RI bureau of mines
report of investigations 6429

# TITANIUM RESOURCES OF NELSON AND AMHERST COUNTIES, VA.

(In Two Parts)

## 2. Nelsonite

By George E. Fish, Jr., and Vernon F. Swanson

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

1964

# TITANIUM RESOURCES OF NELSON AND AMHERST COUNTIES, VA.

## (In Two Parts)

## 2. Nelsonite

By George E. Fish, Jr., and Vernon F. Swanson

* * * * * * * * * * * report of investigations 6429

MARCH 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director

**This publication has been cataloged as follows:**

Fish, George E

Titanium resources of Nelson and Amherst counties, Va. (in two parts) 2. Nelsonite, by George E. Fish, Jr., and Vernon F. Swanson. [Washington] U. S. Dept. of the Interior, Bureau of Mines [1964]

25 p. illus., tables. (U. S. Bureau of Mines. Report of investigations 6429)

1. Titanium–Virginia. 2. Nelsonite. I. Swanson, Vernon F., jt. auth. (Series)

TN23.U7 no. 6429 622.06173

U. S. Dept. of the Int. Library

# CONTENTS

# ILLUSTRATIONS

# TABLES

# TITANIUM RESOURCES OF NELSON AND AMHERST COUNTIES, VA.

## (In Two Parts)

## 2. Nelsonite

by

George E. Fish, Jr.[1] and Vernon F. Swanson[2]

## ABSTRACT

A study was made during 1959-60 of reported nelsonite occurrences in Nelson and Amherst Counties, Va. The investigation was limited to core drilling on one deposit and beneficiation studies on three deposits.

Three diamond-drill holes totaling 562 feet were drilled on the E. M. Hughes property to determine subsurface continuity. Although outcrops as much as 30 feet wide were present on this property, the only nelsonite intersected in the holes ranged from 4 to 18 inches thick. The ilmenite content of the core ranged from 50 to 75 percent.

These nelsonite deposits are of secondary importance as a source of titanium, being small, rarely exceeding 1,500 feet in length and 30 feet in width, but they are high grade. Due to the proximity of some of the bodies it might be possible to mine several of them as one operation feeding one mill.

Electromagnetic separation on composited samples recovered 83.0 percent of the $TiO_2$ as an ilmenite concentrate in 68.5 percent of the weight.

Two flotation procedures were developed. The first method, using oleic acid as a collector and fluosilicic acid as an apatite depressant on deslimed feed, produced an overall recovery of 59.3 percent in batch tests. The second procedure eliminated desliming. Laurylamine hydrochloride removed silicates in an acid pulp followed by an alkaline apatite flotation with oleic acid as the collector and dextrine as the ilmenite depressant. The ilmenite-rich tailing represented a 66.2-percent recovery of $TiO_2$ in the batch tests.

---

[1] Mine examination and exploration engineer, Office of Mineral Resources, Bureau of Mines, Region V, College Park, Md.

[2] Metallurgist, College Park Research Center, Bureau of Mines, Region V, College Park, Md.

---

Work on manuscript completed March 1963.

## INTRODUCTION

In accordance with two larger objectives, development of new sources of mineral supply and maintenance of mineral reserves and stocks of adequate levels, a comprehensive survey of the titanium resources of the United States was undertaken by the Bureau of Mines.

As a segment of a nationwide survey, titanium-bearing deposits in west-central Virginia were investigated during 1957 through 1960. The investigation was made in two parts. Part 1 was a study of ilmenite and rutile-bearing saprolite.[3] Part 2 was confined to high-grade though small nelsonite deposits and is the subject of this report. The work consisted of surface examination, sampling six deposits, core drilling one deposit, and beneficiation tests. The fieldwork was done from October 1959 to February 1960.

## ACKNOWLEDGMENTS

Acknowledgments are made to the property owners in the Nelson County area who provided access to the land and buildings for both Bureau of Mines personnel and equipment and unlimited cooperation during investigation.

## LOCATION AND ACCESSIBILITY

The Roseland Anorthosite-Titanium Belt of Nelson and Amherst Counties is located east of the Blue Ridge Mountains and midway between Lynchburg and Charlottesville, Va. It lies in the northwestern portion of the Piedmont physiographic province. The anorthosite body, average elevation 900 feet, is within 7 to 10 miles of the Blue Ridge Mountains, which have peak elevations of as much as 4,000 feet. The belt is about 16 miles long, with a maximum width of 3 miles (fig. 1).

A good system of primary and secondary highways serves the area. State Highway 151 bisects the area northeast to southwest. U.S. Highway 29 is parallel to the district 4 miles to the east and is connected to Route 151 near Piney River by State Route 158.

The Virginia Blue Ridge Railroad, with a station at Piney River, serves the anorthosite area and connects with the main line of the Southern Railway at Tye River station, 5 miles southeast of that area. The Southern Railway is also easily accessible by highway to stations at Amherst, Arrington, and Shipman.

Electric power is supplied by The Appalachian Power Co. and the Central Virginia Electric Cooperative. Telephone service is provided by the Chesapeake and Potomac Telephone Co. of Virginia, a member of the Bell System.

---

[3] Fish, George E., Jr. Titanium Resources of Nelson and Amherst Counties, Va. (In Two Parts). 1. Saprolite Ores. BuMines Rept. of Inv. 6094, 1962, 44 pp.

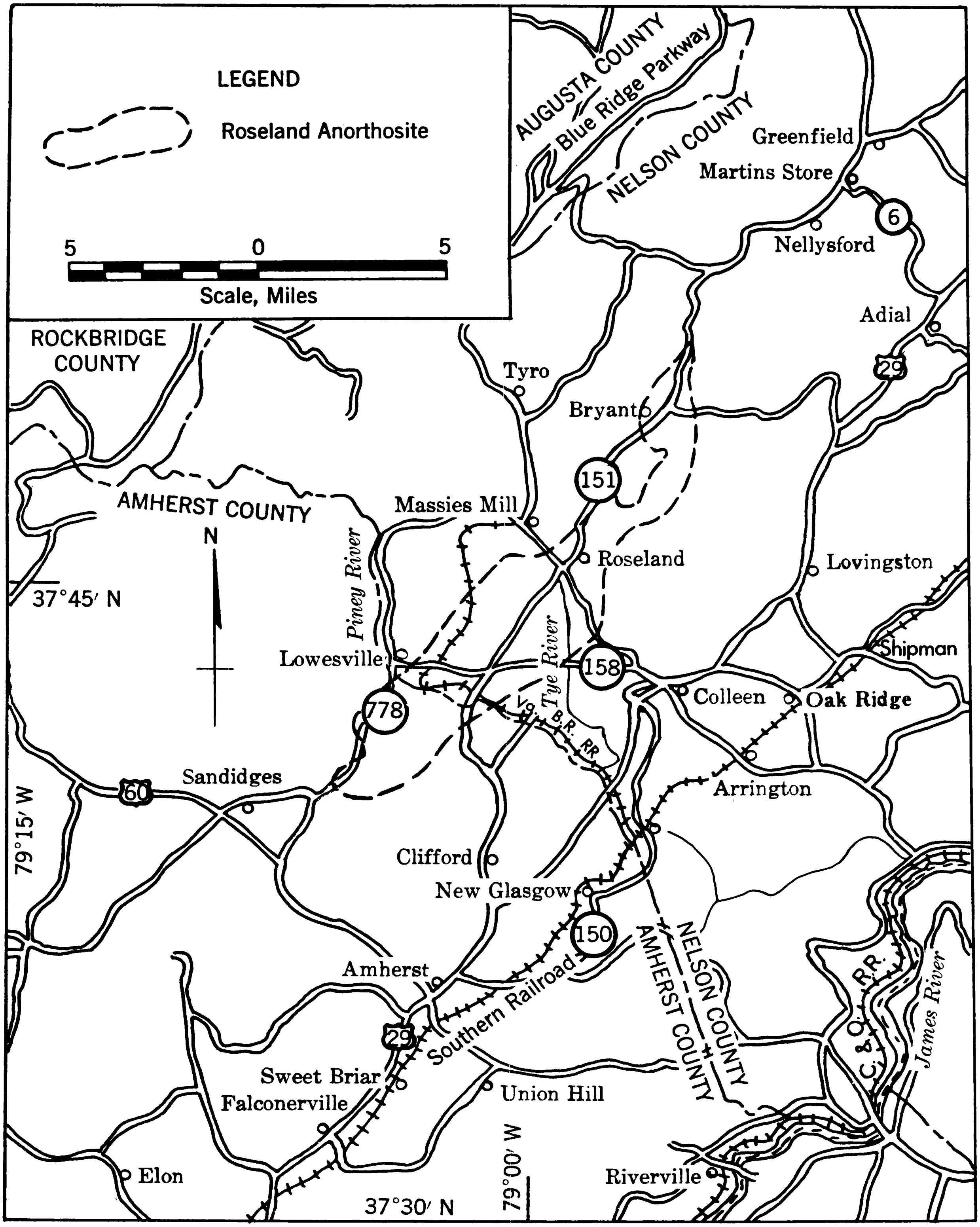


FIGURE 1. - Location of the Roseland Anorthosite.

## PHYSICAL FEATURES AND CLIMATE

The portion of Nelson and Amherst Counties underlain by the Roseland anorthosite is an area of rolling topography of generally low relief. Mars Knob near Bryant, which rises to 1,380 feet, is the only exception.

A large portion of the area is under cultivation, while most of the remainder is covered by second-growth timber. Most of the timber cut is pulpwood used in the manufacture of paper; however, a large quantity is processed into lumber for use by the furniture and building industries.

A white residual soil derived from the decomposition of feldspar covers the central portion of the anorthosite, and the soil near the contact with the gneissic country rock is red.

Water for domestic uses is readily obtainable from wells, and the Tye and Piney Rivers are sources of water for industry. The Tye and Piney Rivers drain the area and join to flow southeastward to the James River, 15 miles away.

The average annual precipitation in the area is about 43 inches, and the average relative humidity is 79 percent in the daytime and 68 percent at night. The average temperature for January is 37.4° F and for July is 76.6° F.[4]

## HISTORY

According to Watson and Taber,[5] the first recorded activity in the Titanium Belt was in 1878 when the Philadelphia and Reading Coal and Iron Co. purchased the surface and mineral rights to the Warwick property on the Piney River and the mineral rights on the Blue Rock farm near Jonesboro, which the company intended to use for the production of iron. A shaft was sunk on the Warwick tract but was soon abandoned. In 1886 the properties were transferred to the Reading Iron Co., but no further work was done until attention was drawn to the phosphate content of the nelsonites.

In 1889 The Virginia Mining and Manufacturing Co. acquired the mineral rights to several properties along Hat Creek near Bryant from which the company intended to mine nelsonite as a source of phosphate. The company soon failed, and the mineral rights were returned to the property owners by court action.

In 1894 the Virginia Phosphate and Paint Corp. purchased the Giles tract near Roseland and the Quinn property near Rose Mill. Both properties were prospected by pits, trenches, and shafts. The company planned to separate the apatite for use in fertilizer and the ilmenite for the production of pigments, but no commercial-scale operations were conducted.

---

[4] U.S. Weather Bureau. Climatological Data, Virginia. Annual Summary, 1954. V. 64, No. 13, pp. 165, 167.

[5] Watson, T. L., and Steven Taber. Geology of the Titanium and Apatite Deposits of Virginia. Virginia Geol. Survey Bull. III-A, 1913, pp. 48-50.

The General Electric Co. began development of a rutile-bearing nelsonite on the Warwick tract in 1907. The ore was shipped to Allentown, Pa., for concentrating. In 1910 this company leased and operated the American Rutile Co. mine and mill for part of the year.

Most of the mineral rights for properties that contain nelsonite deposits are owned today by the American Cyanamid Co. and National Lead Co. No further development of the nelsonites has been made to date.

## AREAL GEOLOGY

The Titanium Belt is an area of Precambrian crystalline rocks that have been intensely although not equally metamorphosed. The Roseland anorthosite is elongated to the northeast, parallel to the regional structure, which strikes approximately N 60° E. It is the host rock of most of the nelsonite deposits. This anorthosite formation covers an area of about 35 square miles commencing 6 miles north of Amherst in Amherst County and extending to a point 2.5 miles northeast of Bryant in Nelson County (fig. 1) where it fingers out in a series of dikelike intrusions into the gneissic country rock.

The central portion of the anorthosite is composed of nearly pure feldspar with some blue, rutilated quartz. Ferromagnesian minerals, in lenses ranging in length from less than 1 inch to 5 or 6 inches, are found in profusion at some localities along the border zone of the anorthosite. Feldspars that were originally coarse grained have been granulated owing to regional metamorphism. Only small isolated occurrences of titanium minerals are present in the feldspathic core, while the border zone near the contact contains most of the important deposits. Numerous quartz veins and dikes rich in ferromagnesian minerals cut the formation throughout.

The surrounding country rock is designated as the Lovingston granite gneiss on the Geologic Map of Virginia.[6] It contains much biotite and ranges in structure from faintly banded to schistose. The gneiss is cut by numerous acidic and basic dikes. Contact between the gneiss and anorthosite is not sharp; rather it is gradational, and the mapped contacts are approximate in many instances. This gradational contact is usually represented by an injection gneiss as seen in exposures in road cuts near Rose Mill in Nelson County.

The anorthosite area is covered with a thick layer of saprolite which almost completely obscures the geologic features. Rock outcrops are primarily found along the major streams and in mines and quarries. Nelsonite is usually present in ridges because it is more resistant to weathering than the host rock.

## CHARACTER OF THE ORE

The name "nelsonite" was proposed by Watson[7] for dikelike bodies in the area essentially composed of ilmenite and apatite, the name being derived from

---

[6] State Conservation and Development Commission, Virginia Geological Survey. Geologic Map of Virginia. 1928.

[7] Page 100 of work cited in footnote 5.

Nelson County where the rock was first identified. Later the name was to include also rocks of a similar nature where apatite, magnetite, hornblende, biotite, or rutile were primary constituents instead of ilmenite.

Nelsonite is a dark rock with an even-granular texture composed of apatite with ilmenite or rutile or both, and occasionally magnetite. Apatite is usually the subordinate constituent, although the ratio of titanium mineral to apatite varies greatly. Analyses range as high as 70 percent ilmenite and 25 percent apatite with minor amounts of accessory minerals. Hornblende or biotite may or may not be present, but pyrite is an almost constant minor mineral.

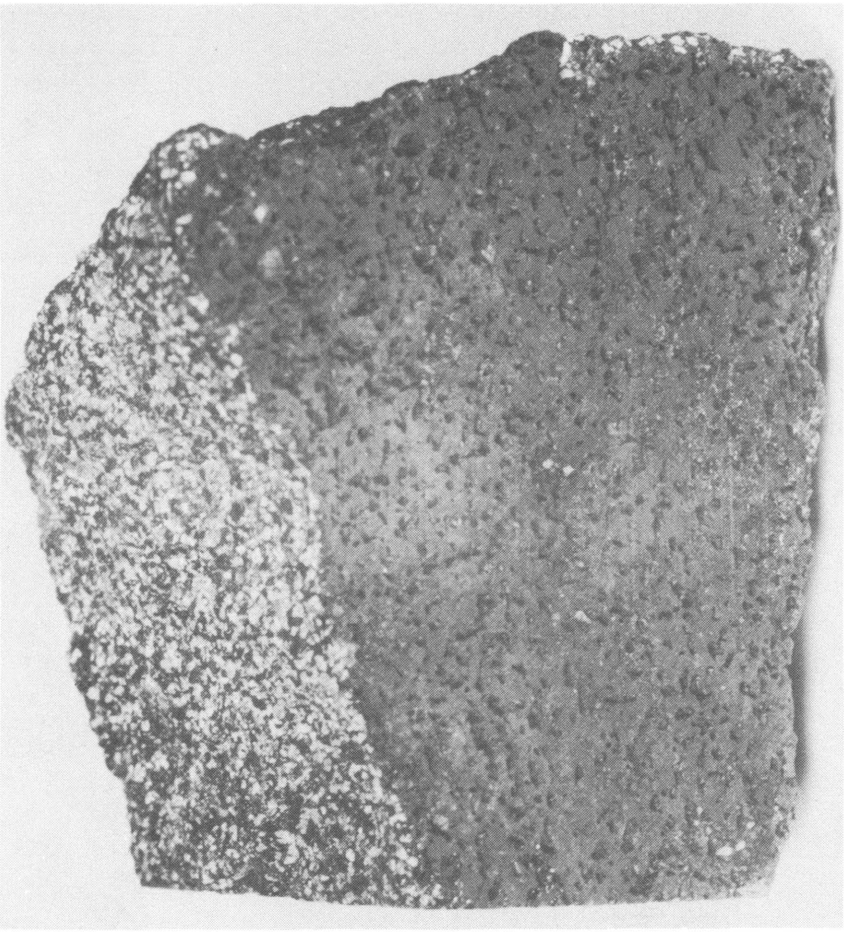


FIGURE 2. - Specimen of Ilmenite Nelsonite Float Showing Pitted Surface Due to Leaching of Apatite.

Ilmenite nelsonite is the most prevalent type found in the area. It usually occurs near the border of the anorthosite, although it also occurs in the gneissic country rock near the contact with anorthosite. The few occurrences of rutile nelsonite are confined to the anorthosite.

The nelsonites cut across the formations and are tabular in shape but in some instances are very irregular and lenticular. They have been traced along strike for as much as 1,500 feet, but most commonly they are only 200 to 300 feet long, ranging in width from a few inches to 50 feet.

Since the nelsonite is highly resistant to weathering, abundant float material is present over the deposits. Nelsonite float is present in large pieces weighing up to 10 or 15 pounds. This material is commonly very dark and has a pitted surface (fig. 2) because the apatite has been leached out, leaving only the more resistant titanium minerals. When it is unweathered, ilmenite nelsonite has a black and white spotted appearance (fig. 3). The apatite grains are rounded, while the ilmenite appears to be massive on a polished surface.

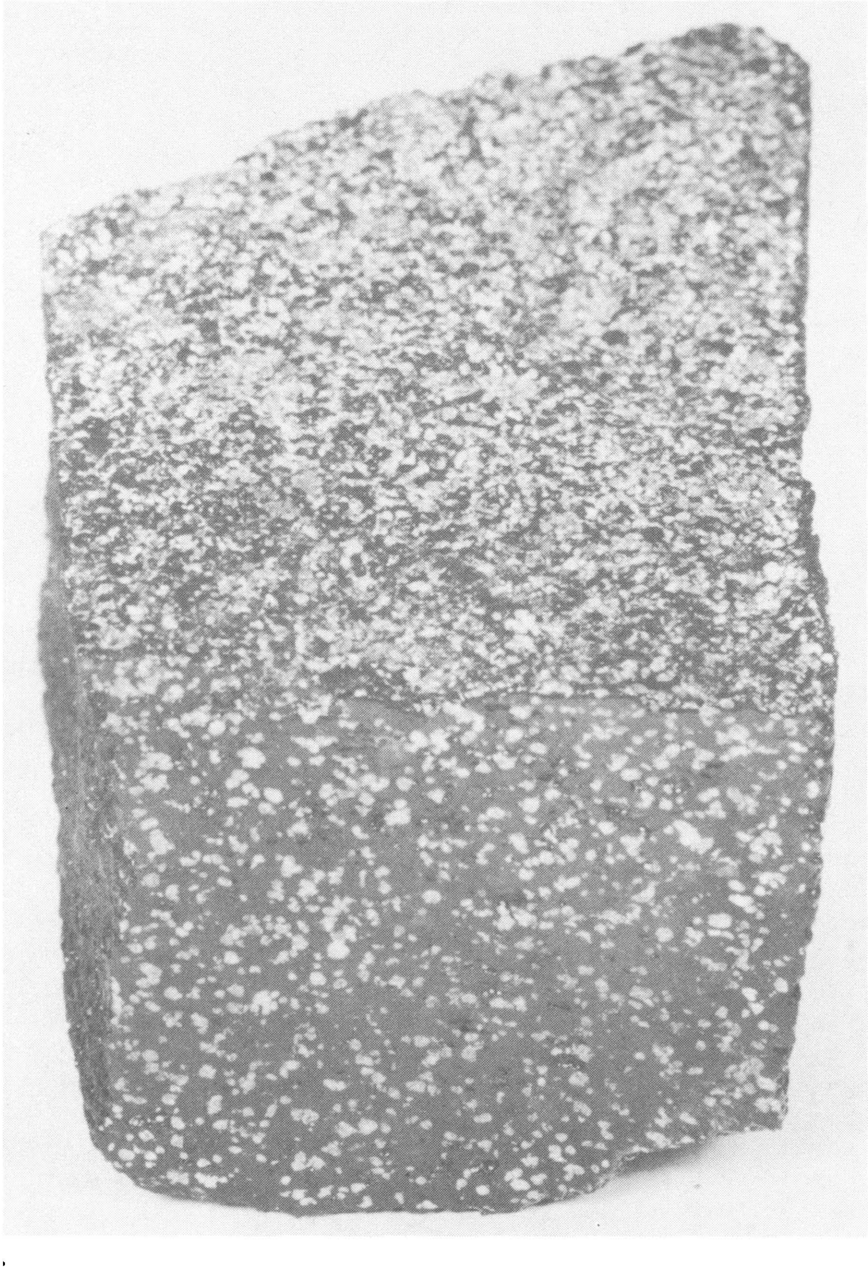


FIGURE 3. - Polished and Unpolished Surface of Ilmenite Nelsonite Exhibiting Black and White Spotted Appearance on Fresh Surface.

Rutile nelsonite commonly has the same appearance as the ilmenite variety, although it is dark reddish brown. Figure 4 shows a polished surface of this material that is composed of almost solid rutile with scattered ilmenite grains on the left end grading to a typical nelsonite appearance on the other end.

Some of the ilmenite is nonmagnetic, while some contains minute intergrowths of magnetite which impart magnetic properties to the mineral.

## INVESTIGATION

A reconnaissance of 20 titanium-bearing mineral deposits in or associated with the Roseland anorthosite was made. The deposits included both nelsonite dikes and disseminated titanium minerals in anorthosite and diorite. Figure 5 shows the locations of the nelsonite dikes.

Samples of nelsonite float material and core from one old drill hole were obtained, and beneficiation studies were made in a Bureau laboratory.

### Fieldwork

The preliminary work on the nelsonite dikes consisted of mapping old workings and of surface sampling the most prominent deposits. This fieldwork was conducted from October 1959 to February 1960.

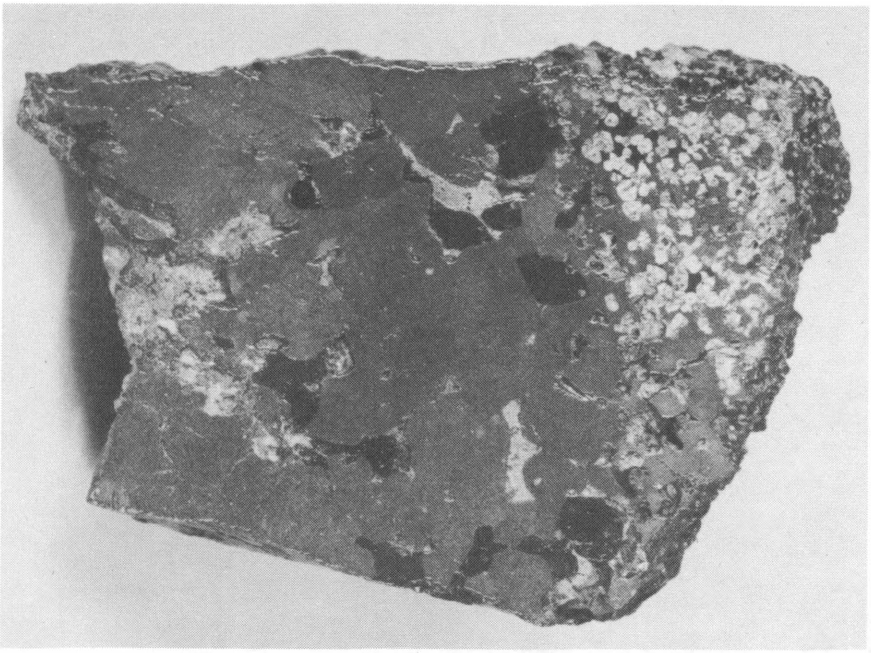


FIGURE 4. - Specimen of Rutile Nelsonite. Gray is rutile, white is apatite, black is ilmenite, some blue quartz is evident in mottled area to the left.

Of the total deposits investigated, six deposits are described in detail in the following sections of the report. One of these deposits, E. M. Hughes, was selected for more detailed studies than the others. Three diamond-drill holes were drilled on this property; they totaled 562 feet over a horizontal distance of 1,400 feet.

## E. M. Hughes Deposit

The Hughes property is 1/2 mile southeast of Jonesboro between Hat Creek and State Route 151 (fig. 6). The surface rights are owned by E. M. Hughes of Roseland. Mineral rights on the property are part of a large parcel known as the Blue Rock farm owned by the American Cyanamid Co.

Three nelsonite outcrops and float zones are present on this property. They are the surface expression of three dikes that occur en echelon striking N 60° E parallel to the regional strike of the formations and dipping steeply to the southeast. The nelsonite contains from 60 to 70 percent ilmenite. Outcrops are banded with alternate layers that are mostly ilmenite and layers that are predominantly apatite which are parallel to the strike of the dike.

Three BX-AX diamond-drill holes (fig. 7) were drilled from sites at two outcrop and float zones. Hole BR-1 was drilled on a bearing of N 30° W at an angle of minus 45° to intersect the nelsonite below the zone of weathering. Saprolite extended to a hole depth of 150 feet. The only nelsonite intersected was at a hole depth of 79 feet and was only 4 inches thick. Saprolite cut during the drilling was alternate layers of kaolin and red clay derived from the decomposition of anorthosite containing ferromagnesian lenses. Drilling was stopped in this mafic facies of the anorthosite at a hole depth of 250 feet. Only traces of titanium mineralization were found in the saprolite and unweathered anorthosite.

Hole BR-2 was drilled vertically from a site 120 feet northwest of BR-1. The hole intersected completely decomposed nelsonite to a depth of 28.5 feet, where it passed into decomposed anorthosite barren of titanium minerals. It was bottomed at a depth of 112.0 feet in the same material.

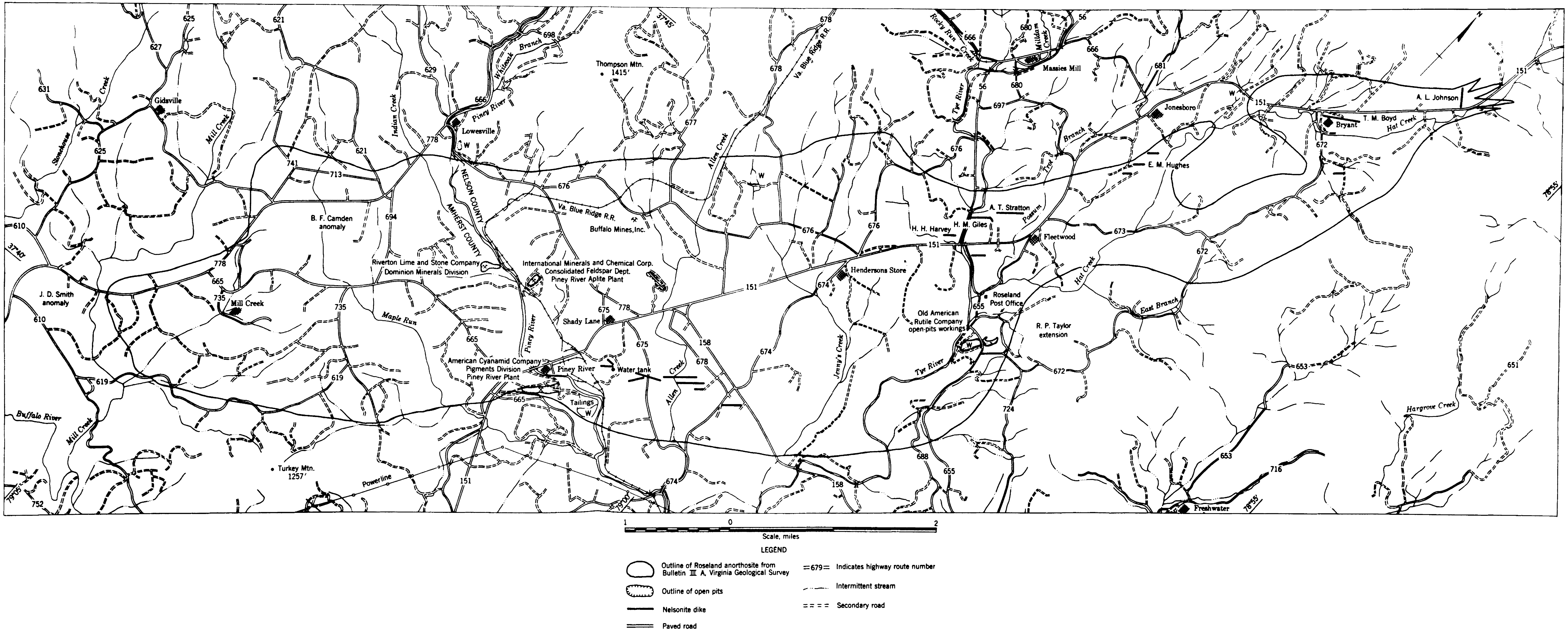


FIGURE 5. - Major Nelsonite Dikes in Roseland Anorthosite (From Bull. III-A, Va. Geol. Survey).

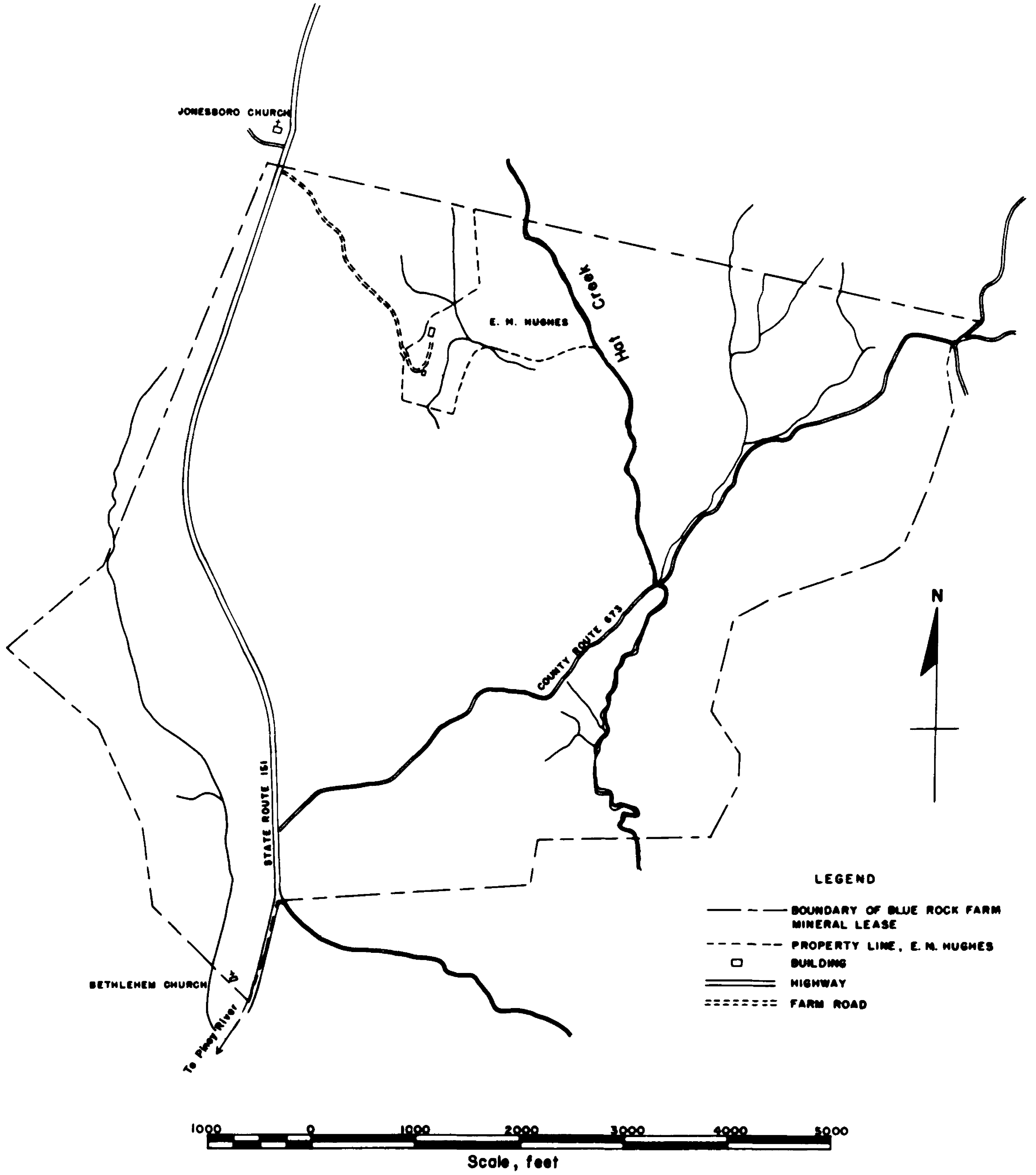


FIGURE 6. - Surface Map of Blue Rock Farm Mineral Rights, With Outline of E. M. Hughes Property.

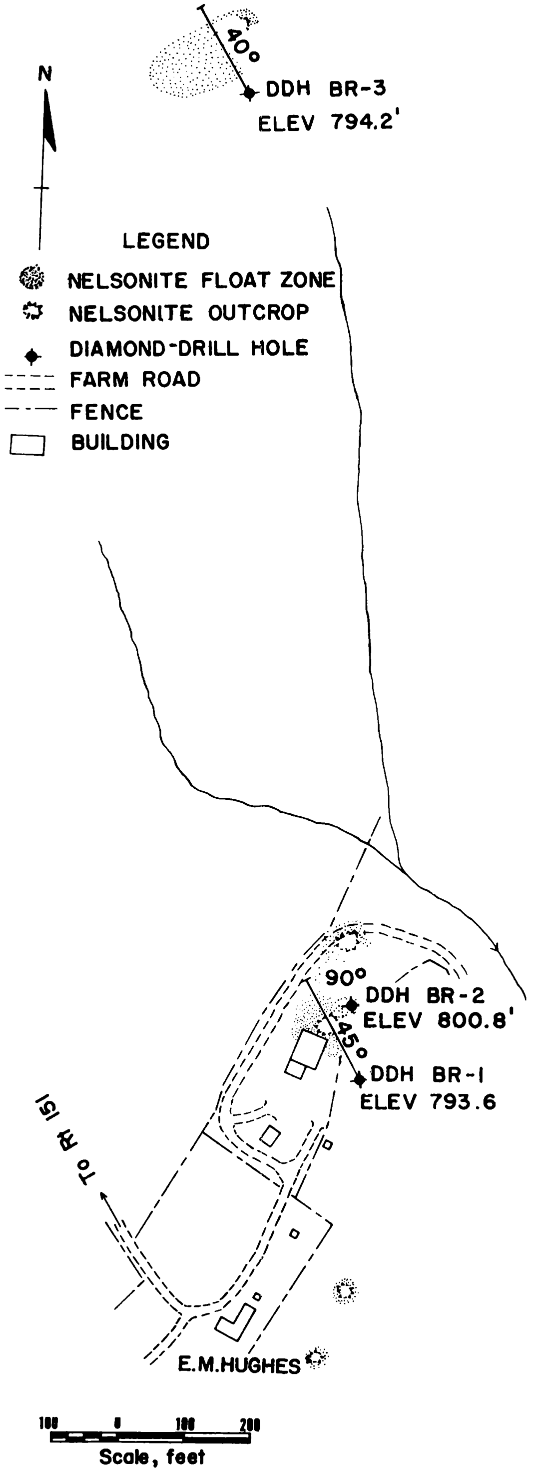


FIGURE 7. - Surface Map of E. M. Hughes Property, With Drill Hole Locations, Nelsonite Outcrops, and Float Zones.

This nelsonite is evidently lenticular and pinches out with depth. No evidence was found that an abrupt change in dip occurs.

Hole BR-3 was drilled on a bearing of N 30° W at an angle of minus 40° from a site about 1,400 feet northwest of BR-2. At this location there is one outcrop of nelsonite striking N 60° E and dipping steeply to the southeast, partly surrounded by a large float zone elongated in the same direction as the strike. One dike only 18 inches thick, with barren, decomposed anorthosite above and below, was intersected at a hole depth of 85 feet. The hole was bottomed in partially decomposed anorthosite at a hole depth of 200 feet. This nelsonite dike pinches out with depth as does the first dike drilled.

The ilmenite in the dikes on this property ranges from 60 percent to about 70 percent. Some of the ilmenite has altered to leucoxene.

## T. M. Boyd Deposit

The Boyd property is 0.2 mile northeast of Bryant on the east side of State Route 151 just north of the intersection of County Highway 672 (fig. 5). Surface rights are owned by T. M. Boyd of Bryant, and mineral rights are owned by the American Cyanamid Co. A large ilmenite nelsonite dike, striking N 59° E with a near vertical dip, is present on the property and can be traced by old prospect pits, trenches, widely scattered outcrops, and float material (fig. 8) for a strike distance of 1,500 feet. It is difficult to determine the width of the dike because all the old workings are completely caved, but in places it is probably as much as 25 feet wide. One vertical shaft had been sunk on the dike to a reported depth of 50 feet. This shaft is now badly caved and filled with rubbish, but the walls that are visible are composed of nelsonite containing 60 percent ilmenite

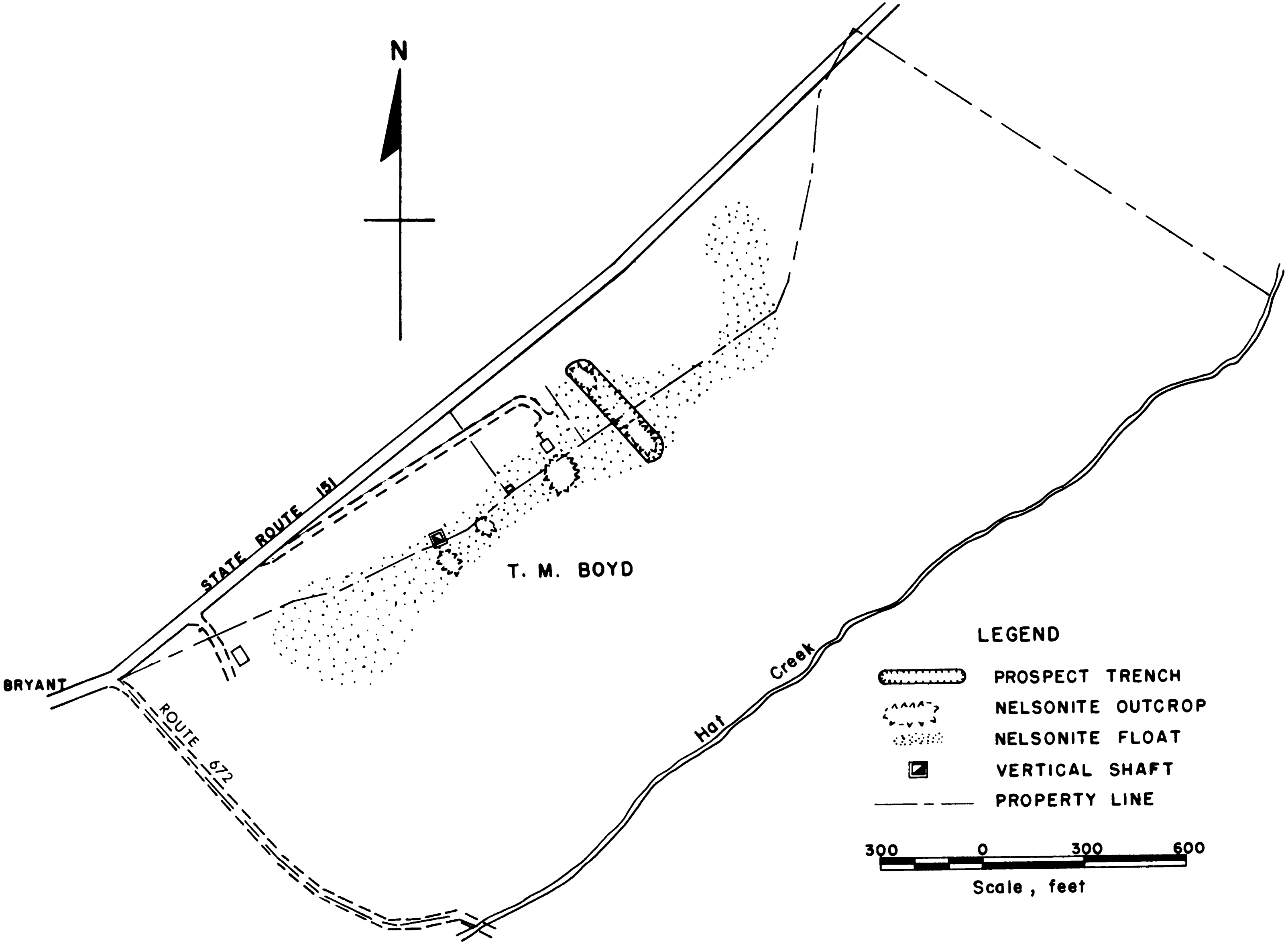


FIGURE 8. - Surface Map of T. M. Boyd Property, With Prospect Workings, Nelsonite Outcrops, and Float Zone.

by visual estimation. Assuming that (1) the dike is continuous over the full 1,500 feet of traceable length, (2) the average width is 10 feet, and (3) the depth is 50 feet, and using a tonnage factor of 253 pounds per cubic foot, the deposit contains a conservatively estimated 95,000 tons of ore averaging approximately 60 percent ilmenite, or 29,000 tons of titanium dioxide. This is one of the most prominent nelsonite dikes in the area, but no agreement could be made with the surface owner for more detailed investigations.

## J. D. Johnson Deposit

The Johnson property is 1.5 miles northeast of Bryant and west of State Route 151. Surface rights are owned by J. D. Johnson of Bryant. Mineral rights were bought by C. K. Leeth in 1933, transferred to the Burgess Titanium Co., and are now owned by the Sherwin Williams Co.

Several old prospect trenches, pits, and drill holes have penetrated a nelsonite dike (fig. 9) that strikes N 80° W and dips 57° to the north. It extends for about 700 feet along strike, averages 40 feet in width, and exceeds 100 feet in depth. Titanium dioxide in samples taken from the surface range from 20.2 percent to 39.1 percent, while fresh samples of diamond-drill core, obtained from the property owner, range from 21.3 percent to 23.6 percent. Phosphorous pentoxide in the core ranges from 6.6 percent to 9.5 percent. Grain counts were made on a composite sample consisting of 128 feet of AX-size drill core. They indicate a mineral composition of 65.5 percent opaque mineral which is mostly ilmenite with some magnetite and traces of pyrite, 15.6 percent apatite, 9.5 percent pyroxene, amphibole, and other associated ferromagnesian minerals, and 9.4 percent others (quartz, feldspar, mica, and some sphene-leucoxene). Chemical analysis of the sample showed a titanium dioxide content of 25.1 percent. All analyses were made by the Bureau of Mines. Ore-dressing studies were made on a portion of the same sample, and the results are presented in the section on beneficiation.

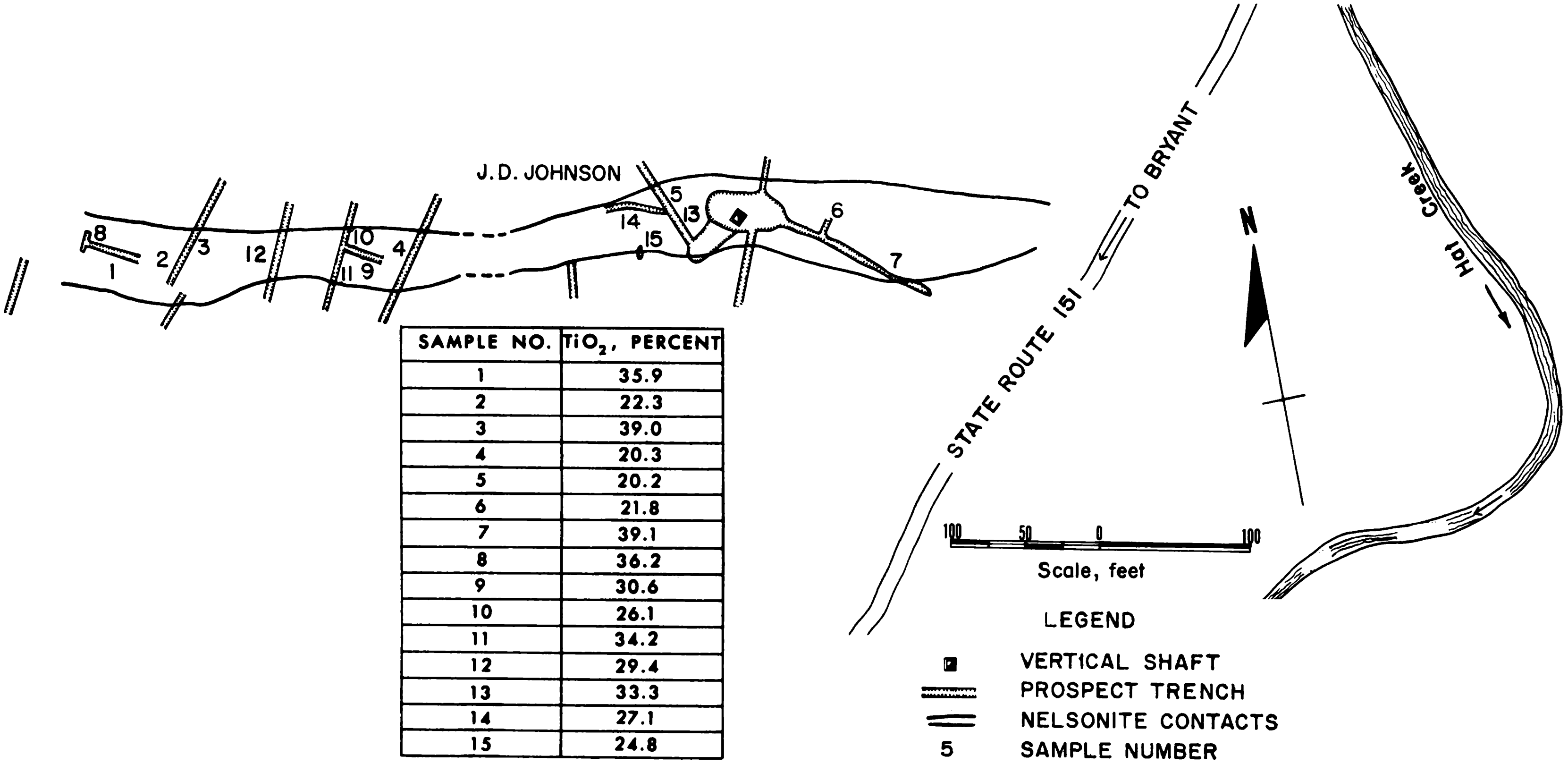
Analyses of the surface samples are tabulated in figure 9.

## A. T. Stratton Deposit

The Stratton property is 1 mile northwest of Roseland on the west side of State Route 151 (fig. 10). It is on a low ridge about 1,000 feet from the highway. The surface is owned by A. T. Stratton of Roseland, and the mineral is owned by the National Lead Co., New York, N.Y.

Old workings on the property consist of one open cut and a series of small trenches and pits (fig. 11). Some of the trenches trend N 35° W and the remainder N 50° W. The dike strikes N 55° E with a near vertical dip and can be traced for 800 feet along strike. One trench at the top of the ridge exposes the dike for a width of 25 feet; the dike here averages 60 percent ilmenite. All but this trench have been filled. No outcrops were observed, but abundant nelsonite float litters the surface.

One open cut is present at the southwestern end of the dike; the cut is about 35 feet deep and 100 feet long. It was completely caved, but a photograph



| SAMPLE NO. | $TiO_2$, PERCENT |
|---|---|
| 1 | 35.9 |
| 2 | 22.3 |
| 3 | 39.0 |
| 4 | 20.3 |
| 5 | 20.2 |
| 6 | 21.8 |
| 7 | 39.1 |
| 8 | 36.2 |
| 9 | 30.6 |
| 10 | 26.1 |
| 11 | 34.2 |
| 12 | 29.4 |
| 13 | 33.3 |
| 14 | 27.1 |
| 15 | 24.8 |

FIGURE 9. - Surface Map of J. D. Johnson Property, With Prospect Workings, Nelsonite Contacts, and Analyses of Surface Samples.

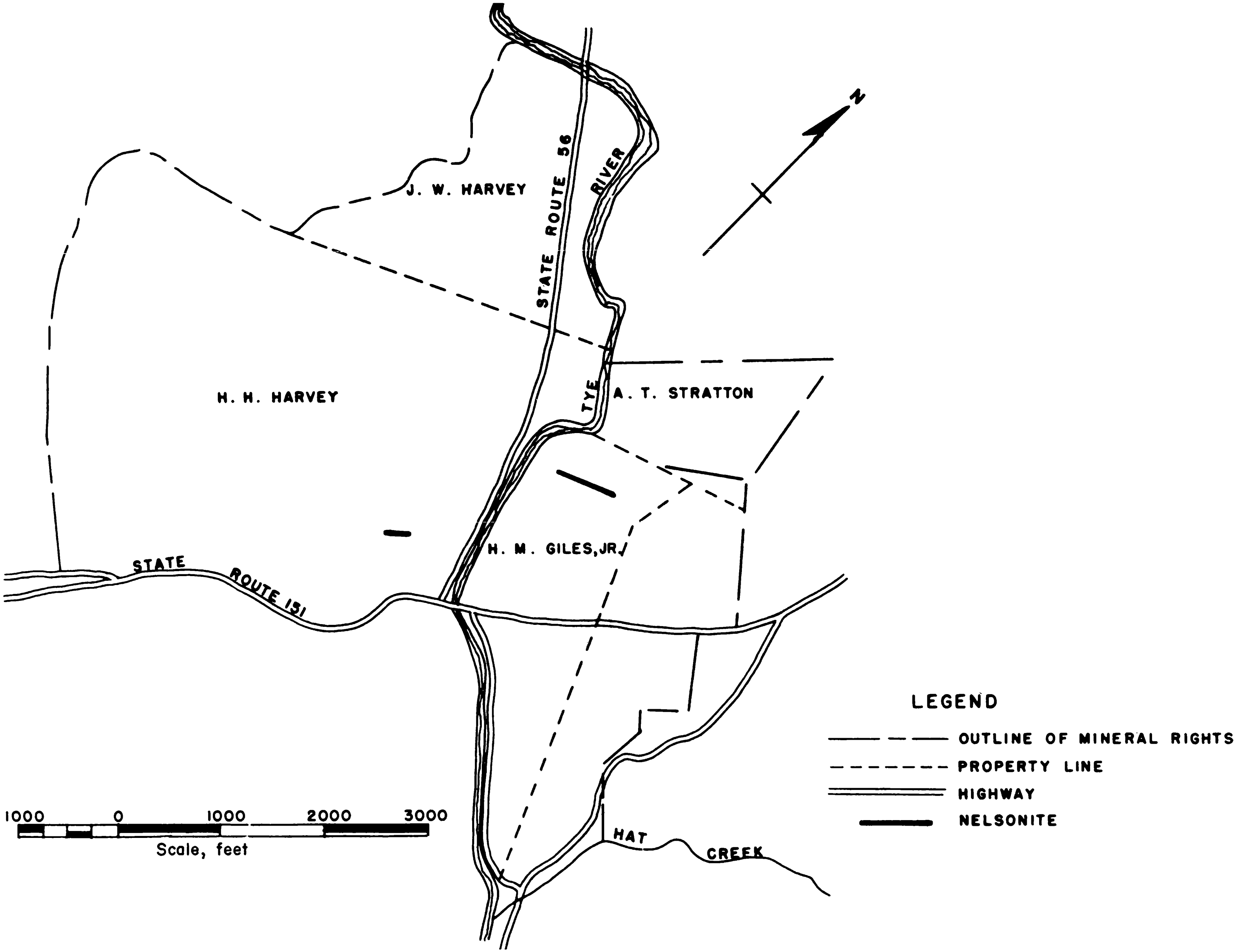


FIGURE 10. - Surface Map of Mineral Rights Along Tye River.

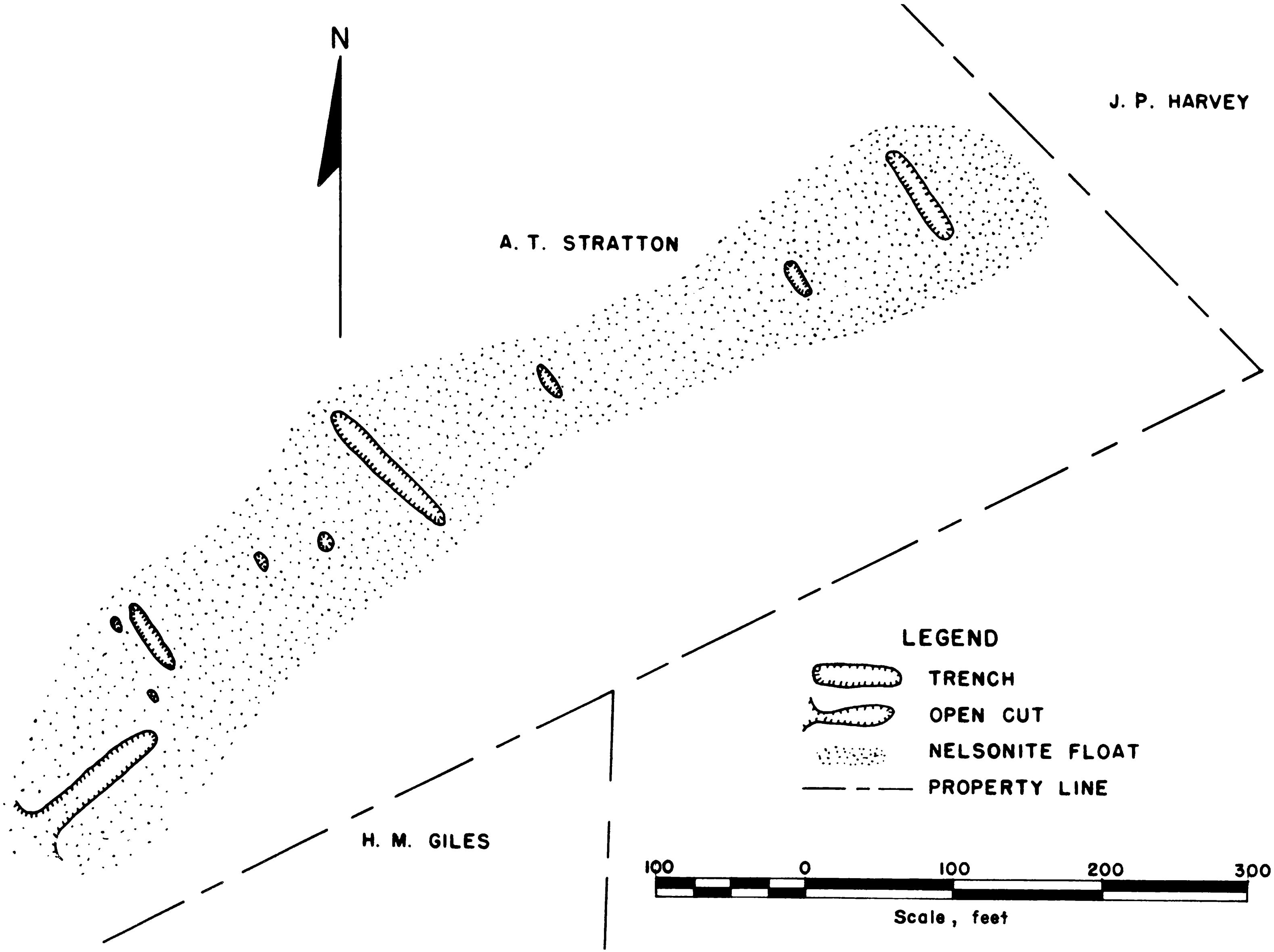


FIGURE 11. - Surface Map of A. T. Stratton Property, With Prospect Workings and Nelsonite-Float Zone.

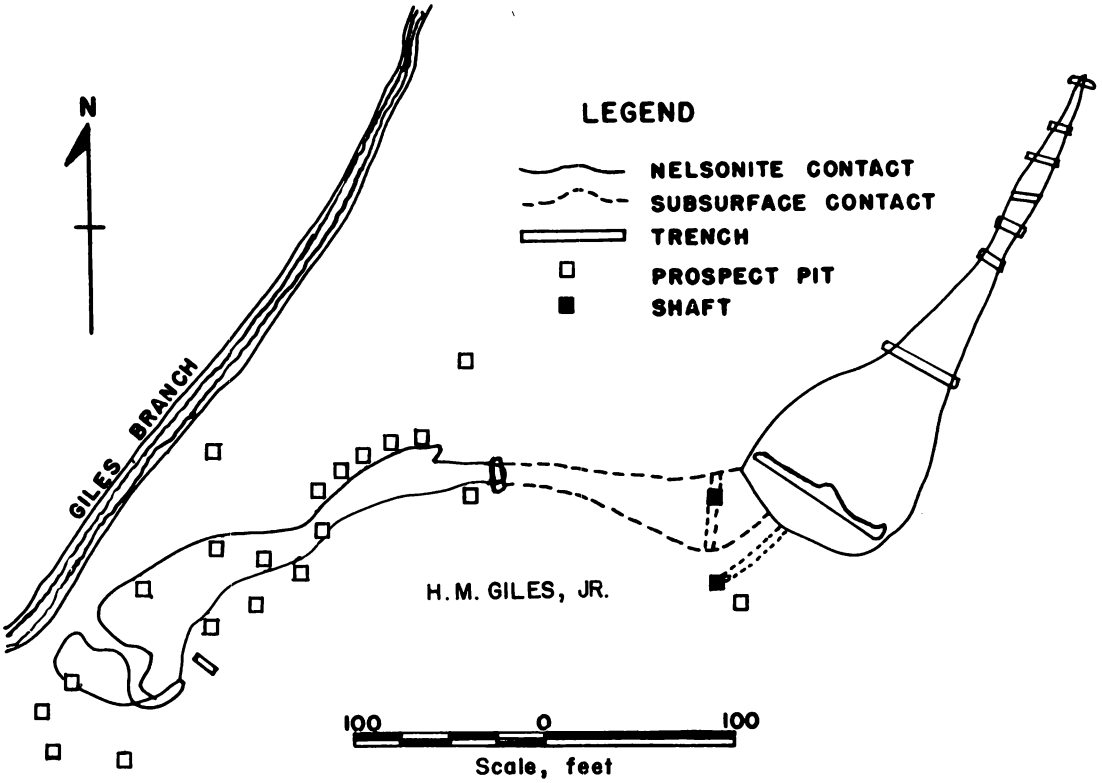


FIGURE 12. - Surface Map of H. M. Giles, Jr., Property, With Prospect Workings and Nelsonite Contacts. (From Bull. III-A, Va. Geol. Survey.)

presented by Watson and Taber[8] that was taken in the cut when the dike was exposed indicates a width of 8 feet near the surface with a near vertical dip and pinching out at a depth of about 20 feet.

Samples of nelsonite float were taken for ore-dressing studies, and the results are presented in the section on beneficiation.

## H. M. Giles, Jr., Deposit

The surface of the Giles property is owned by H. M. Giles, Jr., of Roseland, and the mineral rights are owned by the National Lead Co. (fig. 10). It is 1 mile northwest of Roseland, east of the Tye River and just south of the Stratton property. The deposit has been penetrated by a series of trenches, small pits, shafts and some drilling (fig. 12). All of these old workings are filled, but much ilmenite nelsonite float litters the surface. The nelsonite averages 60 to 70 percent ilmenite by visual estimate and exhibits the typical nelsonite characteristics. This body is lenticular in shape and very irregular in surface outline (fig. 12). No mining has been done on a commercial scale.

---

[8] Page 116 of work cited in footnote 5.

A rutile nelsonite dike is situated on the same property, 0.6 mile northwest of Roseland and 600 feet east of the junction of State Highway 151 and County Highway 655. It is of very limited extent, but analyses indicate 65 percent titanium dioxide with 8 percent phosphorous pentoxide. The American Rutile Co. removed most of the material, and all that remains is a small amount of float.

### General Electric Deposit

The General Electric deposit is 1,700 feet southeast of Piney River Post Office and 3,500 feet northeast of where State Highway 151 crosses the river. The mine is located on the tract of land that is now the site of the American Cyanamid Co., Pigments Division, plant.

Two nelsonite dikes, one striking N 71° E and the other east-west, dipping 50° southeast and 50° south respectively, were exploited to a depth of 100 feet by one vertical shaft, an inclined shaft, and an adit from which several hundred feet of drifts were driven. This work was carried out by the General Electric Co. in 1907.

The nelsonites vary in width from a fraction of an inch to 5 feet. They consist of both the ilmenite and rutile varieties, with the former being predominant. Over a very short distance, the ore changes from the ilmenite variety to the rutile variety and back again.

In some cases blue, rutilated quartz becomes a prominent part of the rutile nelsonite. The rutile nelsonite sometimes has a banded appearance, grading from almost pure apatite to pure rutile or from pure rutile to a normal rutile nelsonite. As in other nelsonites, pyrite is a minor constituent of the rock along with some biotite and graphite. Detailed descriptions of the old mine workings and nelsonite occurrences within the mine are presented by Watson and Taber.[9]

At the present time all the workings are inaccessible. Some old dumps and nelsonite float are the only remaining evidence of the deposit.

## Beneficiation Studies

The objective of the beneficiation work, conducted by the Bureau at the College Park (Md.) Research Center, was to obtain an ilmenite concentrate containing less than 0.1 percent $P_2O_5$[10] for potential use in pigment production. The titanium content was not given a minimum limit because subsequent studies indicated that variable amounts of magnetite-ilmenite intergrowth affected the maximum obtainable grade, which ranged from 31.0 percent to 53.4 percent $TiO_2$.

### Description of Beneficiation Samples

Three sample lots were used in the beneficiation studies, representing characteristics of three different properties. The samples are described in table 1.

---

[9] Pages 173 to 193 of work cited in footnote 5.

[10] Milliken, F. R. Metallurgy of National Lead Co., MacIntyre Development. Trans. AIME, v. 183, 1949, p. 108.

TABLE 1. - Beneficiation sample analyses

| Sample | Type of material | Property of origin | Percent | |
|---|---|---|---|---|
| | | | $TiO_2$ | $P_2O_5$ |
| 1................ | Float........... | T. M. Boyd........ | 36.2 | 6.8 |
| 2................ | Drill core...... | J. D. Johnson..... | 25.1 | 8.11 |
| 3................ | Float........... | A. T. Stratton.... | 38.9 | 5.0 |

## Flotation Studies

As apatite was the minor constituent of the ore, the first flotation tests attempted to float it from the ore, leaving the ilmenite as an enriched tailing. A typical test on sample 1 involved grinding a portion of the sample in a steel ball mill to minus 65-mesh and conditioning the sample in a flotation cell for 10 minutes, using 8.0 pounds NaOH to give a pH of 10.6, 1.9 pounds caustic starch to depress the ilmenite,[11] and 1.0 pound oleic acid per ton of feed to float the apatite. The resulting enriched tailing analyzed 43.8 percent $TiO_2$ and 3.52 percent $P_2O_5$. Total $TiO_2$ recovery in the tailing was 87.6 percent. The apatite concentrate after two cleaners assayed 4.76 percent $TiO_2$ and 19.8 percent $P_2O_5$.

Apatite flotation did not satisfactorily separate the ilmenite and apatite; therefore, it was necessary to attempt flotation of ilmenite, using depressants to prevent the flotation of the apatite. Various preliminary tests indicated that the flotation feed had to be deslimed before attempting flotation of the ilmenite. The following test was typical of an ilmenite flotation.

Sample 3 provided the feed for the second test. The sample was ground to minus 65-mesh in a ball mill and then deslimed by screening on 325-mesh. The oversize was conditioned for 5 minutes with 0.58 pound of ammonium fluosilicate $[(NH_4)_2SiF_6]$[12] to give a pH of 4.9, and with 1.0 pound of oleic acid per ton of feed to collect the ilmenite. A scavenger flotation was made on the rougher tailings, the scavenger concentrate being kept separate from the rougher concentrate for evaluation purposes. The rougher concentrate was cleaned twice; the final concentrate assayed 47.6 percent $TiO_2$ and 0.41 percent $P_2O_5$. The material balance and reagent data are shown in table 2.

A dry magnetic separation was made with a magnetic field strength of 750 gauss in an induced-roll magnetic separator on both the concentrate and the scavenger tailings of the preceding test 2 to determine any possible difference between the collected and noncollected ilmenite. From the concentrate, a magnetic fraction was obtained that analyzed 45.8 percent $TiO_2$. At the same field strength, a magnetic product was obtained from the scavenger tailing that analyzed 39.6 percent $TiO_2$. At a field strength of 1,950 gauss, the concentrate yielded a magnetic fraction analyzing 48.9 percent $TiO_2$ and the scavenger tailing produced a magnetic fraction analyzing 45.5 percent $TiO_2$. Since in all cases no nonopaque contaminants were observed with the magnetics, the conclusion was that varying amounts of magnetite contaminated the ilmenite as an intergrowth impurity and that the magnetite was not being collected as efficiently as the ilmenite.

---

[11] American Cyanamid Company. Froth Flotation. Mineral Dressing Notes, No. 21, January 1955, p. 18.

[12] Mayer, S. P. Flotation of Ilmenite Ores. U.S. Pat. 2,557,455, June 19, 1951.

TABLE 2. - Flotation of ilmenite, test 2, sample 3

Material Balance

| Product | Weight-percent | Analysis, percent | | Distribution, percent | |
|---|---|---|---|---|---|
| | | $TiO_2$ | $P_2O_5$ | $TiO_2$ | $P_2O_5$ |
| Concentrate............ | 47.3 | 47.6 | 0.41 | 59.2 | 3.9 |
| 2d cleaner tailing..... | 5.9 | 42.8 | 5.36 | 6.7 | 6.4 |
| 1st cleaner tailing.... | 5.5 | 26.4 | 16.70 | 3.8 | 18.6 |
| Scavenger concentrate.. | 6.1 | 44.1 | 2.94 | 7.0 | 3.6 |
| Scavenger tailing...... | 14.7 | 20.1 | 9.27 | 7.7 | 27.6 |
| Minus 325-mesh discard. | 20.5 | 28.9 | 9.64 | 15.6 | 39.9 |
| Calculated head..... | 100.0 | 38.1 | 4.95 | 100.0 | 100.0 |
| Assay head......... | - | 38.9 | 5.00 | - | - |

Operating Data

| Step | pH | Time, min | Reagents, pounds per ton of total feed | |
|---|---|---|---|---|
| | | | $(NH_4)_2SiF_6$ | Oleic acid |
| Conditioner........... | 4.9 | 5.0 | 0.58 | 1.0 |
| Rougher............... | 5.8 | 3.5 | - | - |
| Scavenger............. | 4.6 | 4.0 | .08 | .2 |
| 1st cleaner........... | 4.2 | 7.0 | .48 | .4 |
| 2d cleaner............ | 4.2 | 3.5 | .20 | - |

By using essentially the same procedure as in test 2, it was possible to obtain a concentrate analyzing 52.1 percent $TiO_2$ and 0.24 percent $P_2O_5$, with 59.3 percent $TiO_2$ recovery in 44.2 percent of the total weight. The primary difference in procedure was the use of a higher pH during the rougher and first two cleaner flotations of this test. The material balance and operating data are given in table 3.

A different approach to the cleaning of ilmenite by flotation was presented by L. L. McMurray[13] in a paper on ilmenite recovery from a North Carolina ore. His procedure was to perform an amine float to remove sericite and talc, the major gangue minerals in the ore he investigated. Ralston[14] mentioned the same procedure being used on a Virginia nelsonite ore, with apatite also floating with the silicates, leaving an enriched ilmenite product. The collector in both instances was laurylamine hydrochloride.

Several tests on sample 3 were made using laurylamine hydrochloride as the collector. Apatite was not collected by this reagent in any of the tests conducted on this ore. A modified reagent scheme was developed wherein a laurylamine float was made first and then apatite was floated using oleic acid, the ilmenite being left as an enriched residue. It was discovered that desliming the feed was unnecessary if a small amount of polyacrimide flocculant was added as a preconditioning agent.

---

[13] McMurray, L. L. Froth Flotation of a North Carolina Ilmenite Ore. Mining Technology, vol. 8, No. 1, AIME, 1944, Tech. Pub. 1653, 6 pp.

[14] Ralston, Oliver C. Flotation and Agglomerate Concentration of Nonmetallic Minerals. BuMines Rept. of Inv. 3397, 1938, pp. 36-37.

TABLE 3. - Improved ilmenite flotation, test 3, sample 3

Material Balance

| Product | Weight-percent | Analysis, percent | | Distribution of $TiO_2$, percent |
|---|---|---|---|---|
| | | $TiO_2$ | $P_2O_5$ | |
| Concentrate............ | 44.2 | 52.1 | 0.24 | 59.3 |
| 4th cleaner tailing..... | 3.3 | 42.8 | - | 3.6 |
| 3d cleaner tailing...... | 9.2 | 23.2 | - | 5.5 |
| 2d cleaner tailing...... | 8.2 | 31.3 | - | 6.6 |
| 1st cleaner tailing..... | 3.0 | 30.3 | - | 2.3 |
| Rougher tailing...... .. | 10.7 | 26.4 | 7.01 | 7.3 |
| Minus 325-mesh.......... | 21.4 | 28.1 | - | 15.4 |
| Calculated head...... | 100.0 | 38.9 | - | 100.0 |
| Assay head.......... | - | 38.9 | 5.00 | - |

Operating Data

| Step | pH | Time, min | Reagents, pounds per ton of total feed | |
|---|---|---|---|---|
| | | | $(NH_4)_2SiF_6$ | Oleic acid |
| Conditioner............ | 6.3 | 2.0 | 0.1 | 1.0 |
| Rougher................ | 6.3 | 2.5 | - | - |
| 1st cleaner............ | 6.5 | 2.0 | - | - |
| 2d cleaner............. | 5.3 | 1.5 | .1 | - |
| 3d cleaner............. | 4.2 | 1.5 | .1 | - |
| 4th cleaner............ | 3.7 | 1.0 | .1 | - |

To improve the removal of iron stain from the silicates present in the ore, fluosilicic acid ($H_2SiF_6$) was substituted for the sulfuric acid during the laurylamine flotation. Fluosilicic acid had the advantage of being able to attack the silicate surfaces. The best test (No. 4) of this series left an ilmenite residue analyzing 50.3 percent $TiO_2$, 0.16 percent $P_2O_5$, and 0.63 percent $SiO_2$, with a $TiO_2$ recovery of 66.2 percent in 53.10 percent of the weight. The results of this test are presented in table 4. A wetting agent was added to the rougher flotation in each step to provide froth control.

Sample 2 was a composite of a drill core rather than a float sample as were the others. Comparison of the percent opaques with the head feed grade indicates that the ilmenite would contain only 38 percent $TiO_2$ if perfectly concentrated.

Several flotation tests were made on sample 2, using a direct ilmenite flotation procedure. The collector for these tests was an emulsion made up of a fatty-acid resin-acid product, fuel oil, and petroleum sulfonate in water in the ratio of 6:6:1:39. Difficulties were encountered during these tests because the apatite would "slow float;" that is, the first part of the froth would be relatively clean ilmenite, and then apatite would begin floating in increasing quantities before the ilmenite flotation was completed. This phenomenon is well illustrated in test 5 on sample 2.

TABLE 4. - Laurylamine prefloat procedure, test 4, sample 3

Material Balance

| Product | Weight-percent | Analysis, percent $TiO_2$ | $P_2O_5$ | $SiO_2$ | Distribution of $TiO_2$, percent |
|---|---|---|---|---|---|
| LaHCl[1] concentrate.......... | 3.3 | 22.3 | - | - | 1.8 |
| 2d LaHCl cleaner tailing.... | 4.8 | 27.1 | - | - | 3.2 |
| 1st LaHCl cleaner tailing... | 10.2 | 30.3 | - | - | 7.7 |
| Enriched residual material.. | 53.1 | 50.3 | 0.16 | 0.63 | 66.2 |
| 1st apatite cleaner tailing. | 11.7 | 42.8 | - | - | 12.4 |
| 2d apatite cleaner tailing.. | 2.6 | 46.3 | - | - | 3.1 |
| 3d apatite cleaner tailing.. | 1.3 | 44.6 | - | - | 1.4 |
| 4th apatite cleaner tailing. | 2.5 | 32.4 | - | - | 2.0 |
| Apatite concentrate......... | 10.5 | 8.57 | 34.5 | - | 2.2 |
| Calculated head.......... | 100.0 | 40.4 | - | - | 100.0 |
| Assay head............... | - | 38.9 | 5.0 | - | - |

Operating data

| Step | pH | Time, min | Reagents, pounds per ton of feed: Defloc-culant | 35 pct $H_2SiF_6$ | LaHCl | Pine oil | Wet-ting agent | $Na_2CO_3$ | Dex-trine | Oleic acid |
|---|---|---|---|---|---|---|---|---|---|---|
| LaHCl conditioner | 5.0 | 2.0 | 0.007 | 1.3 | 0.20 | 0.05 | 0.05 | - | - | - |
| LaHCl rougher.... | 5.0 | 10.5 | - | - | [2] .02 | .05 | - | - | - | - |
| 1st LaHCl cleaner | 6.1 | 6.0 | - | - | - | - | - | - | - | - |
| 2d LaHCl cleaner. | 6.1 | 6.0 | - | - | - | - | - | - | - | - |
| Oleic acid conditioner..... | 9.4 | 4.0 | - | - | - | - | - | 2.6 | 1.5 | 2.5 |
| Oleic acid rougher | 9.5 | 8.0 | - | - | - | - | - | 2.0 | - | 1.0 |
| 1st oleic cleaner | 9.5 | 5.0 | - | - | - | - | - | - | - | - |
| 2d oleic cleaner. | 9.5 | 3.0 | - | - | - | - | - | - | - | - |
| 3d oleic cleaner. | 9.5 | 2.0 | - | - | - | - | - | - | - | - |
| 4th oleic cleaner | 9.5 | 2.0 | - | - | - | - | - | - | - | - |

[1] Laurylamine hydrochloride.

[2] Stage added carefully; an excess causes complete flocculation.

A sample was ground to minus 100-mesh in a ball mill and conditioned for 15 minutes with 4.3 pounds fluosilicic acid to give a pH of 6.3 and with 20.8 pounds of the fatty-acid resin acid, fuel oil, petroleum sulfonate, water emulsion per ton of feed. The rougher concentrate was cleaned twice. During the third cleaning step, froth was pulled for 35 seconds and kept separate from the remainder of the froth which was pulled for another 3 minutes. The first concentrate had 39.62 percent of the total weight and analyzed 36.9 percent $TiO_2$ and 0.78 percent $P_2O_5$; this product recovered 61.3 percent of the $TiO_2$. The second concentrate had 14.41 percent of the total weight and analyzed 32.3 percent $TiO_2$ and 5.73 percent $P_2O_5$. The second concentrate recovered 19.5 percent of the $TiO_2$. The material balance and operating data for this test are given in table 5.

TABLE 5. - Ilmenite flotation, test 5, sample 2

Material Balance

| Product | Weight-percent | Analysis, percent | | Distribution of $TiO_2$, percent |
|---|---|---|---|---|
| | | $TiO_2$ | $P_2O_5$ | |
| 1st concentrate.......... | 39.6 | 36.9 | 0.78 | 61.3 |
| 2d concentrate........... | 14.4 | 32.3 | 5.73 | 19.5 |
| 3d cleaner tailing....... | 6.8 | 28.5 | - | 8.2 |
| 2d cleaner tailing....... | 7.6 | 17.6 | - | 5.6 |
| 1st cleaner tailing...... | 11.1 | 7.5 | - | 3.5 |
| Rougher tailing.......... | 20.4 | 2.2 | - | 1.9 |
| Calculated head....... | 100.0 | 23.8 | - | 100.0 |
| Assay head............ | - | 25.1 | 8.1 | - |
| Combined concentrates. | 54.0 | 35.7 | 2.1 | 80.8 |

Operating Data

| Step | pH | Time, min | Reagents, pounds per ton of feed | | | |
|---|---|---|---|---|---|---|
| | | | 35 pct $H_2SiF_6$ | Acid[1] | Fuel oil | Petroleum sulfonate |
| Conditioner............. | 6.3 | 15.00 | 4.3 | 10.0 | 10.0 | 0.8 |
| Rougher.................. | 6.3 | 5.30 | - | - | - | - |
| 1st cleaner............. | 5.1 | 4.70 | 2.8 | - | - | - |
| 2d cleaner.............. | 4.7 | 4.00 | 2.8 | - | - | - |
| 3d cleaner.............. | - | - | - | - | - | - |
| 1st concentrate.......... | 4.7 | .58 | - | - | - | - |
| 2d concentrate........... | 4.3 | 2.92 | - | - | - | - |

[1] Fatty-acid resin-acid product.

## Other Beneficiation Studies

The Boyd and Stratton nelsonite samples both contained enough magnetite to make partial enrichment by wet magnetic separation possible. The Hughes property nelsonite apparently contained no magnetite and would not respond to wet magnetic separation. An example of a wet magnetic separation on the Stratton nelsonite (sample 3) is typified by test 6. Here, a hand magnet was used to make the separation, while the minus 65-mesh ore was being agitated in a slurry in a laboratory float cell. The magnetic fraction contained 43.7 percent of the weight and analyzed 47.9 percent $TiO_2$ and 0.33 percent $P_2O_5$; $TiO_2$ recovery was 51.2 percent. The remainder of the titanium was in the nonmagnetics, which analyzed 31.5 percent $TiO_2$ and 10.9 percent $P_2O_5$; the nonmagnetics contained 97.7 percent of the $P_2O_5$.

A dry magnetic separation was attempted in test 7 on a portion of sample 3 ground to minus 65-mesh and deslimed at 325-mesh. A laboratory induced-roll magnet was used for the separation. Three products were made: A magnetic concentrate, an intermediate magnetic product (or cleaner tailing), and a nonmagnetic rougher tailing. The magnetic product analyzed 45.8 percent $TiO_2$ and 0.05 percent $P_2O_5$ and recovered 65.1 percent of the $TiO_2$ available to the separation after desliming.

More efficient recovery was obtained from the deslimed feed from sample 3 by performing a wet magnetic separation in test 8 followed by a dry magnetic separation on an induced-roll separator on the nonmagnetic fraction from the wet separation. The wet magnetic concentrate analyzed 46.3 percent $TiO_2$ and 0.06 percent $P_2O_5$, recovering 59.7 percent of the $TiO_2$ available to the separation. An additional 38.7 percent of the $TiO_2$ was recovered from the wet nonmagnetic fraction as a dry magnetic concentrate that analyzed 48.5 percent $TiO_2$ and 0.43 percent $P_2O_5$. The combined magnetic products analyzed 47.1 percent $TiO_2$ and 0.20 percent $P_2O_5$, with a recovery of 98.4 percent of the $TiO_2$ in 91.5 percent of the weight of the deslimed sample. This combined product represents 68.5 percent of the total (undeslimed) feed weight and 83.0 percent of the total $TiO_2$ in the ore.

A high-tension (electrostatic) separation was made on a portion of sample 1 for test 9. The feed was ground to 80.6 percent minus 65-mesh and screened on 200-mesh. The oversize was then separated into conductors (ilmenite), middling, and nonconductors on a laboratory high-tension separator operating with 40,000 volts between electrodes. The conductor fraction analyzed 50.1 percent $TiO_2$ and 0.33 percent $P_2O_5$ to give an overall $TiO_2$ recovery of 73.5 percent. The results of the test are shown in table 6. It is doubtful if an efficient electrostatic separation could be made on the minus 200-mesh material.

TABLE 6. - Electrostatic separation, test 9, sample 1

| Material balance | | | | | |
|---|---|---|---|---|---|
| Product | Weight-percent | Analysis, percent | | Distribution, percent | |
| | | $TiO_2$ | $P_2O_5$ | $TiO_2$ | $P_2O_5$ |
| Conductors | 53.2 | 50.10 | 0.33 | 73.5 | 2.8 |
| Middling | .7 | 35.10 | 4.22 | .7 | .5 |
| Nonconductors | 16.7 | 4.37 | 20.40 | 2.0 | 55.0 |
| Minus 200-mesh discard | 29.4 | 29.20 | 8.84 | 23.8 | 41.7 |
| Calculated head | 100.0 | 36.20 | 6.24 | 100.0 | 100.0 |
| Assay head | - | 36.20 | 6.80 | - | - |

## CONCLUSION AND RECOMMENDATIONS

Although the nelsonite deposits are of limited size, they are high grade. Work on the deposits indicates that many of them are lenticular and pinch out at shallow depths but there are also indications that some of them do extend to greater depths. On the Hughes property, the lenses lie en echelon horizontally and some of them could occur en echelon vertically. It is possible that some method of geophysical exploration, such as gravimetric surveys, could discover nelsonite ore bodies hidden beneath the present erosion surface.

Aerial magnetometric surveys made over the entire anorthosite body and a portion of the surrounding area, particularly along strike to the north and south, could point out concealed deposits. The specific gravity of nelsonite is about 1.5 times that of anorthosite; therefore, gravimetric surveys could be conducted on both sides of the contact between the anorthosite and the gneissic country rock to outline concealed deposits.

Two flotation techniques were developed that could produce ilmenite concentrates of nearly satisfactory $P_2O_5$ grade. The first procedure utilized oleic acid and fluosilicic acid to directly float the ilmenite from a deslimed minus 65-mesh feed. The second procedure was more complicated and used laurylamine hydrochloride to float silicates in an acid pulp, followed by the flotation of apatite in alkaline pulp, leaving the ilmenite as an enriched residue; desliming was not necessary with this procedure.

The simplest separations were made using electromagnetic or electrostatic separations on deslimed feed. Wet magnetic separation recovered some of the ilmenite from certain nelsonite deposits, and by utilizing such a separator it may be possible to use undeslimed feed, desliming only the nonmagnetic portion of the feed.

At the present time, the magnetic separations appear to be the most promising procedures to use with regard to both concentrate grade and recovery and ease of operation.