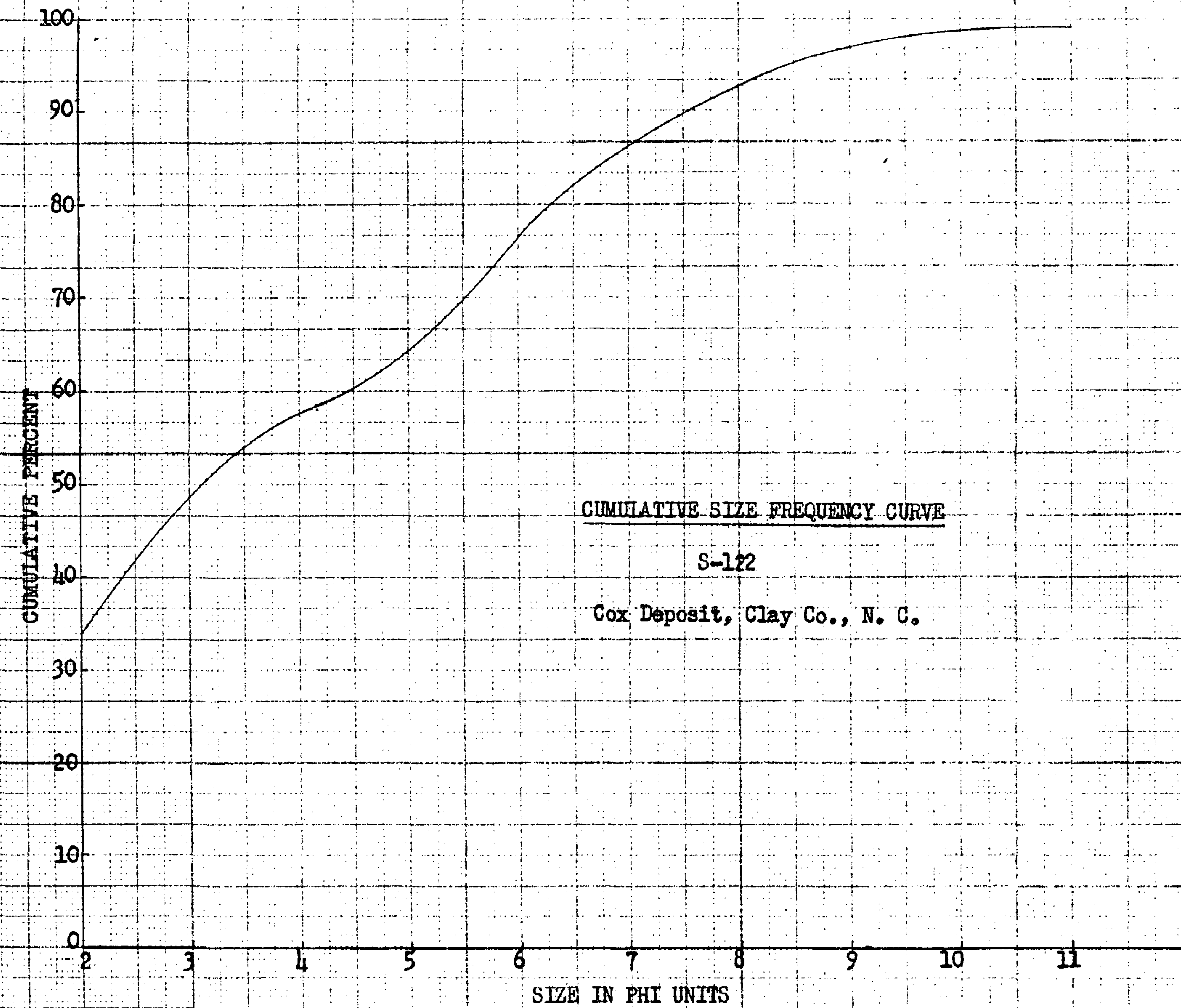

CUMULATIVE SIZE FREQUENCY CURVE
S-122
Cox Deposit, Clay Co., N. C.
CUMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
2
3
4
5
6
7
8
9
10
11
SIZE IN PHI UNITS

Figure 29

kaolinite occurs as vermicular aggregates even in the coarsest fractions where it is interleaved with the mica. The high percentage of mica present is due to the sericitization of the feldspar in the initial stage of weathering which is followed by kaolinization of the secondary mica.

The Piedmont Province of Georgia

Funkhauser Mica Mine, Hartwell, Hart Co., Georgia

The Funkhauser Mine is in operation 1-1/2 miles south of Hartwell. No fresh unaltered pegmatite is exposed. Moist samples were taken from the face of the old pit as well as in the fresh cuts.

Sample S-107 was taken 30 feet from the surface from the pegmatite in the north end of the new pit.

Table 52.

S-107, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ∅	11.5%	31.2%			15.0%	57.7%
2-3.75	2.3	4.7	0.3%		4.3	11.6
3.75-5	0.1	0.5			4.2	4.8
5-6		2.2			8.7	10.9
6-7		1.0			3.9	4.9
7-8		0.7		tr.	2.6	3.3
8-9		0.6		0.1	2.6	3.3
9-10		0.3		0.2	1.3	1.8
10-11				1.0	0.3	1.3
-11				0.3		0.3
Totals	13.9%	41.2%	0.3%	1.6%	42.9%	99.9%

The median sizes for the clay minerals are 0.07 mm. for the kaolinite and one micron for the halloysite.

The halloysite to kaolinite ratio is 1:27.

The cumulative size frequency distribution curve is shown in Figure 30.

The pH measurement was 5.30.

About half of the particles seen in the electron micrographs are halloysite tubes up to five microns in length and vary in diameter from 0.1 to 0.4 microns while the other half are kaolinite books.

Sample S-108 was obtained 2 feet below S-107 and was similar in appearance except that it was more friable due to higher quartz content.

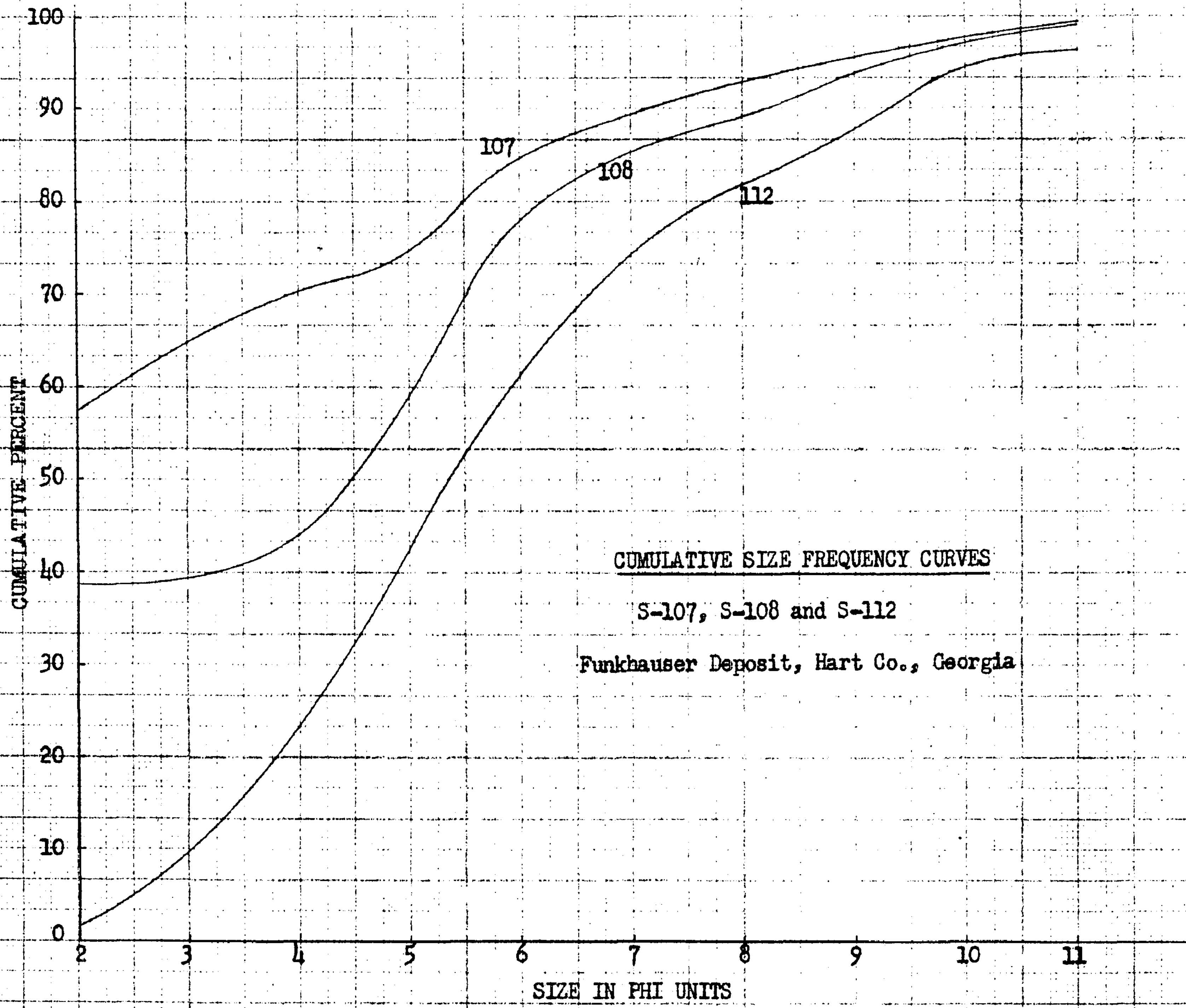

CUMULATIVE SIZE FREQUENCY CURVES
S-107, S-108 and S-112
Funkhauser Deposit, Hart Co., Georgia
CUMULATIVE PERCENT
SIZE IN PHI UNITS
107
108
112
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11

Figure 30

Table 53.

S-108, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Endellite	Kaolinite	Size Analysis
2 ϕ	38.2%	0.6%		0.2%	39.0%
2-3.75		1.2		0.6	1.8
3.75-5		3.5		13.9	17.4
5-6		4.1		16.6	20.7
6-7		1.5		5.9	7.4
7-8		0.7		2.5	3.2
8-9		1.0	0.2%	3.8	5.0
9-10		tr.	1.0	1.9	2.0
10-11			1.3	0.9	2.2
-11			0.5	0.2	0.7
Totals	38.2%	12.6%	3.0%	46.5%	100.3%

The median sizes for the clays are .025 mm. for the kaolinite and 1 micron for the halloysite.

The halloysite to kaolinite ratio is 1:15.

The cumulative size frequency distribution curve is shown in Figure 30.

The pH measurement was 5.30.

Electron micrographs look similar to those taken of S-107 and one is shown in Figure 30.

Sample S-112 was taken from a large feldspar crystal exposed in a new gulley leading from the old pit to the new workings. In the hand specimen it feels gritty as a result of the presence of unaltered feldspar particles.

Table 54

S-112, Mineralogical Analysis of Size Fractions

Size Fraction	Quartz	Mica	Feldspar	Endellite	Kaolinite	Size Analysis
2 ϕ	0.4%		0.8%		0.3%	1.5%
2-3.75	1.5	0.8	7.6	tr.	7.9	17.8
3.75-5	1.7	2.3	10.6	1.2	7.5	23.3
5-6	0.2	1.9	3.2	2.0	11.5	18.8
6-7		tr.	0.8	1.1	10.6	12.5
7-8				1.7	6.5	8.2
8-9				3.2	3.0	6.2
9-10				4.2	3.1	7.3
10-11				0.8	0.5	1.3
-11				3.2	0.1	3.3
Totals	3.8%	5.0%	23.0%	17.4%	51.0%	100.2%

The median sizes of the clay minerals are 0.03 mm. for the kaolinite and 7 microns for the halloysite.

The halloysite to kaolinite ratio is 1:3.

The cumulative size frequency distribution curve is shown in Figure 30.

The pH measurement was 5.80.

Electron micrographs show 50% well-defined kaolinite plates and the other 50% halloysite tubes averaging 3 microns in length and 0.2 microns in diameter.

Thin section mineralogical analysis of S-112 gave the composition shown in Table 55.

Table 55.

S-112, Bulk Mineral Composition

Halloysite and Kaolinite	67.8%
Mica.............................	4.1
Quartz	0.3
Microcline.......................	27.8
Total	100.0%

This analysis compares very well with the mineralogical analysis of S-112 obtained by differential thermal, x-ray and petrographic analysis of the size fractions.

Most of the microcline is altering to secondary mica which in turn is being kaolinized to vermicular kaolinite. When almost completely kaolinite, the books part perpendicular to the basal cleavage at intervals of 0.04 mm. When the kaolinite is derived from the small books of secondary mica, there is no extended parallel orientation of the vermicular aggregates such as that which occurs when the vermicular kaolinite is derived from larger books of primary mica. Some of the microcline is altered directly to halloysite.

Electron micrographs of the less than one micron fraction show about 50% of well-defined kaolinite plates and the remainder halloysite tubes averaging 3 microns in length and 0.2 microns in diameter.

Atwater Mica Mine, Upson Co., Georgia

This mine is located near Thomaston, Georgia. The sample was taken in the north end at the bottom of the 8 foot shaft where the altered pegmatite is stained deep red from hematite.

The feldspar in this pegmatite is altering to secondary mica which in turn is weathering to kaolinite. A small amount of the feldspar is altering directly to halloysite.

SUMMARY OF ANALYTICAL DATA

The mineralogical analyses of samples from the same deposit have been averaged and the average bulk mineral compositions are presented in Table 56. The average halloysite to kaolinite ratios (H:K) show the predominance of kaolinite over halloysite in the Piedmont provinces of the three states and in the southernmost deposit in the Blue Ridge province. On the basis of the samples studied the only region where halloysite predominates over kaolinite is in the Blue Ridge province of western North Carolina.

The Piedmont Province of Virginia

All the kaolin deposits studied in this region were found to be principally kaolinite with some endellite present in minor amounts. In each of the four deposits, the feldspar is altering to secondary mica from which vermicular kaolinite is being derived. The weatheing sequence was studied in thin section and by qualitative x-ray, differential thermal and electron microscope techniques for three of the deposits and a quantitative mineralogical analysis of the size fractions made of a sample from the Nat Kidd Prospect in Roseland. The latter deposit lies close to the Blue Ridge Province of Virginia and contains only a small percentage of endellite as seen from the halloysite to kaolinite ratio of 1:28.

The Piedmont Province of North Carolina

Five occurrences of kaolin clay from this region were studied. Qualitative studies on four samples from gneissic rocks showed a predominance of kaolinite over endellite. Quantitative mineralogical analyses were made on the size fractions from two samples of pegmatitic material from

Table 56.

Average Bulk Mineral Compositions and the Halloysite to Kaolinite Ratios

Deposit	Location	Samples	Quartz	Mica	Feldspar	Halloysite	Kaolinite	H:K
Virginia Piedmont Province								
Nat Kidd Prospect	Roseland	2	0.1%	24.6%		2.3%	45.5%	1:19.8
North Carolina Piedmont Province								
Patterson	Kings Mountain	2	2.8	20.5		13.8	58.0	1:4.2
North Carolina Blue Ridge Province								
Gusher Knob	Avery Co.	12	24.1	16.4	0.5	46.6	12.4	3.8:1
School Hill	Avery Co.	1	58.2	1.9		35.3	4.9	7.2:1
Fluken Ridge	Mitchell Co.	5	5.6	3.4	24.2	59.5	5.2	11.4:1
17 Acre Prospect	Mitchell Co.	6	5.6	10.7		74.5	10.9	6.8:1
Carter Ridge	Mitchell Co.	1		2.9		84.3	12.8	6.6:1
Micaville	Yancey Co.	3	13.2	24.6	7.4	48.2	5.9	8.1:1
Arrowood	Buncombe Co.	2	0.6	2.2	10.7	72.2	15.8	4.6:1
Alexander	Buncombe Co.	9	0.7	7.8	0.1	76.6	12.6	6:1
Whitehall	Swain Co.	1		20.0	0.4	71.2	8.4	8.5:1
Bethel	Haywood Co.	1		1.6		76.5	21.8	3.5:1
Cox	Clay Co.	1	22.2	32.9		1.7	39.4	1:23
Georgia Piedmont Province								
Funkhauser	Hartwell	3	18.6	19.6	7.8	7.3	46.8	1:6.4

the Patterson deposit at Kings Mountain. These samples were also found to be predominantly kaolinite although they varied considerably in the halloysite to kaolinite ratio, one giving 1:109 and the other 1:2.3. The clay sample with the least halloysite is derived from a feldspathic portion of the pegmatite with coarse granitic texture while the other sample is from a large feldspar crystal. Although climate and mineral structure and composition are believed to be the predominant factors, this suggests the effect that texture of the parent rock may have in producing endellite instead of kaolinite.

The Blue Ridge Province of North Carolina (Northern Region)

Eight deposits were studied in this region usually designated as the Spruce Pine pegmatite district. Of these, the Gusher Knob and Micaville deposits are in granitic bodies cut by pegmatitic veins, and the others are in pegmatites.

Endellite predominates over kaolinite in all of these deposits and the halloysite to kaolinite ratio varies from a high of 50:1 to a low of 1:1 with an average for the region of 7.5:1. The feldspars are sodic plagioclase, microcline and perthite. These weather to endellite with the plagioclase being the first to decompose. This can be observed in the hand specimen of partially altered perthite where the hard potash feldspar stands out in relief. Large, only slightly altered microcline crystals may be next to completely altered plagioclase. However, in this region both of the feldspars alter to endellite even though the rate of weathering differs. In only one sample, from the Woody deposit, is a small part of the potash feldspar altered to secondary mica which in turn is kaolinized.

The primary mica alters to vermicular kaolinite in all samples.

In each of the two granitic bodies, which are more uniform in composition than the pegmatites, a study was made of the alteration of the muscovite in a vertical profile. In the Micaville deposit, the mica content in the finer fractions decreases upward in the soil profile as the finest particles of muscovite alter to kaolinite. This correlates with the disappearance of feldspar upward in the profile. The disappearance of the muscovite in the finer fractions is shown in the four vertical sections taken from the sample grid in the Gusher Knob deposit. The four vertical profiles each contain three samples which are separated by a three foot interval (see Figure 15). The mica content for the finest fractions in which the muscovite occurs is listed for the four profiles in Tables 57 and 58.

Table 57.

Mica Content In Finest Fraction
In Which Mica Occurs In Two Vertical Profiles

Sample No.	Size Fraction	Mica Content
50 top	6-7 ø	2.0%
47 middle	6-7 ø	7.5%
42 bottom	6-7 ø	10.0%
52 top	9-10 ø	1.4%
45 middle	9-10 ø	1.7%
44 bottom	9-10 ø	2.0%

Table 58.

Finest Fractions
In Which Mica Occurs In Two Vertical Profiles

Sample No.	Size Fraction	Mica Content
62 top	7-8 ø	trace
59 middle	8-9 ø	trace
54 bottom	9-10 ø	trace
64 top	7-8 ø	trace
57 middle	8-9 ø	trace
56 bottom	9-10 ø	trace

Because of the wide variability in total content and size distribution of muscovite between subsamples, comparison of total mica content with total kaolinite content could not be used to show whether or not the weathering of mica to kaolinite is greater in the top samples in the profile. However, the mica in the finest fractions, which is the first to alter, is seen to disappear upward in the profile.

The Blue Ridge Province of North Carolina (Central Region)

The two deposits in Buncombe County selected for detailed study in this region showed an average halloysite to kaolinite ratio of 5.3:1 which is somewhat lower than that for the average of the Spruce Pine district. Most of the feldspar crystals, whether plagioclase or microcline, alter to endellite. However, some of the microcline from each deposit is altering to secondary mica which in turn is altering to fine-grained vermicular aggregates of kaolinite. There is no cover of river gravels and vegetation is sparse so that maximum intensity of leaching presumably was not effected in these deposits to leach all of the potash from the microcline.

The primary mica is altering to vermicular kaolinite.

The Blue Ridge Province of North Carolina (Southern Region)

An increase in the amount of kaolinite derived from pegmatite is noted in this region over that of the Central Region. In one sample from the southernmost deposit studied in the Blue Ridge Province near Hayesville the halloysite to kaolinite ratio was found to be 1:23. This was the only sample from the North Carolina Blue Ridge province that was found to be higher in kaolinite content than halloysite. However, only one sample was obtained from this deposit and it may not be representative. In all of the deposits in this region including Macon, Swain, Haywood and Clay Counties the feldspar in part alters to secondary mica which in turn is kaolinized. In a perthite crystal from the Whitehall deposit the plagioclase was altered to endellite and the microcline to kaolinite through the intermediate stage of mica. However, in the samples studied from this region the halloysite to kaolinite ratio averages 3:1 showing a decrease from that of the central region of the Blue Ridge province. The primary mica in all deposits alters to vermicular kaolinite.

The Piedmont Province of Georgia

The kaolin clays derived from pegmatities in this region show a predominance of kaolinite over halloysite. The ratio of halloysite to kaolinite is as low as 1:27 in one sample and averaged 1:6.4 for the three samples analyzed. Most of the feldspar is altering to secondary mica which in turn is altering to vermicular kaolinite, and a small part of the feldspar alters to endellite. The primary mica alters to vermicular kaolinite as is the case in all the deposits studied.

EXPERIMENTAL EVIDENCE OF ALTERATION

Alteration of Feldspar to Endellite

Thin section — In thin section the feldspars (microcline, perthite and plagioclase) are observed altering to endellite. The latter is characterized by very low birefringence. The absence of fine-grained kaolinite is evidenced by the close check of the mineralogical composition obtained by a point count of the thin section with the composition obtained by the x-ray, differential thermal, and electron microscope analysis of size fractions.

Differential thermal analysis — This technique showed that some weathered feldspar crystals were altered to over 90% endellite. This was substantiated by x-ray analysis.

Mineralogical analysis of size fractions — The percentage of endellite checks with that obtained by the thin section method indicating that the criteria used for identifying the mineral in thin section are correct and the quantitative mineralogical analyses are valid.

Alteration of Feldspar to Secondary Mica

Thin section — The principal evidence for this type of alteration is found in the thin sections. Crystals of feldspar can be seen altering to books of mica which in turn are altering to vermicular kaolinite. Simultaneous extinction shows that fragments of feldspar in the mica and kaolinite matrix are remnants of the same original crystal. The books of secondary mica derived from feldspar are smaller and do not give as high a retardation as primary muscovite although they represent a mineral of the muscovite type as shown by x-rays. The books of secondary mica are not parallel to each other and this results in a random arrangement of vermicular kaolinite aggregates in contrast to the oriented aggregates derived from a larger book of primary muscovite.

Point counts of the mica in thin sections give percentages for this mineral which are in accord with results obtained by mineralogical analysis of size fractions.

X-ray analysis — The x-ray technique used does not differentiate between primary and secondary mica.

Mineralogical analysis of size fractions — In those clays which are predominantly vermicular kaolinite and are derived from pegmatite and granite as high as 40% of mica is present. The samples taken from a weathered feldspar crystal in a pegmatite probably originally contained much less than 20% of primary muscovite. This indicates that much of the mica must have formed from the feldspar.

Alteration of Primary Muscovite to Kaolinite

Thin section — Books of mica can be observed altering on the edges and along certain preferential planes to smaller vermicular aggregates of kaolinite. When kaolinized, the books show a parting perpendicular to the basal cleavage at 0.02 to 0.04 mm. intervals. Point counts of the kaolinite give percentages that correspond with those obtained by mineralogical analysis of the size fractions.

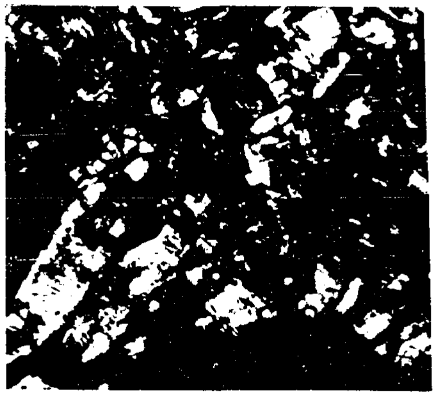
X-ray analysis — Books of mica which were washed thoroughly and x-rayed in a moist condition, were found to be muscovite mica and kaolinite. In no sample, even though the mica was embedded in a matrix of endellite, was endellite found more intimately associated with the mica. The kaolinite is pseudomorphous after the mica and the basal planes of the kaolinite orient, in general, parallel to those of the mica. Deviations occur as a result of parting and a curving of the vermicular kaolinite aggregates as the mica is increasingly altered.

Optical studies -- Unaltered muscovite gives a clear interference figure with a 2V of 35° to 45°. As the muscovite alters to kaolinite, the optic figure becomes increasingly blurred and indistinguishable.

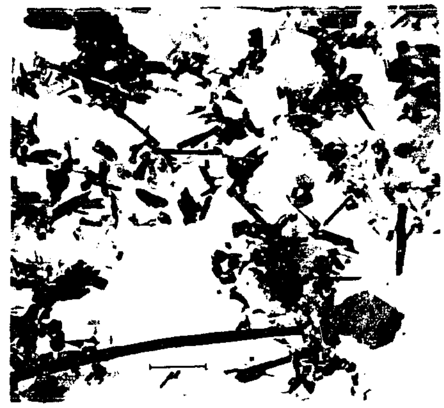
Alteration of Secondary Mica to Kaolinite

Evidence for this is the same as that for the primary mica altering to kaolinite. Distinguishing the alteration of secondary mica from that of primary muscovite is discussed in a previous section.

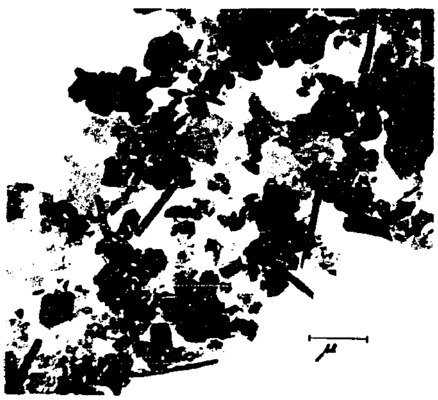
Sparks Deposit, Mitchell Co., N.C. Microcline weathering to halloysite. x50.



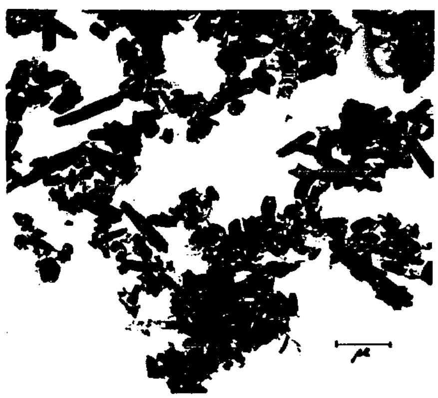
Bethel Deposit, Haywood Co., N.C. Vermicular kaolinite aggregates. x50.



Nat Kidd Prospect, Nelson Co., Virginia. Electron Micrograph of clay derived from granite.



Funkhauser Deposit, Hart Co., Georgia. Electron micrograph of clay derived from pegmatite.



Gusher Knob Deposit, Avery Co., N.C. Electron micrograph of clay derived from plagioclase.

Arrowood Deposit, Buncombe Co., N.C. Electron micrograph of clay derived from a perthite crystal.

PLATE 1

CONCLUSIONS

Residual kaolin clays derived from pegmatites and granites in the Southern Appalachian region show a general increase in halloysite content to that of kaolinite southward from Virginia into North Carolina where a maximum of halloysite content is noted in the Spruce Pine district. Southward from the Spruce Pine district to the southern end of the Appalachian chain there is a decrease in the percentage of halloysite to kaolinite formed from weathering of the pegmatites and granites until at the southernmost deposit kaolinite predominates over halloysite. Kaolin clays derived from weathering of pegmatites in the Piedmont region of Georgia are predominantly kaolinite with minor amounts of halloysite. In the Piedmont provinces of Virginia and North Carolina kaolinite predominates over halloysite in the kaolin clays but there is an increase in the amount of halloysite westward to the highlands.

Halloysite was observed forming only from feldspars. Under intense conditions of leaching such as are prevalent in most of the Spruce Pine district, both plagioclase and potash feldspars weather to halloysite although the rate of weathering for the microcline is much slower. The morphology of the resulting halloysite is very much the same from both types of feldspar although in general the halloysite formed from the microcline tends to consist of long tubes and that from plagioclase of stubby tubes.

Where leaching is less intense, all of the plagioclase and most of the microcline alters to halloysite but some of the microcline alters to kaolinite through the intermediate stage of secondary mica. This is evidenced in the central region of the Blue Ridge province of western North Carolina and is common in the southern region although locally all the feldspar may alter to endellite. A further decrease in the intensity of leaching results in the alteration of plagioclase to halloysite and of all the microcline to secondary mica and then to kaolinite.

The final stage is where almost all the feldspar alters to secondary mica and eventually to vermicular kaolinite with minor amounts of halloysite being formed from a small part of the feldspar. This is the case in the Piedmont provinces although locally considerable halloysite may form if leaching conditions are favorable.

The vermicular kaolinite in the halloysite deposits usually is not present in size fractions below 2 microns and a relatively pure halloysite can be obtained by fractionation.

The nature of the clay end products resulting from weathering of granites and pegmatites in the Southern Appalachian region is believed to be a function of three main variables - mineral composition, climate, and topographic expression. The sequence of weathering of the minerals is sketched in Figure 31. pH measurements on all of the kaolin clays studied were all in the range 4.65 to 6.3 with the average pH 5.50. No correlation could be made between pH and kaolinite versus halloysite content.

Formation of halloysite from the weathering of feldspar appears to be a function of climate and topographic expression while the rate of formation depends on the type of feldspar, the degree of fracturing and texture of the rock. A granite with high quartz content is more susceptible to disintegration and chemical attack than a pegmatite. The physico-chemical environment favorable to the formation of halloysite includes water saturation, as shown by the stability fields in Figure 10, and solutions charged with humic and carbonic acids percolating through the fractured feldspar. The best expression for this environment is present in the Spruce Pine district where pegmatites and granites underlie river terraces covered with a capping of river gravels and thick vegetation. It is in this district where the highest percentage of endellite is found. Whether the 3-dimensional network of feldspar with its channels excercises any structural control leading to the formation of the tubular endellite crystals is unknown. Effective leaching from the feldspar of all its bases probably destroys the structure completely leaving colloidal silica and alumina. The reorganization of the gels into the relatively random and hydrated structure of endellite is the logical step under these environmental conditions. Where leaching of the potassium is not effected, secondary mica forms as the first alteration product and subsequently changes to vermicular kaolinite. Although acid conditions may be favorable, the degree of fracturing and drainage may inhibit rapid removal of the potassium in certain parts of the crystal resulting in simultaneous formation of endellite from feldspar and kaolinite from secondary mica. On the basis of pH measurements the secondary mica appears to be forming under acid conditions. There is no evidence of an alkaline environment. A two stage process involving first the formation of secondary mica under alkaline conditions and second the formation of endellite and kaolinite at a later time under acid conditions does not seem to fit the experimental data gathered in this study. Feldspars weathering to vermicular kaolinite through the intermediate stage of secondary mica, with minor amounts of endellite forming from the feldspar, are in an acid environment. It has been proposed that the vermicular kaolinite present in a matrix of halloysite may be formed by the reorganization of the halloysite. This is refuted by the fact that endellite, not halloysite, is always the variety present. This indicates that the environmental conditions are conducive to the formation of endellite and have not changed appreciably since Tertiary time.

No matter what the intensity of leaching, and even in those cases where all of the feldspar alters to endellite, the primary mica is observed to be always altering to vermicular kaolinite. Thus, in a completely weathered perthite crystal for example, patches of vermicular kaolinite derived from the disseminated mica books will occur in a matrix of endellite derived from the feldspar. This is an apparent anomaly which can be explained on the basis of chemical composition and structural control even though the environmental conditions are favorable for the formation of endellite.

The kaolinite books are pseudomorphous after the mica but show a parting perpendicular to the basal cleavage at intervals of 0.04 mm. or less. This corresponds with the median sizes of 0.02 to 0.04 mm. for the kaolinite in the size analyses. Once the feldspar is altered to secondary mica, even though subsequent conditions may be favorable for the formation of endellite, the compositional and structural control imposed by the mica will cause vermicular kaolinite to be the next weathering product. The decomposition of muscovite, $(OH)_2KAl_3Si_3O_{10}$, to kaolinite, $(OH)_8Al_4Si_4O_{10}$, can be regarded as essentially a simultaneous leaching of the potassium and corresponding addition of water. The 1:1 aluminum to silicon ratio in muscovite is the same as in kaolinite and a completely leached and hydrated muscovite has the same ratio of alumina, silica and water as kaolinite. Although muscovite is of the 2:1 structural type with an octahedral "gibbsite" layer interposed between two silica tetrahedral sheets, and kaolinite is of the 1:1 structural type with alternating silica tetrahedral and octahedral "gibbsite" sheets, the fact that both are extended sheet structures influences the formation of kaolinite from mica. The mechanism of the conversion from a 2:1 structure type to a 1:1 type involves migration of silicon and aluminum but how the rearrangement is accomplished is not evident. The presence of the proper proportion of alumina, silica and water in an altered muscovite to give kaolinite coupled with the similarity in sheet structures is believed to explain the alteration of mica to kaolinite even in the stability field of endellite.

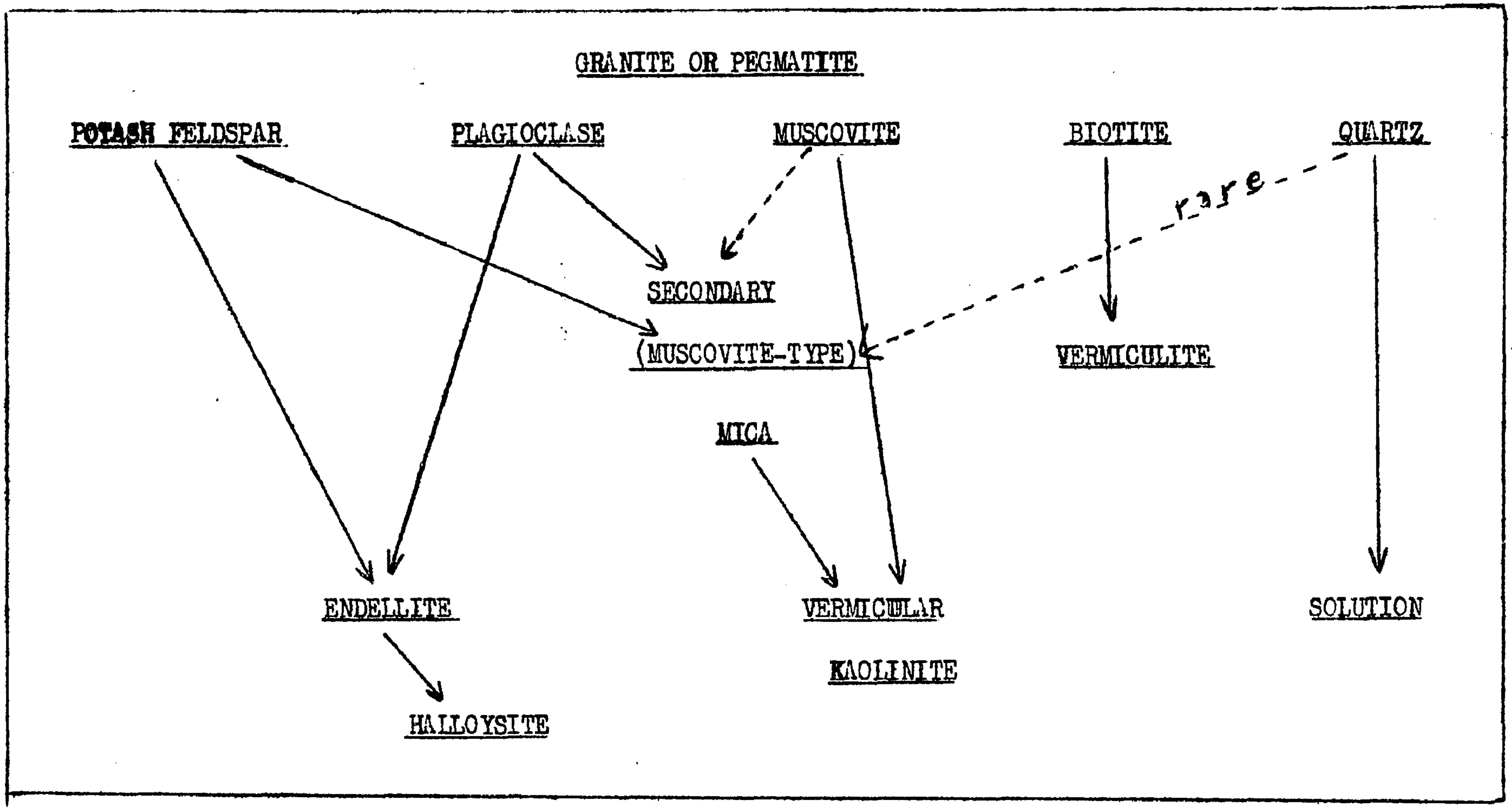


Fig. 31. Weathering sequence of minerals in a pegmatite or granite

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ACKNOWLEDGEMENT

I wish to express my appreciation to Dr. T. F. Bates, who suggested this study and made the equipment available, and also for his general direction of the research.

Advice was freely given by Dr. E. F. Osborn on the stability studies.

I wish to thank Dr. C. D. Jeffries of the Department of Agronomy for liberal use of the facilities in his laboratory for testing techniques on his apparatus and for making base-exchange capacity determinations. Mr. G. W. Kunze was of great help in making these determinations. Mr. R. M. Gruver kindly ran samples in his differential thermal analysis unit.

In the field work cooperation was kindly given by Elizabeth E. Keener and Silas V. Morefield, Amelia Court House, Virginia; Robert Taylor, Roseland, Virginia; C. E. Craven, Calco, and V. V. Kelsey, Dominion Minerals, Piney River, Virginia; W. D. Lee, Agronomy Department, North Carolina State College, Raleigh, North Carolina; C. E. Hunter and L. J. Hash, Regional Minerals Division, Tennessee Valley Authority, Asheville, North Carolina; S. W. Enloe, Jr. and Lee White, Harris Clay Co., Spruce Pine, North Carolina; Paul Henline, Spruce Pine Mining Co., Spruce Pine, North Carolina, and T. L. Kesler, Cartersville, Georgia.

The investigation was conducted as part of a research program sponsored by the geophysics branch of the Office of Naval Research.