TITANIUM

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CONTENTS

ILLUSTRATIONS

TABLES

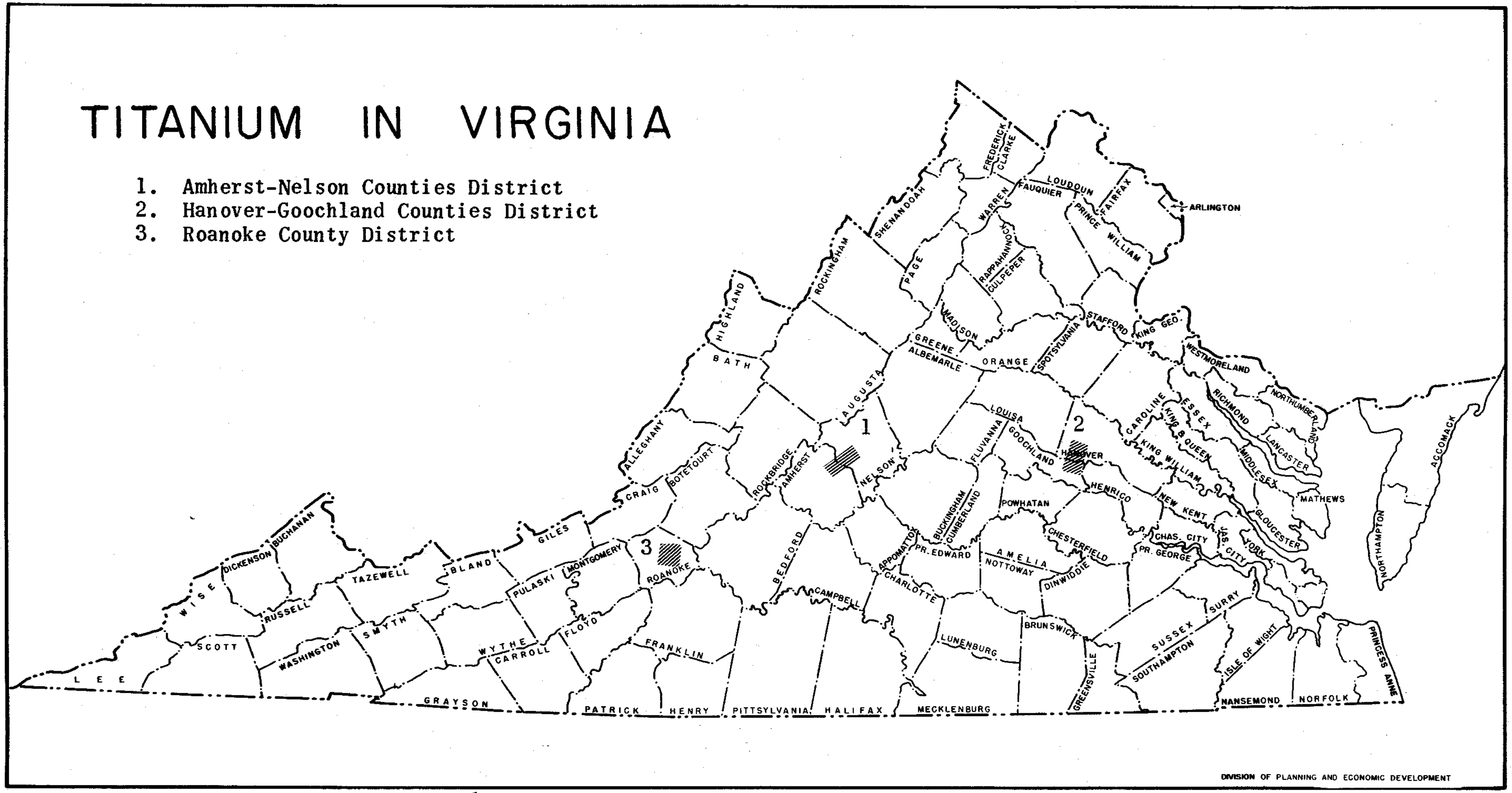

Figure 1. Outline map of Virginia showing location of commercially operated titanium deposits.

TITANIUM

By Arthur A. Pegau

INTRODUCTION

Titanium-bearing deposits everywhere have assumed new importance because of the recent production of titanium metal by modern technology. Titanium, although a late-comer in the field of industry, promises to be the outstanding new metal of the twentieth century. Often referred to as "the wonder metal," titanium is now regarded as one of the most valuable structural materials.

CHARACTERISTICS AND USES OF TITANIUM

Characteristics of Titanium

The element titanium, a metal of the tin group, is not found free in nature. Its principal occurrence is in the two minerals rutile (TiO_2 - titanium 60 per cent, oxygen 40 per cent) and ilmenite ($FeTiO_3$ - titanium 31 per cent, iron 37 per cent, oxygen 32 per cent). Titanium has an atomic weight of 47.90. The specific gravity is 4.5, between that of iron, which is 7.5, and that of aluminum, which is 2.7. Titanium is hard and brittle at ordinary temperatures, but at red heat it can be forged; it melts at 1800°C (3272°F). Titanium burns in pure oxygen at 610°C to form titanium dioxide (TiO_2), which is a brilliant white powder with an unusual hiding power or opacity. A pure transparent gem, titania, has been produced synthetically from this oxide. This gem is characterized by a refractive index (brilliance) which is higher even than that of diamond. However, titania is much softer than diamond, the hardest of all known substances.

The metal titanium is a ductile silver-gray substance that resembles iron in appearance. Light and strong, it retains its strength under great heat. This metal, while only 56 per cent as heavy as steel, is as strong as ordinary varieties of steel; and although only 60 per cent heavier than aluminum, it is 5 times stronger than alloyed aluminum.

Uses of Titanium

Titanium is used in three forms: rutile, ilmenite, and titanium metal.

The principal use of rutile until about 1900 was in the manufacture of artificial teeth. Between 1900 and 1930 the chief uses were in the ceramic industry, in incandescent media, and in metallic alloys. In the porcelain industry rutile was used to give a beautiful soft yellow color under the glaze. Rutile was used in mantles for gas lights, in electrodes for electric lights, and in filaments in incandescent electric lamps. As luminants, the value of titanium compounds is due to their high fusion and vaporization points, radiation efficiency and, in the case of arc lamps, their spectrum, which is one of the richest in number of lines given by any of the elements. Rutile is used in the manufacture of titanium carbide (TiC), which radiates more light and is more durable than carbon electrodes.

Both rutile and ilmenite have been used in the form of ferro-titanium to increase the fluidity of iron and to remove oxygen and nitrogen, yielding a product that is stronger and more durable under shock and strain. Other uses of rutile and ilmenite have been in the manufacture of compounds used in sky writing, making smoke screens, and in mordants and dyes. Alone, titanium salts act as powerful mordants, yielding fast, bright colors. Titanium salts also are used in dyeing textiles such as cotton, wool, and silk, and in fixing the tannin in leather.

Since 1930 the most important use of rutile, and a minor use of ilmenite, has been in the preparation of a welding rod coating which shields the rod from oxidation during the welding process. At the present time this use accounts for about 80 per cent of the production of rutile.

Whereas rutile has been used since about 1880, ilmenite was considered a nuisance until about 1914. First used along with rutile as a deoxidizer and scavenger of molten metals, ilmenite was later employed in the manufacture of iron-titanium alloys and in the steel industry. Since 1920 the most important use of ilmenite has been in the production of titanium oxide as a paint pigment, which when combined with other paint compounds makes the whitest of paints. The opacity of titanium oxide is twice that of zinc oxide and three times that of lead oxide. Titanium paints are excellent for both interior and exterior uses. This pigment enters into many articles of our daily life: The linoleum in kitchens, white shoe polish, window shades, stationery and false teeth.

Ilmenite's greatest potential is as a source of titanium metal. Ilmenite is the chief mineral, if not the only mineral, used in the production of this metal.

Titanium metal and its alloys, because of lightness, strength, and resistance to corrosion, are used in civilian and military equipment. The present uses of this metal fall into four general categories: military and civilian aircraft, marine equipment, chemical equipment, and ordnance. In military and civilian aircraft its light weight, strength, and ability to withstand high operating temperatures make it especially desirable. As speed increases, aircraft frames must be stronger and able to withstand higher temperatures. Titanium metal fits these requirements. Because of its resistance to sea water, titanium metal is especially adapted to marine equipment. Generally resistant to corrosion, it is desirable in equipment that is exposed to oxidizing, chlorine, and chloride reagents. Unalloyed titanium metal is used in ordnance because it is more resistant to projectiles than any armor plate now in existence.

GEOLOGY OF TITANIUM

Mineralogy

General Statement

Titanium occurs in nature in the form of very stable compounds, usually oxides. Of the forty-six titanium minerals, rutile and ilmenite, both oxides, are the only important sources of the element. Leucoxene, a calcium-titanium silicate formed from ilmenite, in recent years has been recovered from Florida beach sands. Leucoxene can be used in many of the same ways as rutile. Brookite, which has the same composition as rutile but different crystallization, was one of the chief minerals in the Arkansas deposits which were worked from 1933 through 1944.

Rutile, TiO_2

Rutile crystallizes in the tetragonal system and occurs as well-formed crystals, vertically striated or furrowed, and as granular masses. Twinning is frequent. This mineral has a reddish-brown to red color, a hardness of 6.5, a specific gravity of 4.25, and a colorless streak. The color, streak, and semi-metallic luster are distinguishing properties.

Ilmenite, $FeTiO_3$

Ilmenite crystallizes in the hexagonal system and rarely occurs in crystals large enough to be seen by the unaided eye. It is found as embedded grains, masses, and plates in rocks, and as irregularly rounded grains in sands. Ilmenite is black with a reddish to brownish tinge, has a dark-brown to black streak, a hardness of 5 to 6, and a specific gravity of 4.5 to 5. Ilmenite is weakly magnetic, whereas magnetite, which it resembles, is strongly magnetic. The color, streak, and magnetism are characteristic.

Chemical Tests for Titanium

There are two chemical tests for titanium. In one, sulfuric acid is used, in the other, hydrochloric acid. The former test, although the easier, is not as decisive, particularly if iron is present. In the first test the mineral specimen is powdered thoroughly, fused with sodium carbonate (Na_2CO_3), and dissolved in dilute sulfuric acid (H_2SO_4). Hydrogen peroxide (H_2O_2) is added a drop at a time. If the solution contains titanium it immediately turns reddish-yellow to deep amber, depending on the concentration of titanium. In the second test, made if iron is present, the mineral specimen is powdered and mixed with 6 times its volume of sodium carbonate. This mixture then is fused, placed in a test tube containing concentrated hydrochloric acid to which a small piece of pure tin has been added, and boiled until the fused material is thoroughly dissolved. If the solution contains titanium it will assume a delicate violet to pink color, depending upon the amount of titanium present.

PETROGRAPHY AND MODE OF OCCURRENCE

General Statement

Titanium minerals, particularly ilmenite, occur in accessory amounts (under 5 per cent) in igneous, sedimentary, and metamorphic rocks. Commercial deposits of these minerals, however, are found only in a limited variety of occurrences. These types of deposits or modes of occurrence are of two general kinds, sand deposits and hard rock deposits. Sand deposits include beach and stream or fluviatile deposits, whereas hard rock deposits include ilmenite-magnetite deposits, ilmenite-hematite deposits associated with anorthosite, and disseminated deposits in anorthosite, nelsonite dikes, and pegmatites.

Sand Deposits

Stream or Fluviatile Deposits

Stream or Fluviatile deposits are concentrations formed along major stream courses by flowing water, the most effective separator of light from heavy minerals. Concentration results from local slackening of stream velocity which allows the heavy minerals to settle out from the lighter ones which are carried on by the stream. This is the chief mode of occurrence of gold. The only reported commercial deposit of titanium ore of this type is in Malaya, where ilmenite is obtained as a by-product of tin mining.

Beach Sand Deposits

Beach deposits are formed along seashores by the concentrating effects of wave and current action. Sands along the shore are shifted by shore currents, and lighter materials are moved faster and farther than heavy, thereby concentrating the heavy minerals.

At Travancore, India, ilmenite and, to a lesser extent, rutile and magnetite have undergone an unusual beach concentration resulting in beach sands that contain 50 per cent ilmenite and 5 or more per cent minerals such as rutile and zircon. Similar sands in California, Florida, North Carolina, Brazil, and Australia. The sands of Florida contain ilmenite, rutile, and leucoxene while those of North Carolina contain ilmenite, zircon,and monazite.

Hard Rock Deposits

Ilmenite-Magnetite Deposits

Certain minerals that usually occur in very small amounts in the original magma may become concentrated into bodies of sufficient size and richness to be valuable mineral deposits. A well known example of an ilmenite-magnetite deposit is that at Lake Sanford, near Tahawus, New York, in which the ratio of magnetite to ilmenite is about 3 to 1. This deposit is associated with anorthosite, a variety of gabbro composed of calcic feldspars and iron-magnesium-aluminum silicates in which calcium feldspar is the chief constituent.

Ilmenite-Hematite Deposits

An example of an ilmenite-hematite deposit, also associated with anorthosite, is found in the Allard Lake region of Quebec. This deposit, yielding a slag that contains 70 per cent titanium dioxide, is the largest of this type yet discovered.

Nelsonite Deposits

The rock nelsonite is composed essentially of ilmenite and apatite (calcium phosphate), with rutile as the third most abundant mineral. Nelsonite occurs as dike-like bodies as much as 2,000 feet in length, although lengths of several hundred feet are more common. The average width is about 65 feet. Some of the bodies have been worked to depths of more than 100 feet, but their exact depth is not known. Nelsonite bodies were earlier considered to be of direct magmatic origin, but C. S. Ross suggests that parts of the dikes have been replaced by titanium minerals.

Nelsonite bodies are now the chief sources of ilmenite and minor sources of rutile and apatite in Virginia. They occur in Amherst and Nelson counties along the borders of an anorthosite body and the rock enclosing it (Lovingston quartz-monzonite gneiss).

Disseminated Deposits

The chief occurrence of rutile, in Virginia, is as a dissemination in a rock called anorthosite, made up essentially of feldspar. In the Nelson-Amherst district, this anorthosite was later replaced in part by potassium feldspars, blue quartz, and the titanium-ore minerals rutile and ilmenite. Rutile in anorthosite varies in amount from 2 to 10 per cent, although percentages of 4 to 5 are more common. Ilmenite, though almost always present, is less abundant than rutile.

GEOGRAPHY OF TITANIUM

General Statement

The element titanium is very widespread. It is present in many rocks and minerals, and varying amounts are found in soils, clays, sands, coal ash, and sea water. Traces of titanium also have been found in plants and animals, even in the flesh of human beings. Nevertheless, commercial deposits of titanium are not numerous and are unevenly distributed.

In this discussion, consideration will be given to world distribution, then to a summary of deposits in the United States, with a final brief statement about occurrences in Virginia.

World Distribution of Titanium

General Statement

Deposits of titanium-bearing minerals are found in nearly every country in the world, and new deposits are being developed as the demand for these minerals increases. According to U. S. Bureau of Mines Minerals Yearbook, 1951, published in 1954, commercial deposits of rutile are reported to occur in Australia, Brazil, French Cameroon, French Equatorial Africa, India, Norway, Senegal, and the United States. Deposits of ilmenite have been worked in Australia, Brazil, Canada, Egypt, India, Malaya, Norway, Portugal, Senegal, Spain and the United States. The most important deposits of rutile are in Australia, French Cameroon, Norway, and the United States, whereas the chief deposits of ilmenite are those in India, Norway, Canada, and the United States.

Rutile

Australia.- The Bureau of Mineral Resources at Canberra announced recently that Australia has the largest known deposits of titanium in the world in the beaches and sand dunes for about 50 miles north and south of the New South Wales-Queensland border. These deposits have been the chief source of rutile in recent years.

Norway.- Rutile occurs in the vicinity of Kragero in southern Norway, confined to an even-granular aplite, called kragerite. This deposit was one of the world's chief sources of rutile for many years.

Ilmenite

India.- The beach deposits at Travancore, India, have been, probably, the world's chief source of ilmenite. In addition these sands contain rutile and monazite, along with zircon, garnet, and other minerals.

Norway.- Norway has a large body of ilmenite-magnetite associated with anorthosite. The ore averages 17 per cent TiO_2. This deposit is estimated to contain 30 million tons of ilmenite.

Canada.- There are several deposits of ilmenite-hematite ore enclosed in anorthosite near Allard Lake, Quebec. It has been estimated that this district could supply 1,500 tons of ore per day, averaging 35 to 36 per cent TiO_2, for 225 years.

Other Deposits of Ilmenite.- Beach deposits similar to those at Travancore, India, occur on the coasts of Brazil and of New South Wales and Queensland, Australia. Large ilmenite deposits have been reported to occur in the Ilmen Mountains, Karelia, Russia, and the beach sands at Hondu, Japan, which are said to contain 10 million tons of ore averaging 8 to 12 per cent TiO_2.

Distribution of Titanium in the United States

General Statement

As the demand for titanium-bearing minerals increases, new deposits of these minerals are being sought and developed in the United States. Deposits of ilmenite and rutile, not all known to be commercial, have been reported from Arkansas, California, Colorado, Georgia, Idaho, New York, North Carolina, Minnesota, Montana, Rhode Island, Virginia, and Wyoming. The principal commercial production of ilmenite in recent years has been from New York, Florida, North Carolina, and Virginia. Florida, Arkansas, and Virginia have been the chief sources of rutile.

New York.- The ilmenite deposit at Lake Sanford (Tahawus) is the largest deposit of this mineral in the United States. The ore is an ilmenite-magnetite mixture in anorthosite and gabbro and carries a small amount of vanadium. It is reported that proved ore reserves total 15 million tons and that probably reserves of this district are prodigious.

Florida.- Beach sands near Starke produce ilmenite and a mixed product containing rutile and an altered ilmenite, leucoxene. Ilmenite and zircon are recovered from beach sands near Melbourne, and large quantities of rutile are recovered from beach sand deposits near Jacksonville.

North Carolina.- Ilmenite is recovered from black sand deposits near Finley. Operations which were begun here in 1942 reached their peak in 1951.

Virginia.- The nelsonite deposits at Piney River and the rutile deposit near Roseland in the south central part of the Piedmont region are discussed later under that portion of this report devoted to titanium deposits in Virginia.

HISTORY OF PRODUCTION OF TITANIUM MINERALS

World Production

General Statement

Statistics on annual production before 1925 of countries other than the United States are not available, nor are data of annual world total production before 1940. The annual production of rutile and ilmenite of the principal producing countries, for which information is available, is shown in Tables I and II, respectively.

World Production of Rutile, 1925-1938

World production of rutile was not great for any year from 1925 to 1938, because although the use of rutile for welding rods began about 1930, large quantities were not utilized for this purpose until about 1940. During this period Norway was the main producer reporting limited production annually from 1925 through 1938.

World Production of Rutile, 1939-1951

This period was characterized by annual increases in the production of rutile and by an increase in the number of producing countries. Australia reported the first production of rutile in 1939, and has since so increased her output that she is now the chief producer. Since 1945 Australia has been responsible for over half the annual world production of rutile. The bulk of the remainder has been furnished chiefly by the United States and, to a less extent, by French Cameroon.

The most significant increase in the production of rutile was between 1936 and 1943, when the estimated annual tonnage rose from 1,000 to 20,000 metric tons. In 1951 there was a tonnage increase of about 70 per cent, perhaps related to increased consumption in the United States.

World Production of Ilmenite, 1925-1938

As shown in Table II, world production increased each year throughout the period. The annual production of ilmenite reported by India from 1928 through 1938 was greater than that of all the other countries combined. Noting the statistics for each of the two five-year intervals from 1928 through 1937 will give an idea of the increase in world production of ilmenite. The amount produced in 1928-1932 was 166,605 metric tons, and in 1933-1937, 583,347 metric tons. The 1938 production of 256,268 metric tons was nearly half that of the previous 5 years. Analysis of the production of ilmenite shows that the production rate had greatly accelerated before World War II. This increased rate of production of ilmenite resulted from the growing demands of the paint industry; and as is discussed later, this demand in the United States was met by imports from India and increased domestic prodution.

World Production of Ilmenite, 1939-1951

This period is characterized by the great increase in the production of ilmenite in the United States, and the leveling off of world production at around 800,000 metric tons during the last three years. The tonnage of ilmenite reported from India decreased greatly during the years 1942-1944, probably due to a decrease in exports to the United States. However, the most notable aspect of the ilmenite production picture since 1940 has been the increase in the number of countries producing and in the quantity produced by many countries. Twenty-seven years ago a significant statement, or at least it seems so in retrospect, was made by Frank L. Hess in Mineral Resources of the U. S., 1925. "The largest use for titanium minerals is one that would probably have been least suspected before it became a fact--the making of white pigment from the black iron-rich mineral, ilmenite. During the last few years this use has grown until it is now by far the largest use for titanium and promises to be much larger." This prediction has been borne out by subsequent production statistics. In 1925 seven countries produced about 15,000 metric tons of ilmenite; in 1951, 26 years later, 11 countries produced an estimated 800,000 metric tons of ilmenite, 99 per cent of which was consumed in the manufacture of pigments. The history of mineral industries reveals no similar case where the production of one mineral has increased so rapidly as has that of ilmenite. This increase has resulted almost entirely from one use--white pigment. With the use of ilmenite in the production of the metal titanium, what will be the effect on production and reserves?

History of Titanium Production in the United States

General Statement

The history of titanium production in the United States may be divided into four periods: 1880-1900, in which the only titanium mineral produced was rutile, in small quantities; 1901-1928, in which both rutile and ilmenite were produced, and data on production are available; 1929-1938, in which both minerals were produced in increasing amounts, but no figures on production are available; and 1939-1951, in which there were tremendous increases, particularly in the production of ilmenite, and for which period detailed statistics are available.

First Period, 1880-1900

As shown in Table III, the annual production of titanium never exceeded 1,000 pounds during this period, though the annual value of the ore produced ranged from $300 to $3,000. The only titanium mineral produced was rutile, and practically the whole production was from Chester County, Pa.

A small amount of rutile, sold as curiosities, specimens, and gems, was obtained from Alexander County, N. C., and Graves Mountain, Ga.

Second Period, 1901-1928

During the second period there was a great increase in production, which was measured in tons rather than in pounds (Table IV). This increase in the production of rutile may have resulted from production in Virginia, first reported in 1901. From 1901 through 1912 rutile was still the only titanium mineral produced. Most of the rutile produced from 1901 to 1928 was from the deposit near Roseland, Nelson County, Va. Operations near Jacksonville, Fla., furnished the chief supply from 1925 through 1928. These operations were discontinued in 1928, but later resumed.

Ilmenite, which was recovered as a by-product in the separation of rutile, was considered at first to be a nuisance, but gradually the quantity of ilmenite produced exceeded that of rutile. From 1913, the year of first production, through 1921, ilmenite was obtained from the rutile deposits near Roseland, Va. In 1916 Florida reported its first production from beach sands at Pablo Beach and from 1922 through 1924 was the chief producer of ilmenite concentrates.

Third Period, 1929-1938

The third period was one in which there was a blackout of available data on the production of rutile and ilmenite in the United States. Although the U. S. Bureau of Mines was not permitted to publish the figures, production of rutile and ilmenite was reported for every year during this period. This statement by Paul M. Tyler and A. V. Petar appeared in the Minerals Yearbook, 1934, p. 535. "Actual figures of domestic production cannot be published without revealing individual operations, but it is common knowledge that the output is of the order of several hundred tons of rutile and a thousand tons or more of ilmenite annually." The principal production of rutile during this period was by the American Rutile Company, at Roseland, Nelson County, Va. The only other state reporting rutile production from 1928-1938 was Arkansas.

Virginia was the only state reporting ilmenite production during the period 1929-1938. Production was from two localities, one at Roseland, where ilmenite was recovered as a by-product of the rutile operations, and the other at Piney River in Nelson County, where ilmenite occurs in association with apatite in the rock nelsonite. The Southern Mineral Products Corporation, a subsidiary of the Vanadium Corporation of America, acquired ilmenite-bearing properties in adjoining parts of Nelson and Amherst counties in 1929. This company reported production of apatite beginning in 1932 and of ilmenite in 1934, and for each year thereafter until 1943. Ilmenite production showed great yearly increases particularly after 1937, because many of the difficulties encountered in making a good product (white pigment) from ilmenite were then overcome. That there was a substantial annual increase in production in this period is shown by the average annual production of 5,000 short tons in the late twenties and an annual production of 15,000 short tons in 1939.

Fourth Period, 1939-1951

Production of both rutile and ilmenite, as well as of two other titanium minerals, brookite and leucoxene, increased tremendously. The annual production of rutile concentrates (Table V) rose from 2,657 short tons in 1940 (no data are available for 1939) to 11,988 short tons in 1949, the last year for which statistics are now available. The increase in the production of ilmenite was even more impressive, rising from 14,602 short tons in 1939 to 535,835 short tons in 1951. The total value of titanium ores produced in the United States rose from $576,929 in 1940 to $6,702,046 in 1949.

Virginia was the principal producer of rutile concentrates during the years 1939-1944. Florida became the leading producer of rutile in 1945 and the only one in 1950, the operations near Roseland, Va., having been discontinued in 1949. The 1949 production of 10,559 short tons of rutile emanated from Starke, Fla., on the property of E. I. du Pont de Nemours and Company; the operations of the Rutile Mining Company of Florida, near Jacksonville; and the property of the Florida Ore Processing Company, near Melbourne. The increase in rutile production for this year was due partly to the addition of figures for an altered ilmenite, leucoxene, to rutile. The entire 1950 production of rutile in the United States came from the three beach sand deposits mentioned above, at or near Jacksonville, Starke, and Melbourne on the Florida coast.

Virginia was the principal producer of ilmenite during the years 1939 through 1942. The annual production of approximately 500 short tons during the latter part of the 1920's had increased to about 20,000 short tons in 1940, and to an estimated 30,000 short tons in 1950. Even this great increase of ilmenite production in Virginia was inadequate to supply the increasing demands. Under the agreement between the U. S. Bureau of Mines and the various cooperating states, it is not permissible to publish production statistics of any mineral commodity when there are less than three producers. Annual production figures for rutile and ilmenite in Virginia can not be released herein since production of these titanium ores has been by less than three producers.

Considerable quantities of ilmenite were recovered from the rutile operations in the beach sands of Florida. A 20,000 to 30,000 short ton annual production was reported from Finley, N. C., during the years 1942 through 1950. In 1942, a property near Tahawus (Lake Sanford District, N. Y.)

was brought into production by the National Lead Company and by 1949 was the leading producer of ilmenite not only in the United States but in the world. The Tahawus operation was largely responsible for the phenomenal increase in domestic ilmenite production from 23,297 short tons in 1941 to 203,551 short tons in 1943. The production of 486,099 metric tons in 1951 was more than 50 per cent of the world total, estimated at 800,000 metric tons.

IMPORTS AND CONSUMPTION OF TITANIUM MINERALS IN THE UNITED STATES

Imports

General Statement

The first record of imports of titanium minerals into the United States was 1,606 pounds of steel-hardening material during the latter half of 1918. The source of this importation is not known, nor is the nature of the material. No other report of imports of titanium minerals between 1919 and 1928 is available. In September 1922, the Tariff Act of 1922 became effective. Under this act all imports of titanium compounds, mixtures, and ores must be declared for tax purposes. However, the Bureau of Customs did not list the titanium ores separately until 1928, when the amount of ilmenite was reported. Beginning with 1929 the importations of rutile and ilmenite were reported separately, and this practice has since been continued.

The annual imports of rutile and ilmenite are shown in Table VI. A discussion of the amounts and sources of rutile and ilmenite follows.

Amount of Importations

The amount of rutile imported into the United States before 1932 was negligible. The reason for this probably was that until rutile was first used for welding rods, about 1930, there was no great demand for it. From 1932 through 1943 there was a general increase in imports, the peak--more than 14,000 short tons--being reached in 1943. In 1938 the rutile content of the zircon-rutile-ilmenite sands was first included in the total of rutile imports. In 1942, for the only time so far as available records show, the quantity of rutile imported exceeded that of ilmenite. Since 1948 the rutile content of zirconiferous sands from Australia has not been listed separately, and the amount of rutile imports decreased sharply. The tonnages of rutile imported in 1949 and 1950 were the smallest since 1940. However, in 1951 there was a three-fold increase in the amount of imports over 1950.

The quantity of ilmenite imported into the United States showed an increase each year from 1928 through 1939. See Table VI. This increase paralleled the increase in the use of ilmenite for titanium pigment. As a consequence of the phenomenal rise in ocean freight rates in 1940, from $4.00 a long ton at the beginning of the year to $20.00 a ton at the end of the year, the receipts of ilmenite from foreign sources were greatly curtailed, and imports declined from a total of nearly 286,576 short tons in 1939 to 7,227 short tons in 1942. Because of Allied successes, which permitted the sea routes to be opened to shipping and the reduction in ocean freight rates, the quantity of ilmenite imported increased greatly in 1944. Since the peak year of 1949--when 324,157 short tons were imported--there has been a decline in the amount of ilmenite imported into the United States.

Sources of Importations

Norway was the sole exporter of rutile to the United States previous to 1933. Brazil furnished the bulk of imports from 1934 until 1938, when shipments were first received from Australia. Since 1947 Australia has been the only country to ship rutile into the United States.

Travancore, India, except for a few years, has been the chief foreign source of ilmenite from 1922 to the present time. Substantial amounts of foreign ilmenite were furnished by Senegal up to 1931. Norway was our second most important source of foreign ilmenite during the years 1934 to 1939. India, since 1941, has furnished from 75 to 90 per cent of the total United States imports of ilmenite. The bulk of the remainder of the ilmenite imported into the United States has come from Canada, Norway, Brazil, and Australia. In 1951, imports from India, the dominant source, dropped slightly, whereas those from Canada, consisting mostly of slag, tripled in quantity.

Consumption

General Statement

Data on the consumption of rutile and ilmenite in the United States are available only since 1941, when the total amounts consumed were reported to be 6,361 short tons and 275,106 short tons, respectively.

Rutile Consumption

The amount of rutile consumed annually in the United States during the eleven year period from 1941 through 1951 varied considerably. See Table VII. The average annual United States consumption during this period was 10,036 short tons.

The consumption of rutile in the United States has amounted to about 46 per cent of the world production of this mineral during the eleven year period from 1941 through 1951. The total production in the United States during these years was about 50 per cent of the total amount of rutile consumed during that period. The remaining amount had to be supplied by imports from other countries, principally Australia and Brazil.

Ilmenite Consumption

During the eleven year period from 1941 through 1951 the consumption of ilmenite in the United States has generally shown an annual increase, attaining a peak of over 713,000 short tons in 1951, the last year for which data are now available. The amount of ilmenite consumed in the United States in 1951 was about 80 per cent of the total world production for that year. During the period from 1941 through 1951, the total consumption of ilmenite in this country was 72 per cent of world production.

During the period for which information on the production and consumption of rutile and ilmenite is available, the United States has produced about 50 per cent of the rutile, and about 60 per cent of the ilmenite it consumed. Also it may be noted that the United States consumes between 40 and 50 per cent of world production of rutile and between 70 and 80 per cent of world production of ilmenite.

TITANIUM IN VIRGINIA

Distribution

General Statement

In Virginia, as elsewhere, the principal titanium minerals are widely distributed, but commercial deposits are limited. Reported occurrences of either or both rutile and ilmenite are listed below by counties, arranged alphabetically. Many are of scientific interest only. Those that have to date proved to be commercially workable deposits are indicated by an asterisk (*).

Amelia County.- In the vicinity of Amelia Court House, in pegmatites and the enclosing biotite gneiss.

*Amherst County.- At Piney River Station, in the rock nelsonite and the enclosing Lovingston gneiss.

Bedford County.- In the Bedford-Moneta district, in pegmatites and the enclosing biotite gneiss and near Forest in mica schist.

Buckingham County.- On Willis Mountain, in kyanite schist.

Campbell County.- Seven miles south of Lynchburg, as inclusions in quartz in mica schist.

Charlotte County.- Two miles northwest of Charlotte Court House, in kyanite schist.

Floyd County.- On Indian Creek, exact locality unknown, in mica schist.

*Goochland County.- Near Peers, in pegmatites and enclosing biotite gneiss.

Grayson County.- One mile south of Galax, associated with kyanite in mica schist.

*Hanover County.- In the vicinity of Gouldin, in pegmatites and associated biotite gneiss.

Henry County.- In the vicinity of Ridgeway, in pegmatites and associated biotite gneiss and hornblende gneiss.

*Nelson County.- Near Roseland, as disseminations in the feldspar rock anorthosite.

Prince Edward County.- In Baker Mountain, in kyanite schist.

*Roanoke County.- Two miles east of Vinton, in the rock nelsonite.

Rockbridge County.- Three miles southwest of Buena Vista, in a titaniferous sandstone at the base of the Unicoi formation.

Production

Rutile

From 1903 until 1925 the average annual production of rutile in Virginia was not more than 200 short tons, and for a period of almost 15 years, 1925-1939, no annual production statistics are available. From 1940 through 1948, the annual production averaged about 2,000 short tons, ten times the average previous to 1925. This stepped-up rate of production appears to have resulted from the use of rutile in the welding rod industry.

Ilmenite

The greatest annual production of ilmenite in Virginia previous to 1925 was that of 600 short tons in 1922. The annual production of this mineral in Virginia since 1939 has ranged from 17,500 short tons to nearly 47,000 short tons, with an average of about 30,000 short tons.

Geology of Titanium Deposits

General Statement

The modes of occurrence of rutile and ilmenite in Virginia may be listed under nine main types as herein briefly described.

Mechanical Mixture of Ilmenite with Magnetite

This type of deposit is the chief source of ilmenite in the United States but is relatively unimportant in Virginia. Titaniferous magnetite has been reported as occurring in hornblende schist in southeastern Grayson County.

Constituents of Pegmatites and Enclosing Rocks

Occurrences of this type have been reported from several localities. In the Rutherford and Morefield mines near Amelia Court House in Amelia County the enclosing rock is the Amelia-Goochland quartz-monzonite gneiss; in the Moneta-Bells district, Bedford County, the enclosing rock is the Moneta biotite-hornblende gneiss. Similar occurrences have been noted near Ridgeway in Henry County, in biotite gneiss and hornblende gneiss. The best known deposits of this type are those near Peers in Goochland County and near Gouldin in Hanover County. Rutile and ilmenite were found on the Bowe farm near Gouldin on the north side of the South Anna River, in Hanover County, and on the Nickols farm in Goochland County. Some of the masses are reported to have weighed 300 pounds. The two minerals, intergrown commonly with feldspar, occur in pegmatite. The enclosing rock at both these localities is the Amelia-Goochland quartz-monzonite gneiss, and the chief mineral is rutile.

The American Rutile Company reported a considerable production from these occurrences during World War II and for a few years thereafter. The material mined was hauled by truck to the treatment plant of the company at Roseland in Nelson County.

In Quartz Veins

Occurrences of this type are not uncommon, particularly in schistose rocks. Titaniferous quartz veins have been reported locally in Grayson County, in Campbell County, and in several other counties in the Piedmont region of the State. This type of deposit has been of scientific interest only.

Constituents of Schists

Titanium minerals, usually rutile and less often ilmenite, are associated with kyanite in kyanite schist. Rutile comprises 2 to 3 per cent of the rock in Baker Mountain in Prince Edward County. Similar occurrences have been noted in Willis Mountain in Buckingham County, near Forest in Bedford County, two miles northwest of Charlotte Court House in Charlotte County, on Indian Creek in Floyd County, and one mile south of Galax in Grayson County.

Mechanical Concentrates in Stream and Beach Sands

Ilmenite is one of the most abundant and persistent of the heavy mineral concentrates in sand along streams in the Piedmont and Coastal Plain regions of the State. A detailed description of this type of deposit is given elsewhere in this article.

Constituents of Sedimentary Rocks

Studies made of the heavy mineral content of sedimentary rocks, particularly sandstones of varying ages, show that ilmenite, and to a less extent rutile, are present in varying amounts. Three miles west of Buena Vista in Rockbridge County there is an occurrence of this type at the base of the Unicoi formation. Here a lenticular body of sandstone contains a 50 per cent mixture of rutile and ilmenite. The titaniferous sandstone, which occurs in a lens one-fourth mile long, is on the northwest limb of the Buena Vista anticline. Hand specimens of the material are usually heavy. The rock is black, with intervening layers of red-brown arkosic material.

Accessory Minerals (Under 5 Per Cent) in Igneous and Metaigneous Rocks

Ilmenite is present as an accessory constituent in most of the igneous and metaigneous rocks of the Piedmont and Blue Ridge regions of the State. The percentage of ilmenite is unusually high in the rocks of the Blue Ridge granitized complex and in sedimentary rocks derived therefrom. Rutile, however, is rarely present except as needles in the quartz, confined chiefly to the Blue Ridge region. The ilmenite is usually altered partially or wholly to leucoxene, a secondary titanium silicate.

Constituents of Nelsonite

Nelsonite is a rock made up primarily of ilmenite and apatite (calcium phosphate), with rutile as the third most abundant mineral. Occurrences of nelsonite bodies have been reported in Amherst and Nelson counties along the border of the feldspathic rock anorthosite, in the rock enclosing the anorthosite (Lovingston quartz-monzonite gneiss), and along the strike, northeast and southwest of the main anorthosite body. Nelsonite has been and is the chief source of ilmenite in the State, and an important source of rutile and phosphate (apatite).

Dissemination in Anorthosite

Anorthosite is made up predominantly of calcic feldspar with the potassium feldspar, microcline, as a minor constituent. The most characteristic subordinate mineral is blue quartz, which ranges in amount from 5 to 20 per cent. Rutile, the fourth most abundant mineral, ranges from a few to 10 per cent, although percentages of 4 to 5 are more common. Ilmenite, although usually present, is less abundant than rutile.

The anorthosite body in the Amherst-Nelson Counties district extends as an irregular belt from about two miles northeast of Bryant, in Nelson County, in a southwest direction across Piney River into Amherst County, a total length of almost 13 miles. The body has a maximum width of 2.5 miles and embraces an area of about 22 square miles. It is approximately midway between Charlottesville and Lynchburg and 5 miles west of U. S. Route 29. The district in which this body is located is monotonously level with an average altitude of about 800 feet.

Future Production Possibilities

General Statement

Future production possibilities of rutile and ilmenite in Virginia are herein considered from the standpoint of both the geology and geography of the deposits.

The two general modes of occurrence of commercial deposits of titanium-bearing minerals, as noted earlier in this report, are hard rock or primary deposits and sand or secondary deposits.

Hard Rock Deposits

The principal commercial deposit of rutile in Virginia is a dissemination in anorthosite. This type of deposit was worked for many years near Roseland, Nelson County. Operations were discontinued here in 1949 because the grade of ore was too low to be mined profitably. It is possible that with an increase in the price of rutile, with a discovery of richer deposits within this anorthosite body, or with improved mining and recovery techniques, operations may be resumed here. The greatest potential source of rutile in Virginia appears to be in this type of deposit.

Pegmatite deposits in Goochland and Hanover counties have furnished small amounts of rutile, particularly during and immediately after World War II. No studies have been made of these deposits since the recent operations. These pegmatite deposits and similar ones in this and other areas are possible potential sources of rutile. However, no definite statement can be made until further field studies and exploratory investigations have been made.

The only other hard rock deposits of rutile in the State that might be potential commercial sources of rutile are those occurring in schist associated with kyanite. Since as much as 2 to 3 per cent rutile is present, in such rocks, it is possible that rutile might be recovered as a by-product of kyanite mining.

The deposits that have yielded the main production of ilmenite in Virginia are the nelsonite dikes, associated with the anorthosite body in Nelson and Amherst counties. It appears that this type of occurrence offers the greatest potential source of ilmenite in Virginia. It is possible that careful field studies and systematic explorations conducted along the strike, northeast and southwest of the present known deposits, will reveal other dikes containing commercially workable deposits of ilmenite. Deposits similar to those in Nelson and Amherst counties occur near Vinton in Roanoke County.

An investigation was made in 1946 by the U. S. Bureau of Mines of the Bush-Hutchins ilmenite-bearing property near Vinton in Roanoke County, which was said to be one of the most promising ilmenite prospects in the State outside the Amherst-Nelson counties area. The results of this investigation were published as U. S. Bureau of Mines, Report of Investigation No. 4112, August 1947.

Soft Rock and Sand Deposits

Too little information is available at this time to form any definite conclusions regarding the potential possibilities of soft rock and sand deposits of rutile and ilmenite in Virginia. However, because sand deposits, particularly beach sand deposits, are important world sources of both rutile and ilmenite, it appears that exploratory investigations of such possible sources in the State may reveal commercial deposits of this type in Virginia.

Suggested areas for prospecting would be in beach sands along the Atlantic Coast and along the major rivers and their tributaries in the Coastal Plain region; also terrace deposits in the Coastal Plain region and possible placer or stream sand deposits at the mouths and along the lower portions of the streams in this and the eastern part of the Piedmont region, and along the land areas bordering Chesapeake Bay.

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TABLE I

World Production of Rutile, 1925 to 1951, inclusive, by Countries *
(In metric tons)

Year	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938
Australia													1,195	468
Brazil								35	96	116	287	768	377	488
Cameroon (French)											45	55	103	118
Norway	52	50	45	59	43	46	21	30	56	247	124	198	187	124
South West Africa												54	16	
United States	42	27												
World Total(a)	94	77	45	59	43	46	21	65	152	363	456	1,075	1,878	1,198

Year	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951
Australia	718	1,643	3,816	5,503	5,717	8,843	9,901	8,283	13,406	15,348	14,206	18,379	33,718
Brazil	489	499	2,369	4,615	4,557	1,564	160	28	5				
Cameroon (French)	160	503	1,399	2,400	2,735	3,320	1,440	1,260	755	576	403	25	
India		934	1,891	2,295	2,396	1,672	620	262	160	129			
Norway	166	156	172	77	116	85	76	63	51		16		
United States		2,620	2,839	2,402	3,617	6,279	6,513	6,761	7,767	6,695	10,875	5,600	
World Total(a)	1,533	6,252	12,887	17,292	19,904	21,763	18,710	16,657	22,144	22,748	25,500	25,320	42,000

* From U. S. Bureau of Mines, Mineral Resources of the United States, 1925-1931; Minerals Yearbook, 1932-1951.

(a) Revised figures includes miscellaneous estimated (unreported) production.

T A B L E II

World Production of Ilmenite, 1925 to 1951, Inclusive, by Countries,*
(In metric tons)

Year	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938
Australia									559				678	462
Brazil	1,500	1,498	1,307	1,498	6,361	80		35				9	234	317
Canada	3,609	181	1,841	2,036	2,493	374	1,369			1,835	2,076	2,328	3,836	188
Egypt								487		164	183	24	317	90
India	332	4,304	18,095	25,713	24,050	29,238	36,748	50,856	53,830	76,858	129,090	141,327	182,142	256,268
Malay States (a)									204	51	2,540	10,376	6,290	6,462
Norway	4,612	4,200	5,733	7,948	7,923	7,630	5,000	13,431	23,213	26,306	37,984	67,194	84,209	62,724
Portugal	3	1,030	703	3,140	56	834	152	766	645	434	264	183	1,456	568
Senegal	181	5,748	5,200	2,110	7,240	5,322	1,074		370	490	1,250	3,227	3,075	8,436
United States	5,049	4,366	3,175											
World Total(b)	15,286	21,327	36,054	42,445	48,123	43,478	44,343	65,625	78,821	106,138	173,387	224,668	282,237	335,515

Year	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951
Australia	683	1,538	3,779	4,588	5,717	7,287	8,494	6,716	10,475	11,756	10,839	12,417	
Brazil	10	12	4,471			3,250	5,000			7,900	650		
Canada	3,351	4,114	11,477	9,100	62,992	30,820	12,834	1,275	6,445	4,029	490	3,177	19,235
Egypt		465	2	691		9	46	146		1,601	635	260	317
India		267,376	131,111	49,977	33,041	102,412	174,848	187,993	265,143	233,098	313,126	216,076	143,174
Malaya(a)	11,098	2,596							13,291	12,909	20,034	25,315	42,341
Norway	55,027	51,700	61,086	60,713	66,191	63,975	28,312	52,574	69,711	90,017	99,013	105,000	105,000
Portugal	502	899	798		121		301	633	243	155	680	47	34
Senegal	4,268	7,082	1,000	4,840	730		3,200	4,191	11,282	3,690	8,338	540	2,500
Spain			71	85	178	548	216	128	150	181	376	637	700
United States	13,247	18,750	21,135	70,042	184,657	252,749	279,880	256,230	305,296	348,126	364,989	424,851	486,099
World Total(b)	88,186	354,532	234,930	200,036	358,627	461,050	513,131	509,886	682,036	713,462	819,170	788,320	799,400

*From U. S. Bureau of Mines, Mineral Resources of the United States, 1925-1931, Minerals Yearbook, 1932-1951.
(a) In February 1948 the previously designated Federated Malay States became Malaya.
(b) Revised figures, include miscellaneous estimated (unreported) production.

TABLE III

Production and Value of Titanium Ores in the United States
1880 to 1900, inclusive*
(In pounds)

Year	Quantity	Value
1880	300	$ 400
1881	200	700
1882	500	1,800
1883	550	2,000
1884	600	2,000
1885	600	2,000
1886	600	2,000
1887	1,000	3,000
1888	1,000	3,000
1889	1,000	3,000
1890	400	1,000
1891	300	800
1892	100	350
1893	No reported production	
1894	150	450
1895	100	350
1896	100	350
1897	100	350
1898	140	700
1899	230	1,030
1900	300	1,300
Total U. S. Production, 1880-1900	8,270	$ 26,580

* From U. S. Geological Survey, Mineral Resources of the United States, 1906, pp. 13-65, 1907.

TABLE VII

Consumption of Titanium Minerals (Rutile and Ilmenite)
in the United States, 1941-1951, inclusive*
(In short tons)

Year	Rutile	Ilmenite
1941	6,361	275,106
1942	10,616	257,535
1943	17,634	302,822
1944	14,813	360,941
1945	9,791	381,178
1946	7,134	404,283
1947	7,692	479,524
1948	10,230	565,000
1949	11,888	510,608
1950	11,721	679,244
1951	17,227	713,363

* From U. S. Bureau of Mines, Minerals Yearbook 1951, p. 1272, 1954

TABLE IV

Annual Production and Value of Titanium Ores in the United States
1901 to 1928, inclusive*
(In short tons)

	Rutile		Ilmenite	
Year	Quantity	Value	Quantity	Value
1901	34	$14,297		
1902	none reported			
1903	54			
1904	43			
1905	16			
1906	41			
1907	118			
1908	16			
1909	100	10,000		
1910	566	44,480		
1911	no production reported			
1912	275	27,500		
1913	305	49,000	240	
1914	94	11,280	89	$ 4,895
1915	250	25,000	300	2,500
1916	110	16,500	95	1,900
1917	206	32,960	1,339	12,667
1918	261	39,150	1,644	18,600
1919	102	20,400	106	2,120
1920	277		268	no value given
1921	no production reported		no production reported	
1922	310		5,181	
1923	270		6,270	
1924			4,769	76,300
1925	46	11,000	5,566	89,000
1926	30	7,500	4,813	77,000
1927	524	129,861	3,500	44,000
1928	176	37,700	918	21,000

Total U. S. Production, 1901-1928

Rutile	4,224	$476,628
Ilmenite	35,098	$349,982

* From U. S. Geological Survey, Mineral Resources of the United States, 1901-1924; U. S. Bureau of Mines, Mineral Resources of the United States 1925-1938.

TABLE V

Production and Value of Titanium Concentrates from Domestic Ores in the United States
1939 to 1951, inclusive *
(In short tons)

Year	Rutile Production Short Tons	Rutile Shipments TiO_2 Content	Rutile Value	Ilmenite Production Short Tons	Ilmenite Shipments TiO_2 Content	Ilmenite Value
1939	no information			14,602	7,668	$ 137,042
1940	2,888	2,475	$ 393,243	20,668	9,505	183,686
1941	3,130	3,192	493,782	23,297	9,930	196,522
1942	2,648	2,466	410,956	77,208	41,328	1,805,823
1943	3,987	3,639	610,879	203,551	94,283	3,738,970
1944	6,922	6,312	1,088,112	278,610	128,095	7,371,279
1945	7,179	6,414	869,920	308,516	141,852	7,359,170
1946	7,453	7,046	996,989	282,447	130,624	4,878,917
1947	8,562	4,813	533,548	336,533	157,328	5,029,490
1948	7,380	9,226	647,334	383,745	177,447	5,793,973
1949	11,988	9,414	489,798	402,334	186,535	6,212,348
1950	no information			468,320	230,826	5,606,584
1951	no information			535,835	261,982	7,689,272

* From U. S. Bureau of Mines, Minerals Yearbook 1943, 1945 (1947) and 1951 (1954)

TABLE VI

Titanium Minerals (Rutile and Ilmenite) Imported for Consumption in the United States, 1928 to 1951, inclusive*
(In short tons)

Year	Rutile	Ilmenite
1928	no report	17,224
1929	5.60	25,072
1930	3.86	24,973
1931	1.00	33,400
1932	88.20	37,510
1933	88.90	43,443
1934	155	80,310
1935	212	134,390
1936	510	142,740
1937	665	172,547
1938	230	234,275
1939	442	286,576
1940	156	221,641
1941	3,114	166,846
1942	6,423	7,227
1943	9,635	74,787
1944	3,699	104,887
1945	3,304	208,836
1946	4,408	240,952
1947	7,576	301,311
1948	8,771	242,119
1949	3,085	324,157
1950	3,427	216,459
1951	11,023	189,078

* From U. S. Bureau of Mines, Mineral Resources of the United States, 1928-1931; Minerals Yearbook, 1932-1951.