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TITANIUM RESOURCES OF THE WORLD

by

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MINERAL DEPOSITS BRANCH
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ABSTRACT

Titanium is the ninth most abundant element in the crust of the earth. The most common primary titaniferous mineral assemblages are: (1) mixtures of ilmenite, magnetite, and in places other iron oxides; (2) nelsonite, an ilmenite-(and occasionally rutile-) apatite rock; and (3) various aggregates of rutile and brookite. Minerals of secondary deposits are often altered, and usually include some leucoxene. Ilmenite-bearing aggregates occur chiefly in anorthosite complexes, layered norite complexes, gabbroic and basic complexes, and nelsonite bodies; small amounts occur in various other rocks. Rutile and brookite occur in nelsonite bodies, anorthosite, acidic dikes and veins, and complex deposits at Magnet Cove, Ark. The secondary deposits include modern and buried beach sands, stream sands, clay, bauxite, and soils. The theories on origin vary with the deposit, but usually indicate either some method of forceful magmatic intrusion, or replacement phenomena. In the United States, ore is mined in Florida, New York, and Virginia; additional potential reserves occur in Arkansas, California, Minnesota, North Carolina, Rhode Island, and Wyoming. In Canada, ore is produced at Allard Lake and St. Urbain, Quebec; potential reserves occur mostly in Quebec. During the period 1941 to 1950 titanium ores were also produced in Australia, Brazil, China, Egypt, French Cameroons, French Equatorial Africa, India, Japan, Korea, Malaya, Norway, Portugal, Russia, Senegal, and Spain. Potential reserves occur in Ceylon, Finland, Madagascar, New Zealand, Sierra Leone, Sweden, Tanganyika, and Union of South Africa. Numerous other deposits contain variable or unknown amounts of titaniferous minerals, and are cited in this report.

INTRODUCTION

Abundance and uses of titanium

Titanium ranks ninth in abundance of the elements in both the outer ten miles of the earth, and in the igneous rocks of the earth. It comprises 0.62 percent by weight of the crust (Clarke, 1924, p. 36), and 0.48 percent by weight of the igneous rocks of the earth (Rankama and Sahama, 1950, p. 39). The listing of some of the more common titanium and titanium-bearing minerals is shown in Table 1.

Compounds of titanium are widely used by industry in paint pigments, papers, textiles, plastics, inks, ceramics, welding rods, steel alloys, abrasives, cutting tools, electrical apparatus, dyes, and smoke screens. Metallurgical developments since the close of World War II indicate that pure titanium metal and its alloys show great promise as light-weight, strong, heat and corrosion resistant materials for use in structural work and aircraft engines.

Table 1. Principal Titanium and Titanium-Bearing Minerals

Mineral	Formula	Percent TiO_2	Reference
Oxides			
Anatase	TiO_2	98.4-99.8	2 p. 585
Brookite	TiO_2	94.1-98.8	2 p. 591
Maghemite	Fe_2O_3	1.37	2 p. 708
Magnetite	$FeFe_2O_4$	up to 7.57	2 p. 701
Rutile	TiO_2	89.5-99.0	2 p. 557
Ilmenorutile	$Fe^2_x(Nb,Ta)_{2x}Ti_{1-3x}O_2$	41.2-54.6	2 p. 557
Tantalian Rutile	"	45.7-71.2	2 p. 557
Titanates			
Geikielite	$MgTiO_3$	63.8-67.7	2 p. 537
Ilmenite	$FeTiO_3$	48.6-57.3	2 p. 537
Perovskite	$CaTiO_3$	58.7-58.8	2 p. 732
Cerian Perovskite (Knopite)	$(Ca,Ce)TiO_3$	47.6-56.4	2 p. 732
Niobian Perovskite	$(Ca,Nb)TiO_3$	38.7-50.9	2 p. 732
Pyrophanite	$MnTiO_3$	50.5-51.8	2 p. 537
Titano-Silicates			
Sphene	$CaTiSiO_5$	34.4-44.9	1 p. 714
Silicates			
Amphibole	complex	variable up to 2.0	1 p. 403
Biotite	complex	variable up to 4.7	1 p. 634
Garnet (var. schorlomite)	$Ca_3(Fe,Ti)_2((Si,Ti)O_4)_3$	variable up to 22.1	1 p. 448
Olivine	$(Mg,Fe)_2SiO_4$	variable up to 6.1	1 p. 456
Pyroxene (var. titanian augite)	complex	variable up to 9.0	3 p. 560

References

1. Dana, 1911
2. Palache, Berman, and Frondel, 1944
3. Rankama and Sahama, 1950

Purpose and scope of the report

This report has been prepared to provide information on the geologic occurrence and resources of titanium throughout the world. It is based solely on published material, most of which is in the library of the U. S. Geological Survey at Washington, D. C. The report does not include any new or unpublished data from field work, but contains information that is found in the articles listed in the bibliography.

The first section of the report concerning geology and mineralogy contains information from publications that were available in the U. S. Geological Survey, Washington, D. C. up to December 1, 1953. The section on descriptions of individual deposits contains information available during the spring of 1952. Therefore, material more recent than early 1952 has not been included in descriptions of deposits.

The word ore is used in this report to describe titaniferous mineral aggregates that could be profitably mined during the summer of 1953. In places it is necessary to refer to writings of authors who have used the term in a looser sense, and in these cases the word is enclosed in quotation marks, so as to distinguish it from ore in the true commercial sense. In parts of the report, direct quotes from other sources use the word ore. The quoted authors, however, may not have intended to imply commercial usability, but may have referred only to those portions of a deposit that contained the titanium minerals.

The author has attempted to give factual reports on geology and reserves, and to introduce a minimum of his own personal interpretations. In some cases, however, it has been necessary to evaluate certain statements in view of findings more recent than those of a given article. This is true of the use of "arizonite", and other mineralogical terms. In some cases, the validity of mineralogical descriptions of a deposit can be questioned, especially if such descriptions are based on insufficient chemical analyses or petrographic work.

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Thanks are due Dr. Olof H. Ödman of the Swedish Geological Survey, who kindly supplied information and provided references on titaniferous deposits in Sweden. Miss Inna Poiré and Miss Taisia Stadnichenko of the U. S. Geological Survey very kindly translated several articles in Russian. Mrs. Barbara Knapp aided by translating an article in Swedish.

PRINCIPAL TITANIUM-BEARING MINERALS IN DEPOSITS

The principal titanium-bearing minerals in deposits are the iron-titanium oxides ilmenite and titanian-magnetite, and the oxides anatase, brookite, and rutile. Sphene may be used as an ore in the Kola Peninsula of Russia, and some interest has recently been shown in perovskite.

Anatase (TiO_2)

Anatase (formerly called octahedrite) has the same chemical composition as rutile (TiO_2), but has different properties and habit; it is known as a polymorph of TiO_2. It crystallizes in the tetragonal system, usually as highly modified crystals with an octahedral habit, and less commonly a tabular habit. Its color is various shades of brown, including yellowish and reddish brown, passing into indigo-blue and black, with paler greens and blues much rarer. It has a colorless to pale yellow streak, subconchoidal fracture, adamantine or metallic adamantine luster, hardness of $5\frac{1}{2}$ to 6, a specific gravity of 3.90, and is brittle. It is essentially TiO_2; two chemical analyses show that it has 98.36 to 99.75 percent TiO_2 and 0.25 to 1.11 percent Fe_2O_3, with one sample having 0.20 percent SnO_2 (Palache, Berman, and Frondel, 1944, p. 585).

"Arizonite"

Although Palache, Berman, and Frondel (1944, p. 773) indicate that "arizonite" is $Fe_2O_3 \cdot 3\ TiO_2$, recent work has shed considerable doubt on the existence of such a mineral species. Examination of X-ray photographs by Overholt, Vaux and Rodda (1950) showed that, "arizonite is an impure mixture of hematite, ilmenite, anatase, and rutile. All of the lines in the pattern can be accounted for by these compounds. This is sufficient evidence to discredit the mineral." These authors believe that the partial destruction of the ilmenite crystal structure by oxidation results in an excess of ferric iron over that common in ilmenite, and produces the mineral assemblage listed above.

Brookite (TiO_2)

Brookite, another polymorph of TiO_2, occurs only as orthorhombic crystals of varied habit, usually tabular. It is brown to yellowish and reddish brown in color, with an uncolored to grayish and yellowish streak, metallic adamantine to submetallic luster, subconchoidal to uneven fracture, a hardness of $5\frac{1}{2}$ to 6, a specific gravity of 4.14, and is brittle. It is essentially TiO_2, with small amounts of ferric iron apparently substituting for titanium; the following analyses are from Palache, Berman, and Frondel (1944, p. 591):

	1	2	3
TiO_2	98.78	98.59	94.09
Fe_2O_3	1.43	1.41	4.50
Rem	--	--	1.40
Total	100.21	100.00	99.99
G		4.13	3.83

1. Magnet Cove, Arkansas. (arkansite)

2. Snowdon, Wales

3. Urals.

Rem. is ignition loss.

Hematite (Fe_2O_3)

Hematite crystallizes in the hexagonal system and occurs as thin to thick tabular crystals, or as pseudo-cubic crystals. Commonly it has columnar to granular, botryoidal or stalactitic shapes. In ilmenite ores it commonly occurs as small intergrowths, less than 1 mm thick, with ilmenite. It has a dark steel-gray or iron-black color, a reddish brown streak, a metallic to submetallic luster, a hardness of 5 to 6, and a specific gravity of 5.26 (Palache, Berman, and Frondel, 1944, p. 528). It is all ferric oxide, Fe_2O_3, with 69.94 percent Fe, and 30.06 percent O. Some titanium is usually present, but analyses showing high amounts are probably caused by admixed ilmenite.

Ilmenite ($FeTiO_3$)

Ilmenite crystallizes in the hexagonal system and may form tabular or rhombohedral crystals, but is more commonly found in compact or granular masses or as disseminated grains. It is iron-black, has a black streak, metallic to submetallic luster, a basal parting, conchoidal fracture, hardness of 5 to 6, a specific gravity of 4.72, is slightly magnetic, and shows twinning. Although part of an iron, magnesium, and manganese titanium-oxide series $(Fe,Mg,Mn)TiO_3$, ilmenite contains only minor amounts of magnesium and manganese, and not more than 6 percent by weight of Fe_2O_3 at ordinary temperatures. Higher amounts of Fe_2O_3 shown in some analyses are presumably due to admixed hematite or magnetite. Table 2, taken from Palache, Berman, and Frondel (1944, p. 537), shows that ordinary ilmenite (crichtonite of some authors) contains 48.6 to 57.3 percent TiO_2 and 24.15 to 45.83 percent FeO. Excess TiO_2 reported in some analyses may be due to admixed rutile, which is known to form intimate mixtures with ilmenite.

In polished sections, ilmenite often shows intergrowths and regularly arranged exsolution lamallae of hematite, maghemite, magnetite, rutile, and spinel.

Minerals related to ilmenite include geikielite ($MgTiO_3$) and pyrophanite ($MnTiO_3$).

Table 2. Selected analyses of ilmenite [1]

	1	2	3	4	5	6	7	8	9	10	11
TiO_2	52.66	52.37	52.50	51.32	54.20	48.64	50.02	52.42	56.43	48.88	57.29
Fe_2O_3	—	—	—	2.10	2.58	5.57	6.03	6.82	7.16	8.94	1.87
FeO	47.34	45.83	44.32	42.38	42.85	41.76	40.87	40.80	33.91	25.44	24.15
MgO	—	1.25	0.79	—	—	0.88	1.72	—	2.10	6.26	15.97
MnO	—	—	1.36	3.37	—	1.10	0.48	0.22	—	2.60	1.10
Rem	—	—	0.06	0.36	—	1.66	1.08	—	—	7.68	0.37
Total	100.00	99.81	99.03	99.53	99.63	99.61	100.20	100.26	99.60	99.80	100.75
Sp. gr.	4.79	—	4.755	4.711	—	—	4.68	4.751	—	4.44	4.345

1. Calculated $FeTiO_3$
2. Mt. Ruwenzori, Belgian Congo
3. Sundsvale, Sweden. Rem. is CaO
4. Ambatofotsikely, Madagascar. Rem. is SiO_2 0.16, U_3O_8 0.20
5. Chibinsky Tundra, Siberia
6. Sasso di Chiesa, Val Malenco, Lombardy. Rem., SiO_2 0.60, Al_2O_3 0.91, H_2O 0.15
7. Val Devero, Ossola, Italy. Rem., SiO_2 0.76, Al_2O_3 0.20, H_2O 0.12.
8. Ferenczfalva, Komitat Krassozörény, Carpathians.
9. Chibinsky Tundra, Siberia
10. Pelotas, Brazil. Grains Rem., SiO_2 5.30, CaO 2.38
11. Layton's Farm, Warwick, N. Y. Rem. is SiO_2

[1] From Palache, Berman, and Frondel, 1944, p. 537.

Leucoxene

Palache, Berman, and Frondel (1944, p. 560) say of leucoxene: "A name loosely applied to dull, fine-grained, yellowish to brown alteration products high in titanium. Found as an alteration product of sphene, ilmenite, perovskite, titanium magnetite, or other titanium minerals. The material consists in most instances of rutile; also, less commonly, of anatase,.... or sphene."

Most investigators have found that leucoxene consists either of fine-grained rutile or anatase, or mixtures of these with hydrous or anhydrous amorphous material. The investigators do not agree, however, upon the exact composition of the crystalline material nor upon the relative amount, if any, of amorphous material present. (Allen, 1950; Broughton and others, 1950, p. 266; Creitz and McVay, 1948, p. 5-6; Hutton, 1950, p. 666-667; 1952, p. 49; Tyler and Marsden, 1938). Because differences of opinion exist concerning the precise nature of leucoxene, it would seem best to follow the advice given by Allen (1950), in his conclusions. He says, "leucoxene should be retained as a petrographic term for the alteration product in which titania occurs in rocks, but it must not be used as a mineral name implying a definite mineral species."

Maghemite (Fe_2O_3)

According to Palache, Berman, and Frondel (1944, p. 708) maghemite crystallizes in the isometric system, and is related to magnetite and the spinel group. It is brown in color, has a brown streak, a hardness of ~5, and is highly magnetic. In polished sections it is isotropic and shows a white to grayish blue color. The specific gravity is not given. Some partial analyses follow:

	1	2	3	4	5	6
FeO	8.67	2.40	12.16	7.09	12.03	8.96
Fe_2O_3	89.15	85.3	66.01	71.51	67.7	64.34
TiO_2	1.37	—	5.34	9.6	7.55	8.54
Cr_2O_3	—	—	0.35	n.d.	tr.	tr.
V_2O_3	—	—	0.5	0.99	n.d.	0.14
Rem.	1.19	7.40	—	—	—	—

1. Alameda County, Calif. (Palache and others, 1944, p. 708). Rem. is SiO_2 1.15, Al_2O_3 0.04, MgO and CaO trace. Mixture of magnetite and maghemite.

2. Iron Mt., Shasta County, Calif. (Palache and others, 1944, p. 708). Rem. is H_2O 3.1, insol. 1.80, volatiles 2.5, CaO present.

3-6. Near Pretoria, South Africa (Frankel and Grainger, 1941, p. 104). Maghemite with included ilmenite laths.

It is generally believed that maghemite forms by the oxidation of magnetite, or by dehydration of lepidocrocite. Many analyses are of material which has been observed only in polished sections of titaniferous magnetite ores. The existence of maghemite in these ores is based principally upon the excess Fe_2O_3 that remains after FeO has been combined with TiO_2 to make normative ilmenite. Because the observed material is isometric, and because the analyses show excess normative Fe_2O_3, it has been argued that maghemite is present.

Strauss (1947) throws considerable doubt on the existence of maghemite in the titaniferous ores of the Bushveld in South Africa. Detailed polished section work on these magnetite-ilmenite-maghemite ores led him to conclude that the grayish-white mineral, usually identified as maghemite, is the oldest mineral in the section. Although it is impossible to make positive identification of magnetite in the sections some is probably present, but would naturally then have to be younger than the grayish-white mineral. It is therefore doubtful if this grayish-white material is maghemite, because maghemite is generally believed to be younger than magnetite. Strauss (p. 46) says, ... "The use of the term 'maghemite' for the gray Bushveld ore therefore appears to be unjustifiable.... It is possible that the Bushveld 'magnetite' was originally a complex, variable and unstable compound of the general form $(Fe^2, Mn, Mg, Ti^2)(Fe^3, Al, Cr, V, Mn, Ti^3)_2O_4$, which under certain conditions broke down to the inhomogeneous material now known."

Magnetite ($FeFe_2O_4$)

Magnetite crystallizes in the isometric system as octahedral or sometimes dodecahedral crystals, or may occur in massive, granular, coarse or fine aggregates. Its color is black to brownish black and the streak is black. It has a parting parallel to the octahedron faces, a metallic to semimetallic luster, a hardness of $5\frac{1}{2}$ to $6\frac{1}{2}$, a specific gravity of 5.175, and is strongly magnetic.

Oriented growths of magnetite with other minerals have been observed, some of which are as follows. Minerals that are included within magnetite include hematite, hercynite(?), ilmenite, and pyrophanite. Magnetite occurs as inclusions within hematite, ilmenite, and muscovite. Overgrowths of chlorite, hematite, and rutile have been observed on magnetite. Overgrowths of magnetite have been noted on hematite and olivine.

The general formula of magnetite is AB_2O_4 where A is Mg, Fe^2, Zn, Mn, and less often Ni, and B is essentially Fe^3, with Al, Cr, Mn^3, and V^3 substituting for the Fe^3 in comparatively small amounts. Titanian magnetite (also called titanomagnetite or titaniferous magnetite) may contain as much as 7.5 percent TiO_2, substituting perhaps for both ferric and ferrous iron in the lattice. Most analyses on supposedly high-titanium magnetite were obviously made on nonhomogeneous material containing what was probably considerable exsolved ilmenite (Palache, Berman, and Frondel, 1944, p. 702). Analyses of titanian magnetite are given in Table 3.

Table 3. Analyses of titanium-bearing magnetites _/

	1	2	3	4	5	6	7	8	9
Fe_2O_3	68.85	68.92	61.71	59.71	54.97	23.98	46.95	61.95	59.01
FeO	30.78	29.32	25.66	22.70	26.69	40.10	26.58	18.72	16.82
TiO_2	Tr	Tr	2.35	5.32	7.57	32.20	5.01	1.31	2.40
Al_2O_3	0.21	—	—	0.62	5.64	1.74	15.14	6.57	10.37
MgO	Tr	—	Tr	3.24	5.15	0.70	5.83	6.74	9.47
MnO	—	Tr	8.20	8.46	—	0.42	—	3.40	2.10
SiO_2	0.27	—	0.59	0.16	0.14	0.10	0.13	1.10	—
Rem.	Tr	1.76	1.44	—	0.10	—	0.11	—	—
Total	100.11	100.00	99.95	100.21	100.26	99.24	99.75	99.79	100.17
G				4.913		4.725			4.558

1. Magnetite, Lover's Pit, Mineville, N. Y. Rem. is CaO, trace.
2. Magnetite, nickeloan. Pregrattan, Tirol. Rem. is NiO, 1.76.
3. Magnetite, chromian and manganoan. Siberia. Rem. is Cr_2O_3 1.42, ignition loss 0.02.
4. Magnetite, manganoan and titanian. St. Joseph du Lac, Quebec.
5. Magnetite, titanian. Norway. Rem. is CaO, 0.10.
6. Magnetite, titanian(?). Near Vaskapu, Hungary.
7. Magnetite, aluminian. Magnet Cove, Ark. Rem is CaO, 0.11.
8. Magnetite, magnesian and aluminian. Schelingen, Kaiserstuhl, Germany. Average of two analyses.
9. Magnesioferrite, ferroan. Magnet Cove, Ark.

_/ From Palache, Berman, and Frondel, 1944, p. 700-701.

Perovskite ($CaTiO_3$)

Although perovskite morphologically shows isometric symmetry, detailed microscopic and X-ray studies indicate that it may be orthorhombic, or, more likely, monoclinic (Palache, Berman, and Frondel, 1944, p. 730). It occurs as pseudo-isometric cubes which commonly have irregularly distributed faces that are striated parallel to the sides; it occasionally occurs as reniform masses showing small cubes. Its color is black, grayish black, or reddish brown to yellow; it has a colorless to grayish streak, an adamantine to metallic-adamantine luster, a hardness of $5\frac{1}{2}$, and a specific gravity of 4.01 ± 0.04. The composition is essentially calcium titanium oxide ($CaTiO_3$) with various substitutions possible. In dysanalyte, a niobium-rich variety, niobium substitutes for titanium up to the ratio of 2 parts of niobium to 5 parts of titanium. In knopite, a cerium- and rare earth-rich variety, cerium and other rare earths substitute for calcium up to 4 parts of rare earths to 7 parts of calcium. Some analyses from Palache and others (1944, p. 732) follow:

	1	2	3	4	5	6	7
Na_2O	—	—	—	0.79	n.d.	4.37	Tr
CaO	41.24	40.29	38.35	33.32	11.00	25.60	21.69
MgO	—	—	—	—	0.24	—	Tr
FeO	—	0.86	2.07	4.19	1.70	9.22	1.81
$(Y, Er)_2O_3$	—	—	—	—	4.43	—	—
$(Ce,La)_2O_3$	—	—	—	6.81	32.75	2.80	8.80
SiO_2	—	—	—	—	Tr	2.21	Tr
TiO_2	58.76	58.63	58.66	54.12	47.59	50.93	39.90
Nb_2O_5	—	—	—	—	—	4.86	22.32
Rem	—	—	—	0.59	1.07	0.23	4.93
Total	100.00	99.78	99.08	99.82	98.78	100.22	99.45

1. $CaTiO_3$.
2. St. Ambrogio, Piedmont, Italy.
3. Oberwiesenthal, Saxony.
4. Cerian perovskite (knopite). Norrvik, Alnö region, Sweden. Rem. is K_2O 0.38, H_2O 0.21.
5. Cerian perovskite(?), Siberia. Rem. is MnO 0.84, ign. loss 0.23.
6. Niobian perovskite (dysanalyte). Vogtsburg, Kaiserstuhl, Germany. Rem. is MnO 0.23.
7. Niobian perovskite. Uva Province, Ceylon. Rem. is MnO 0.17, Fe_2O_3 4.76. $(Ce,La)_2O_3$ contains Ce 60 percent, La 25 percent, Di 10 percent.

Rutile (TiO_2)

Rutile crystallizes in the tetragonal system as prismatic, often slender to acicular, crystals showing a vertically striated or furrowed prism zone. Geniculated and contact twins of varied habit are common. It also occurs as coarse to fine granular massive masses. The color is reddish brown, passing into red, although yellowish, bluish, violet, black, and rarely grass-green varieties are known. The streak is pale-brown to yellowish. Ferrian, niobian, and tantalian varieties are black with gray or greenish black streak, and a chromian variety is green to black. Rutile has a distinct prismatic cleavage, a metallic adamantine luster, conchoidal to uneven fracture, a hardness of 6 to 6½, and a specific gravity ranging from 4.23 for essentially pure TiO_2 to 5.6 for niobian and tantalian varieties. Although it is essentially TiO_2, important amounts of niobium, tantalum, and ferrous iron are reported. The formula for these varieties may be written $Fe^{2}_{x}(Nb,Ta)_{2x}Ti_{1-3X}O_2$, where x does not exceed about 0.2. The significant amount of ferric iron in many analyses indicates a possible further complication of the rutile formula. Table 4, from Palache, Berman, and Frondel (1944, p. 557), indicates several varieties of rutile including a ferrian variety with up to about 11 percent of ferric iron in substitution(?) for Ti, a tantalian variety with tantalum and niobium substituting for titanium, and a niobian variety (also called ilmenorutile) with more niobium than tantalum substituting for the titanium.

Table 4. Analyses of rutile [1]

	1	2	3	4	5	6	7	8	9
TiO_2	98.96	97.46	91.96	89.49	71.15	45.74	41.20	53.04	54.57
Fe_2O_3	—	2.62	6.68	11.03	—	—	—	—	—
FeO	0.78	—	—	—	15.84	8.27	11.38	10.56	12.29
Nb_2O_5	—	—	—	—	—	6.90	23.48	21.73	32.15
Ta_2O_5	—	—	—	—	10.14	35.96	23.48	14.70	—
SnO_2	—	—	1.40	—	0.05	2.67	—	—	—
Rem.	0.54	—	—	0.45	1.80	0.70	0.68	Tr	0.11
Total	100.28	100.08	100.04	100.97	98.98	100.24	100.22	100.03	99.12
G.	4.264	—	4.249	4.41	4.91	5.30	5.54-5.59	5.14	4.64

1. Prilepec, Serbia. Rem. is Cr_2O_3 0.03, V_2O_3 0.13, H_2O 0.38.
2. Graves Mt., Georgia. Average of three analyses.
3. Ferrian rutile, West Cheyenne Canyon, Colo. 0.7 percent quartz deducted.
4. Ferrian rutile (nigrin), Bernau, Bavaria.
5. Tantalian rutile (strüverite), Ampangabé, Madagascar. Rem. is Al_2O_3 1.80.
6. Tantalian rutile (strüverite), Perak, Malaya. Rem. is SiO_2 0.20, MnO trace, H_2O 0.50.
7. Niobian rutile, Craveggia, Piedmont, Italy. Rem. is CaO 0.51, MgO 0.17, MnO trace. Average of two analyses.
8. Niobian rutile (ilmenorutile). Ilmen Mts., Russia. Rem. is CaO.
9. Niobian rutile (ilmenorutile), Iveland, Southern Norway. Rem. is CaO 0.11, MgO trace.

[1] From Palache, Berman, and Frondel, 1944, p. 557.

Sphene ($CaTiSiO_5$)

Sphene crystallizes in the monoclinic system and commonly occurs as wedge-shaped or flattened crystals, that may be twinned, or as prismatic crystals; sometimes it occurs in massive or compact aggregates. It has rather distinct prismatic cleavage, a brown, gray, yellow, green, rose-red or black color, a white streak, an adamantive to resinous luster, a hardness of 5 to 5.5, and a specific gravity of 3.4 to 3.56. Analyses from Dana (1911, p. 714) show that it contains 34.44 to 44.92 percent TiO_2, 22.25 to 29.59 percent CaO, 29.12 to 34.57 percent SiO_2, and none to 7.84 percent Fe_2O_3, with minor amounts of FeO, MgO, MnO, or Al_2O_3.

MINERALOGY OF COMMON TITANIFEROUS AGGREGATES

The naturally occurring titaniferous aggregates consist not of a single titanium-bearing mineral but rather of many minerals, including gangue, often intergrown with one another. The titanium deposits are divided into primary, those found in bedrock; and secondary, those derived from the primary deposits by processes of weathering.

Primary

The following descriptions of the primary deposits discusses principally the composition and characteristics of the titaniferous minerals, whereas the relationship between these minerals and country rock, and information on composition and relative amounts of gangue are discussed in the section on geology. The titaniferous minerals of the primary deposits include: (1) ilmenite-bearing aggregates that range from almost pure ilmenite to mixtures of ilmenite and magnetite; (2) rutile-bearing mixtures that may either occur with the ilmenitic ones, or may be entirely different; and (3) brookite-bearing deposits.

Ilmenite

The only commercially exploitable body of pure ilmenite occurs at the Yadkin Valley deposit, Caldwell County, North Carolina. Polished sections of ore examined by Singewald (1913b, p. 85) showed no evidence of intergrowths, and indicated that the individual grains averaged less than half a millimeter and rarely exceeded 1 mm. Singewald believed the deposit was almost pure ilmenite because of the homogeneous character, and because analyses of ore (including gangue) indicated a maximum of 41 percent TiO_2.

Ilmenite-hematite

Ilmenite-hematite deposits consist of ilmenite with as much as 20 percent included hematite, and are especially common in many Canadian deposits such as Allard Lake, Ivry, and St. Urbain, Quebec. The ore at Allard Lake is dense black coarse-grained ilmenite in thick, tabular, well-formed crystals that include about 15 to 20 percent hematite. The hematite occurs as oriented, discontinuous blades, the larger of which may also contain smaller blades of included ilmenite which in turn contain still smaller blades of hematite. Analyses indicate the ore contains as much as 36 percent TiO_2 (Hammond, 1949, p. 120; 1952, p. 644).

The ore of St. Urbain is massive black crystalline aggregates of ilmenite that average an eighth to a quarter of an inch in diameter, and contain about 20 percent hematite as intergrown lamellae about 0.2 mm wide. These hematite lamellae are essentially parallel within a given ilmenite grain, and their length greatly exceeds their width. Minor fluctuations in width generally occur along their length, and they commonly taper abruptly at the ends. The presence of smaller parallel lamellae between the larger ones gives the ore an appearance similar to the perthitic structure of perthite feldspar (Gillson, 1932, p. 565-566; Mawdsley, 1927, p. 45; Warren, 1918, p. 433-434).

Ilmenite-magnetite

The most common ilmenite-bearing assemblages contain magnetite. These vary from coarse-grained aggregates of essentially homogeneous ilmenite and magnetite with little or no gangue, to aggregates of finely intergrown ilmenite and magnetite with large amounts of gangue. Such a large number of gradations exist between these two extremes that only some of the more common ilmenite-magnetite mixtures will be described below.

Some of the occurrences at Lake Sanford, N. Y., are characteristic of the better, coarse-grained ilmenite- and magnetite-bearing deposits. The individual grains of ilmenite and magnetite at the National Lead Company deposit average 1 to 3 mm in diameter, and commonly the subhedral ilmenite is embayed by anhedral magnetite. Intergrowths are apparently rare within ilmenite, but small intergrowths of ilmenite within magnetite are common, especially in the ores within anorthosite. These intergrowths in magnetite occur as small discontinuous plates and small "flecklike intergrowths" of ilmenite, both parallel to the octahedral planes of the magnetite, and as small irregular concentrations of ilmenite between magnetite grains (Stephenson, 1948, p. 412-416). Calculations based on Stephenson's observations of polished sections indicate an average of 46.7 percent magnetite and 39.8 percent ilmenite. Analyses of this rich ore show 20.7 to 24.7 percent TiO_2 and 46.6 to 53.4 percent Fe (Balsley, 1943, p. 115).

Ilmenite-magnetite deposits characterized by numerous inclusions of ilmenite within magnetite are more common than the occurrences described above. Coarse intergrowths of ilmenite within magnetite are found in material from the Tuscarora mine, Guilford County, North Carolina. According to Singewald (1913b, p. 88) ilmenite grains comprise one-fifth to two-fifths of a polished section, and range in size from 0.2 mm to 2.0 mm. Magnetite grains are evidently larger (Singewald does not state their size) and contain coarse, plate-like intergrowths of ilmenite that are spaced 0.2 to 0.5 mm apart, average 0.1 mm in width and 2 mm in length, and attain a maximum length of 4 mm.

Variations in the size and type of inclusions are typical of titaniferous material from Iron Mountain, Wyoming and Lake and Cook Counties, Minnesota. The Minnesota deposits contain variable amounts of ilmenite and magnetite, and have many kinds of ilmenite inclusions within the magnetite. The smallest inclusions of ilmenite within magnetite are submicroscopic and merely give polished surfaces of magnetite "a dull-gray mottled effect to a bright iridescent effect." The size of these inclusions also ranges up to coarse networks of ilmenite laths within magnetite, that have a maximum length of 2 to 3 mm (Singewald, 1913b, p. 109). At Iron Mountain, Wyoming, the number of intergrowths is evidently proportional to the amount of gangue. The rich "ores" have very few intergrowths, but the "lean ores" are characterized by numerous inclusions within magnetite. Spinel forms "dot-like" inclusions, and ilmenite forms a minute network of lamellae that are visible only under high magnification and are parallel to the octahedral planes of the magnetite (Warren, 1918, p. 429-430). Newhouse and Hagner (1951, p. 13) also claim that, "the ilmenite lamellae range in size from those observable only under high magnification to others which can be seen with the naked eye."

The most minute and largest number of ilmenite inclusions is found in deposits such as Iron Mine Hill, Rhode Island, and Taberg, Sweden. The following description of the ilmenite and magnetite in the Rhode Island deposit is essentially a paraphrasing of Singewald's description (Singewald, 1913b, p. 45-46). Polished and etched ilmenite-magnetite surfaces have individual grains of ilmenite that form "only a small percentage of the ore" and rarely have a maximum dimension of 2 mm. The greater part of the "ore" has a dull-black background on which a reticulate structure of ilmenite in magnetite is developed. This structure is "marked by the minuteness of the lines and the closeness with which they are crowded." They range in fineness from sizes that are not resolvable with a magnification of 60 times, to lines which have a maximum length of 0.15 mm.

Warren (1918, p. 432-433) indicates, however, that the ilmenite and magnetite form a mesh-like matrix surrounding the silicate minerals. He recognizes two kinds of inclusions within the magnetite: (1) a coarse-grained intergrowth of a silicate mineral, probably spinel, parallel to the octahedral planes, and (2) a very fine-grained intergrowth of ilmenite, that is also essentially parallel to the octahedral planes. This intergrowth is much finer than anything shown by Singewald.

The titaniferous material at Taberg, Sweden (Hjelmqvist, 1949, p. 19-20) consists solely of 0.2 to 1 mm grains of titano-magnetite, with lamellar intergrowths of magnesium-spinel and ilmenite. The spinel laths, which have a maximum length of 0.2 mm and a width of 2 microns, are generally parallel to the cubic faces of the magnetite. The ilmenite lamellae are parallel to the octahedral faces of the magnetite and are generally only 0.01 to 0.05 mm long and 0.1 to 0.2 microns thick. Chemical analysis of the titano-magnetite showed it contained 15.3 percent TiO_2, 36.7 percent FeO, and 32.4 percent Fe_2O_3, in addition to 6.2 percent Al_2O_3 and 4.4 percent MgO.

An ilmenite-magnetite occurrence with minor amounts of hematite is found in the Egersund region of Norway. Ilmenite and magnetite, which both occur as grains 3 to 5 mm in diameter, contain inclusions of albite and spinel. In addition, the ilmenite contains small needles of hematite, 0.02 to 0.03 mm long, and one micron thick. One sample had 23.8 percent TiO_2, 36.6 percent FeO, and 36.0 percent Fe_2O_3 (Evrard, 1944, p. B117).

Ilmenite-magnetite-maghemite

Deposits of ilmenite, magnetite, and maghemite, with minor amounts of other iron-bearing minerals are common in the Bushveld complex of South Africa. The mineral assemblages are apparently similar to the ilmenite-magnetite aggregates described above, except for the presence of the maghemite and minor amounts of hematite. Unfortunately there is not always general agreement on the exact composition of the assemblages. Some observers indicate that the Bushveld "ore" is largely ilmenite and maghemite with very little magnetite (Schwellnus and Willemse, 1944), whereas others claim that both magnetite and maghemite are present (Frankel and Grainger, 1941; Wagner, 1928). It is conceivable that these differences are due to variance in material, but it is also possible that microscopic examination is open to various interpretations. In fact, Strauss (1947) believes that the existence of a mineral "maghemite" in the South Africa "ores" is extremely doubtful (see p. 21 , maghemite).

According to Wagner the common "ores" contain ilmenite grains up to 26 mm in diameter and averaging 3.5 to 9 mm, imbedded in a matrix of interlocking dark grains of magnetite partly altered to maghemite. Other material contains grains of ilmenite and maghemite, and shows that the maghemite may be much broken by cleavage and irregular cracks, and may even contain laths of ilmenite.

Frankel and Grainger (1941) in a detailed study found two types of "ore": (1) "ore" of equigranular polygonal grains that average 3 mm in diameter and fit closely together with very little intergranular material, and (2) "ore" with grains of greater than average size that have no well-defined boundaries between them, but contain interstitial material that is principally ilmenite and hydrated iron oxides. The ilmenite occurs (1) in the interstitial material as separate, lath-shaped particles that are as much as 5 to 6 mm long and 1 mm wide, (2) as individual grains, occasionally twinned, that are as much as 5 by 13 mm in a section, and (3) as inclusions within magnetite and maghemite, that average 5 microns in width and 18 microns in length.

These titaniferous deposits and similar ones from Singhbhum, India (Dunn and Dey, 1937) supposedly contain the mineral coulsonite, a vanadian magnetite or vanadian maghemite. The existence of this mineral was supposedly confirmed by some workers (Frankel and Grainger, 1941, p. 105-106) although they feel it might be a vanadium-rich variety of maghemite, rather than the separate mineral species proposed by Dunn and Dey (1937, p. 131). Strauss, on the other hand, could find no evidence for the existence of either "coulsonite," or a vanadium-rich variety of magnetite or maghemite, because his homogeneous "ores" had the same vanadium content as ones which contained more than one type of material. He did not, however, rule out the possibility of coulsonite in other ores (Strauss, 1947, p. 45).

Analyses of ilmenite-magnetite-maghemite "ore" from South Africa show from 11.68 percent TiO_2, 12.62 percent FeO, and 62.25 percent Fe_2O_3 (Frankel and Grainger, 1941, p. 101) to 24.09 percent TiO_2, 14.37 percent FeO, and 55.10 percent Fe_2O_3 (Schwellnus and Willemse, 1944, Table 1).

Magnetite

Many magnetites containing appreciable amounts of titanium may not contain ilmenite inclusions, since the titanium substitutes for atoms in the magnetite. Analyses of homogeneous magnetite show as much as 7.5 percent TiO_2 (Palache, Berman, and Frondel, 1944, p. 702).

Nelsonite

According to Watson and Taber (1913, p. 101-102), nelsonite is usually a holocrystalline rock of ilmenite or rutile, or both, accompanied by apatite and occasionally magnetite or subordinate silicate minerals. Individual nelsonite bodies have an average grain diameter of 1 to 3 mm, show a remarkable uniformity of granularity, and have very little change in composition from wall to wall. In addition to the common hard (ilmenite) nelsonite composed dominantly of ilmenite and apatite with only minor amounts of accessory minerals, there are varieties rich in other minerals, such as rutile nelsonite, magnetite and biotite nelsonite, hornblende nelsonite, and gabbro nelsonite (Watson and Taber, 1913, p. 100-155). Some of the leaner varieties consist mainly of hornblende, albite, and quartz, with only minor amounts of ilmenite and apatite (Ross, 1941, p. 8). Titanium content of nelsonite ranges from 10 percent TiO_2 in gabbro nelsonite to 69.7 percent in rutile nelsonite (Watson and Taber, 1913, p. 120, 140).

Chromium and vanadium in ilmenitic aggregates.

Mineral assemblages containing ilmenite and magnetite generally carry appreciable amounts of vanadium and chromium. In anorthosite-gabbro complexes the magnetite apparently has more of the vanadium and chromium associated with it than does the ilmenite. Detailed mineralogical work on magnetite and ilmenite indicates that substitution of chromium and vanadium is more possible within the magnetite internal structure than within that of ilmenite. Schwellnus and Willemse (1944), in a detailed study of the mineralogical and chemical changes occurring throughout a section of the Bushveld igneous complex, found that the titanium content of the ore increases upwards in the section, whereas the vanadium content decreases. The vanadium content ranges from 1.5 percent V_2O_5 in the lower "ore" bands to nil in the upper bands, whereas the titanium ranges from approximately 8 percent in the lower portions to 24 percent TiO_2 near the top. This led them to conclude (p. 34) that the vanadium is contained in the magnetite (or maghemite) and not the ilmenite. These conclusions were supported by data from concentration tests which showed that vanadium was more abundant in magnetic concentrates (ones containing much magnetite) than in non-magnetic concentrates (ones containing much ilmenite).

In a study of the ilmenite-magnetite ores associated with anorthosites and gabbros at Lake Sanford, N. Y., Balsley (1943) found a relationship between the grade of the ore and the content of vanadium in concentrates from this ore. The ore used in these tests contained from 0.12 to 0.52 percent V_2O_5. Balsley found that magnetic concentrates from lean ore (greater than 25 percent silicates) contained more vanadium for a given weight of magnetite than did concentrates from rich ore. He also found that the vanadium to titanium ratio is greater in concentrates from the lean ores than those from the rich ores. Unfortunately he does not give the mineralogical composition of the magnetic and non-magnetic concentrates, nor any chemical analyses of the non-magnetic concentrates. A study of his Table 3, however, shows that in the ore (both rich and lean) the average ratio of $TiO_2:V_2O_5$ is 72.5, whereas the magnetic concentrates from this show a ratio of $TiO_2:V_2O_5$ of 16.9. This indicates that vanadium is more concentrated in the magnetic concentrate, or in other words, occurs with the magnetite in the ore.

Chromium is also a common minor constituent of ilmenite-magnetite aggregates, and probably occurs within the magnetite lattice. The titaniferous iron "ores" of the Bushveld complex of South Africa show a variance in the chromium content across the section, varying from a maximum content near the base to a minimum near the top; total variance was from 0.02 to 1.00 percent Cr_2O_3. These observations led Schwellnus and Willemse (1944, p. 34) to conclude that the chromium, like the vanadium, is associated with the magnetite or maghemite. The titaniferous magnetites of North Carolina are associated with talc and serpentines (derived from metamorphism of dunites and gabbros) and contain 0.34 to 1.19 percent Cr_2O_3. The magnetic portion is usually relatively richer in chromium than the nonmagnetic portion of the ores, and consequently the chromium is believed associated with the magnetite (Bayley, 1923a, p. 250, 260). The ilmenite-magnetite portions of the Duluth, Minnesota gabbro contain up to 2.4 percent Cr_2O_3 (Singewald, 1913b, p. 108); old analyses of titaniferous iron deposits in anorthositic rocks of Quebec, Canada, show from 0.07 to 0.32 percent Cr_2O_3 (Robinson, 1922, p. 35).

Rutile

Rutile may occur either in ilmenitic deposits, or in deposits of an entirely different geologic nature. Two well-known areas that contain deposits with both rutile and ilmenite are St. Urbain, Quebec, and Amherst and Nelson Counties, Virginia. At St. Urbain, rutile occurs only in the General Electric deposit, where it is disseminated as streaks and bands within the ilmenite-hematite portions. The rutile occurs as individual crystal grains or clusters that show good cleavage but are rarely twinned. It ranges in size from "mere specks up to grains having a diameter of 3.5 mm, the average being about 0.6 mm" (Watson and Taber, 1913, p. 32). The average content of rutile is approximately 6 percent, although some portions contain as much as 20 percent. Partial analyses of this "ore" show 41.6 to 53.4 percent TiO_2, and 28.5 to 34.8 percent iron (Robinson, 1922, p. 43).

Some of the nelsonite of Amherst and Nelson Counties in Virginia is rich in rutile, and consequently was an ore of rutile. The rutile nelsonite is similar to other nelsonites (see p. 42), and consists mostly of rutile, with minor amounts of ilmenite, apatite, magnetite, and subordinate silicate minerals. Ross (1941, p. 9) states that most of the rutile nelsonite is massive, has grains of rutile and apatite averaging 1 to 2 mm in diameter, and contains 75 to 80 percent rutile in the richest portions.

Another type of rutile deposit in the Amherst and Nelson County region consists of about 4 to 5 percent rutile disseminated throughout granulated anorthosite. The individual rutile grains rarely show crystal faces, are irregular or roughly rounded in outline, and range from less than 1 mm to 10 mm in diameter (Ross, 1941, p. 13).

A well-known, apparently commercial deposit of rutile is at Kragerö, Norway, where masses of rutile comprise 5 to 10 percent of quartz and aplite dikes. In the aplitic dikes the rutile occurs as dark brown to gray grains that are 0.5 to 2 mm in diameter, show good cleavage and twinning, have irregular fractures, and in places are altered to leucoxene at their borders (Watson and Taber, 1913, p. 38-39).

In the Magnet Cove region of Arkansas, rutile is confined to feldspar-carbonate veins. The rutile occurs as single acicular crystals averaging 0.1 mm in diameter, as nests of these crystals, as compact acicular rutile masses ranging from less than 0.1 mm up to 1 mm in diameter, and as granular rutile veins and veinlets from 0.1 mm to 5 cm wide (Fryklund and Holbrook, 1950, p. 26-27). About 15 to 20 percent of the rutile has been altered to leucoxene.

Brookite

The only possible commercial source of brookite occurs at Magnet Cove, Arkansas, where subhedral crystals of brookite occur within quartz masses. These crystals generally average less than 0.5 mm in diameter, although a few reach a maximum of 6 to 7 mm in diameter and over one centimeter in length (Fryklund and Holbrook, 1950, p. 62).

Secondary

Secondary deposits are derived from primary titanium-bearing rocks by processes of weathering, and frequently contain more titanium than the parent rock.

Titaniferous minerals in sand deposits

Sand commonly consists of more than 90 percent combined quartz and feldspar, and less than 10 percent of heavier minerals. The heavy minerals in sand are often concentrated into pockets and lenses, and may include amphiboles, cassiterite, chromite, epidote, garnet, hematite, ilmenite, leucoxene, magnetite, monazite, rutile, sphene, staurolite, zircon, and others. Some sands are mined for those minerals in which they are particularly rich, such as the cassiterite-bearing sands of Malaya, the chromite sands of the Oregon coast, the monazite sands of Ceylon, and the rutile sands of Australia.

In sands the common minerals of titanium are ilmenite, rutile, and their alteration products such as anatase and leucoxene. Typical deposits contain distinctly rounded and abraded grains of heavy minerals in amounts between 4 and 90 percent. Titanium minerals often comprise as much as 75 percent of the heavies in India (Viswanathan, 1951).

The mineralogy of the individual deposits is subject to considerable confusion due to the lack of detailed investigation of the titanium-bearing minerals. In commercial practice, iron-bearing titanium minerals of sand are usually grouped under "ilmenite", even though other minerals may be present. Sands with unusually high titanium content are often described in the literature as containing "arizonite", although it is now believed that a separate mineral "arizonite" does not exist (see p.14). It is probable that any sand which can be concentrated to a product containing between 55 and 70 percent TiO_2 is a mixture of ilmenite, leucoxene, rutile, anatase, and various iron oxides rather than being solely "arizonite".

Sand with a high titanium content generally contains much rutile, whereas that with a lower titanium content may contain much unaltered ilmenite.

Buried deposits of beach sands have essentially the same mineral composition as the present beaches. In the Trail Ridge deposits of Florida, however, the heavy sand above the water table contains a greater proportion of leucoxene than that below it. Microscopic and X-ray investigations have further shown that the so-called leucoxene is a mass of submicroscopic rutile crystals formed by the alteration of ilmenite. Cannon (1950, p. 209-210) says that "the alteration, which is essentially a loss of iron oxides, takes place molecule by molecule throughout the series from true ilmenite to pure leucoxene...."

Titaniferous minerals in residual deposits

The titanium minerals of residual deposits are resistant to chemical weathering, and may include ilmenite, rutile, brookite, and leucoxene. The minerals may be imbedded in a loose, porous, friable aggregate of weathered bedrock material, or they may be included within blocks of resistant material such as quartz.

Clay.--Clays derived from basalt and other basic rocks contain grains of ilmenite in addition to the common clay minerals. The latter includes various hydrous aluminum silicates such as montmorillonite, kaolin, and halloysite, in addition to hydrated iron oxides and colloidal material. Although the primary rock may have contained intergrown ilmenite and magnetite, often only ilmenite occurs in the clays, after most of the magnetite is converted to hydrous oxides by the weathering action. Even the ilmenite may be partly altered to leucoxene, or mixed titanium and iron oxides. The lack of petrographic data on the occurrence of ilmenite in clay deposits makes it difficult to give information on composition, or grain-size of the titanium-bearing minerals in the deposits.

Bauxite.--Bauxite, a highly altered rock containing large amounts of aluminum hydroxides, results from the tropical weathering of aluminous rocks such as nepheline syenite. Although reports on bauxite indicate that ilmenite is one of the few minerals remaining from the parent rock, it is probably not pure ilmenite, but may show some partial alteration to leucoxene and other titania-bearing products. Commercial bauxite in Arkansas averages 2.12 percent TiO_2, present as the mineral ilmenite (Calhoun, 1950, p. 5).

Terminology

Articles describing titaniferous ores frequently use poor or incorrect terminology. Much of the confusion in nomenclature arises because the presence of the fine-grained intergrowths between ilmenite and iron oxides makes it impossible to determine if more than one mineral is present unless the ores are examined in polished section. Chemical analyses of this intergrown material naturally give ratios for titanium and iron that do not correspond to any pure mineral. An investigator who is confronted with these unusual chemical analyses, and is unaware that more than one mineral is present, may erroneously identify the ore as a single mineral such as "ilmenite", "titaniferous magnetite", "ilmenorutile", or "titanomagnetite". This false idemtification greatly complicates the nomenclature of the titaniferous ores by the introduction of terms that are meaningless as concerns the exact physical and chemical composition of an ore.

The names, arizonite, ilmenite, and leucoxene are often loosely used in descriptions of the mineralogy of sand deposits. Chemical analyses are not sufficient to determine the mineralogical constituents of titanium-bearing sand, when numerous alteration products of titanium are present; complete chemical, petrographic, and frequently X-ray data are essential to determine exact composition in these cases. For these reasons the reader must be careful in accepting data on the amounts and kinds of titanium-bearing minerals in secondary deposits, unless the author gives chemical, petrographic, and preferably also X-ray data to support his identifications.

In this report, the mineralogical terms used in descriptions of individual deposits are taken from the report concerning the area, unless it is obvious from the original report that an error in nomenclature has been made. The reader must realize that terms such as "ilmenorutile" may refer not to niobian-tantalian rutile, but to a mixture of rutile and ilmenite, or that "titanomagnetite" may not refer to titanian magnetite, but to ilmenite-magnetite intergrowths.

Uses and beneficiation

In the United States the total consumption of ilmenite, the principal raw material for most titanium products, was 713,363 short tons in 1951, and 682,850 short tons in 1952. According to Mineral Market Reports No. 2179, Titanium in 1952, 98.2 percent of the ilmenite consumed in the United States in 1952, and 98.6 percent of it consumed in 1951, was used for the production of manufactured titanium dioxide. This product, used mostly in paint pigments, is also used in papers, plastics, inks, or in other products where its whiteness, opacity, brightness, and chemical inactivity make it most valuable. With the exception of less than a thousand tons in 1951 and 1952, the remainder of the ilmenite was used in the production of titanium alloys and carbide.

Rutile consumption in the United States during 1951 was 17,227 short tons, and in 1952 was 18,317 short tons, of which 67.6 percent in 1951 and 62.2 percent in 1952 was used in the manufacture of welding rod coatings. The welding rod industry has discovered that neither anatase nor brookite (polymorphs of TiO_2) can be used as substitutes for rutile. Although no figures are available on consumption, most, if not all, of the titanium metal plants have been using rutile as the titanium ore.

The titanium industry at present uses ores which can be beneficiated to 44 to 59 percent TiO_2 as ilmenite concentrates, and to 93 to 94 percent TiO_2 as rutile concentrates. Quebec Iron and Titanium Corporation, however, uses ore analyzing 36 percent TiO_2 and 42 percent iron which they charge directly into electric furnaces for the production of a slag analyzing 70 percent TiO_2 and "non-specification" steel.

The beneficiation of titanium ores is affected by the size of the titanium-bearing grains, the number and size of the ilmenite-iron ore intergrowths, and the titanium content of the titanium-bearing minerals. The ores most amenable to ore dressing have distinct grains of ilmenite, preferably at least one millimeter in diameter and free of inclusions. The number of these grains and the amount of titanium in them must be enough to yield a concentrate with at least the minimum titanium content required by industry and with sufficient recovery to make the operation profitable. Some ores are not amenable to ore dressing because: (1) the titanium minerals are extremely fine grained, as in some leucoxene-bearing ores; (2) the titanium minerals occur as small intergrowths within non-titaniferous minerals; or (3) the titanium is in the lattice of a usually non-titaniferous mineral.

A problem often overlooked in titaniferous ores is the change in physical character and titanium content of the ore which takes place with a change in the amount of gangue. Changes in the physical character of the ore occur at Lake Sanford, New York where the most abundant metallic mineral in massive ore (free from silicates) is magnetite, whereas in lean ore it is ilmenite (Balsley, 1943, p. 114-116). Nonetheless, the higher content of ilmenite in lean ores does not necessarily imply that these ores are the better source of ilmenite, for experiments have demonstrated that the greatest recovery of ilmenite is from ores which are comparatively rich and contain roughly 10 to 30 percent silicate minerals. This is possibly due to larger size of ilmenite grains and fewer inclusions within magnetite in these richer ores. A correlation between grain size of ore and amount of silicates in the nearby Cheney Pond ore is shown by Singewald (1913b, p. 64), who says: "In the higher grade ores, ilmenite and magnetite grains attain dimensions of 4 mm; in the leaner ores they scarcely reach 2 mm and average considerably less." In the Laramie Range of Wyoming, the silicate-free massive ores contain distinct grains of pure magnetite and ilmenite, with the magnetite generally in larger grains. Ores with more than 5 percent silicates also contain distinct ilmenite and magnetite grains; however, the magnetite contains abundant exsolution lamellae of ilmenite, ranging "in size from those observable only under high magnification to others which can be seen with the naked eye." (Newhouse and Hagner, 1951, p. 13-14).

Variations in chemical composition of ore minerals often accompany a change in the grade of ore. Although this phenomenon has been noticed in a few cases, it is often overlocked because adequate chemical analyses are lacking. Newhouse and Hagner (1951, p. 14) suggest that ilmenite in ore accompanied by high volumes of silicates "contains a higher per-cent of iron relative to titanium .... than it does in the massive ore." Study of ore at Lake Sanford, New York shows that the non-magnetic con-centrate of rich ore contains 12 to 14.5 percent TiO_2, whereas that from lean ore has only 7 to 12 percent TiO_2 (Balsley, 1943, p. 114).

These important physical and chemical variations of ore in a deposit must be recognized during the development of a deposit. The variations in chemical and physical properties of titaniferous ores make it inad-visable to prepare a plan for ore treatment without adequate and complete sampling.

GEOLOGY OF TITANIUM DEPOSITS

Primary

Deposits containing ilmenite and iron oxides

The majority of titanium-bearing primary deposits contain ilmenite, or ilmenite and iron oxides in various physical and chemical combinations. The types of deposits in which these occur can be divided into the anorthositic complexes, the nelsonite deposits, the layered norite complexes, the gabbroic and basic bodies, and the minor bodies of questionable associations.

Anorthositic complexes.--Ilmenite-bearing bodies are commonly found near the margins of anorthosite massifs, in association with both the anorthositic and gabbroic facies. The character of the country rock, the shapes of the deposits, the mineralogy, and the relationship of the minerals to the country rock may vary widely even in one area. Further complications are introduced by investigators' lack of agreement on the characteristics of a given deposit.

The anorthosite is usually a light- to dark-gray rock containing a predominance of plagioclase feldspar generally ranging from andesine to calcic labradorite. Often blue or gray plagioclase phenocrysts at least 3 inches long are imbedded in a white to greenish fine-grained feldspar ground mass of essentially the same composition. Ferromagnesian silicates, such as pyroxene, hornblende, garnet, and biotite, usually comprise less than 10 percent of the rock. In some places the rock has undergone considerable crushing and granulation, and in others a poorly developed platy structure produced by parallelism of tabular feldspar phenocrysts is apparent. The gabbroic phases, which are not always present, occur as lenses or pods within anorthosite. Typically the gabbro may be a dark colored, fine-grained rock of plagioclase feldspar and pyroxene (hypersthene and augite), with subordinate hornblende, biotite, and garnet, and accessory magnetite, ilmenite, rutile, scapolite, and apatite. Banding occurs in some deposits with alternating layers of feldspars and dark minerals parallel to the lens walls. The gabbro may either have sharp contacts with the anorthosite or it may grade into the anorthosite by a gradual decrease in femic minerals. At Lake Sanford, New York, the gabbro contains 35 to 75 percent mafic minerals and less than 15 percent plagioclase (Stephenson, 1949, p. 403).

The titanium-bearing bodies within anorthosite or gabbro are commonly lenses, and less often irregular veins, dikes or large irregular masses. The lenticular deposits show a wide range in size. Small bodies, such as those near Seven Islands, Quebec, measure on the outcrop 15 by 80 feet (Faessler and Schwartz, 1941, p. 722) whereas large lenses, such as those near Lake Sanford, New York, are over 1,000 feet long and have widths and depths in the hundreds of feet (Balsley, 1943, p. 119-120). The largest of the irregular shaped bodies is the Allard Lake, Quebec deposit which is 3,600 feet long, 3,400 feet wide, and at least 300 feet thick (Hammond, 1949, p. 119).

The deposits range from masses of pure "ore" with no silicates, to grains of titanium minerals irregularly disseminated throughout silicates. The titaniferous portions range from aggregates of ilmenite with about only 15 percent of intergrown hematite, to ilmenite-magnetite bodies with more magnetite than ilmenite; silicates in the gangue are usually plagioclase and the ferromagnesian minerals. Most of the lenses within anorthosite, and a few within gabbro have sharp contacts with the enclosing host rock, whereas most of the lenses in gabbro simply grade into the country rock by a change in amount of titaniferous minerals. The dike and vein bodies often cut across the regional layering, and have sharp contacts with the wall rocks.

The relationship of the bodies to structural features is often not considered, or in some cases is not clear. At St. Urbain, Quebec, Gillson (1932) claims the deposits are related to shear zones within the anorthosite and have a definite trend, whereas both Robinson (1922, p. 47) and Mawdsley (1927, p. 47) claim that the "ores" occur randomly throughout massive anorthosite. Newhouse and Hagner (1951, p. 6-9) found at Iron Mountain, Wyoming complete dependence of the "ore" body locations upon the structure of the enclosing anorthosite.

Layered norite complexes.—Ilmenite and iron oxides are found in certain portions of layered, basic rock complexes in the Transvaal Province of the Union of South Africa and at Freetown, Sierra Leone. The Bushveld igneous complex in the Transvaal is a large saucer-shaped body of banded igneous rocks ranging in composition from bronzitites at the base to granites near the top. The titanium-bearing portions of the complex occur within the Norite Zone, a 15,000 foot thick section that contains norite with locally interbedded "ore" beds, and that may be subdivided into two parts: (1) the bottom third, the Critical Zone, contains the chromite layers, and has as its upper limit the platinum horizons (Merensky Reef); (2) the Main Zone occupies the remainder of the Norite Zone, and at the top is in contact with either granite or interbedded quartzite and felsite. The titaniferous layers are in the upper third of the Main Zone, only a few thousand feet below the base of the granite, and are interbedded with a "spotted, medium-grained norite" accompanied by considerable anorthosite. The "spotted norite" is "an allotriomorphic granular rock composed essentially of labradorite and diallage ... accompanied by bronzite, which, however, is usually present in quite subordinate amounts. Accessory constituents include green hornblende, deep brown biotite, magnetite, pyrrhotite, and apatite" (Wagner, 1928, p. 23). The anorthosites are essentially interlocking anhedra of calcic labradorite or bytownite accompanied by minor diallage and the same accessory minerals as the norite.

The bodies of maghemite, magnetite, hematite, and ilmenite are sheets, or short stout lenses which range in thickness from 1 to 20 feet, and in length from a few feet to at least 10 miles (Wagner, 1928, p. 23). The bodies are conformably interlayered with the rocks of the complex, and dip from 5 to 30 degrees towards the center. These layers occupy two distinct horizons within the norite, one above the other and separated by approximately 1,400 feet of norite. The contact between the titanium-iron bodies and the norite or anorthosite is usually sharp, although in places there is a gradation from norite or anorthosite, through norite with scattered blebs of ilmenite and magnetite, to labradorite-magnetite-ilmenite rock with equal proportions of opaque and non-opaques, and finally to masses of pure "ore".

The norite complex at Freetown, Sierra Leone, is in general features similar to the Bushveld. The Freetown lopolith is essentially an olivine gabbro (including olivine norite and troctolite) with gabbros and norites next in importance. Anorthosite and anorthositic gabbro are the least common rocks, and peridotites comprise only a small volume (Junner, 1930, p. 421). "The lower part of the exposed portion of the intrusion consists mainly of banded olivine-rich troctolite with a layer not far from the base of anorthosite and anorthositic gabbro" (Junner, 1930, p. 420). The titaniferous bodies are usually associated with the anorthositic rocks, and form bands and lenses which are conformable with the banding of the country rock. In a few places the opaque minerals occur as 7 to 15 foot thick layers in the banded troctolites of the lower portion of the complex. The "ore" is massive ilmenite and titanomagnetite, magnetite-dunite, and magnetite-rich troctolite.

Gabbroic and basic complexes.--Many deposits of ilmenite-bearing rock are associated with gabbros and other ferromagnesian rocks of varied composition and shape that generally do not exhibit the well-banded structure so characteristic of the Bushveld and Freetown complexes. The Duluth gabbro, one of the host rocks for ilmenite, contains magnetite-rich gabbro, olivine gabbro with subordinate feldspar, olivine gabbro with feldspar, normal olivine free gabbro and anorthosite (Singewald, 1913b, p. 94). Other bodies may be mostly pyroxenite (Caribou Hill, Colo.), hornblende gabbro (Rainy River, Ontario), olivine norite (Taberg, Sweden), and gabbro (Iron Mine Hill, Rhode Island). In North Carolina the basic country rocks are talc, serpentine, chlorite, and hornblende-bearing schists which were formed by the metamorphism of olivine gabbros, peridotites, and dunites (Bayley, 1923a, p. 260).

The size and shape of the basic country rocks vary from small dikes 50 to 100 feet wide and 1,500 feet long (Caribou Hill, Colo.), to saucer-shaped complexes which are 125 miles long, up to 25 miles wide and cover 2,400 square miles (Duluth gabbro complex, Minn.).

The shape of the mineral concentrations is extremely irregular, and may vary greatly within an individual deposit. At Caribou Hill, Colo., the deposit is merely a titanium-rich phase of the country rock, with numerous thin mineralized veinlets and stringers spread throughout the rock. Some mineralization also occurs in small pockets and lenses within the host rock (Singewald, 1913b, p. 127). According to Broderick (1917, p. 677-694), titaniferous deposits in the Duluth gabbro complex show the following diverse shapes: (1) irregular shaped masses that cut across gabbro banding with sharp contacts, and range in size from small blocks to bodies measuring 250 by 4,000 feet; (2) conformable layers that are 1 inch to 5 feet thick and grade into the banded gabbro in which they occur; and (3) irregular shaped dike-like bodies that have sharp contacts with the host rock, and cut across it without regard to structure. Other deposits throughout the world have their own individual size and shape, but can usually be fitted into one of the categories outlined above.

Most of the mineralized portions, with the exception of some ilmenite deposits of North Carolina, contain magnetite-ilmenite mixtures. The Rhode Island deposit contains cumberlandite, an unusual rock composed of olivine and labradorite grains imbedded in a matrix of ilmenite and magnetite.

Nelsonite bodies.--Nelsonite has been recognized only in Virginia where it occurs in irregular masses associated with a small anorthosite body. The anorthosite was probably uniformly coarse grained, but through granulation has become an extremely varied rock of large, light bluish-gray feldspars 10 to 20 cms in diameter, surrounded by nearly pure white granulated feldspar. It is about 75 percent sodic andesine and 25 percent microcline, with minor amounts of quartz and secondary silicates. The anorthosite body which is about 12 miles long and a maximum of 4 miles wide, is enclosed in a well foliated biotite-bearing quartz-monzonite gneiss.

The size and shape of the nelsonite bodies vary greatly. Some are dike-like and may be traced a maximum of 2,000 feet along their strike, although lengths of several hundred feet are more common; the width varies from a few inches to more than 65 feet. Other bodies are lenticular and where exposed for considerable distance are seen to pinch and swell both along the strike and dip. They may even branch and split before completely pinching out. The contacts between the nelsonites and the country rock are usually sharp, although a gradation between the two is especially common in the rutile nelsonites.

Most of the nelsonites occur at the borders of the anorthosite mass, although ilmenite nelsonites, free from rutile, are also found in the surrounding quartz-monzonite. Rutile nelsonite is confined to the anorthosite, and magnetite nelsonite to the quartz monzonite. Although Ross (1941, p. 20-23) believes that the nelsonite bodies in the anorthosite were emplaced only in areas which showed crushing and shearing, other authors find no such correlation.

Miscellaneous.--The geologic occurrences of the ilmenite-bearing rocks of New Jersey are not typical of titaniferous deposits. Bayley (1910) described isolated bodies of titaniferous "ores" within gneisses of variable composition. Smith (1933, p. 658) lists the following occurrences for the New Jersey deposits: (1) irregular bodies in limestone; (2) irregular masses of magnetite in gneiss; (3) disseminated "ores" in gneiss; and (4) lens or pod-shaped bodies enclosed in gneiss. These occurrences are typical of non-titaniferous magnetites, and may refer chiefly to those deposits with only minor amounts of titanium. Because detailed geologic investigations are lacking for much of the area, some of the high titanium deposits may be similar to other titaniferous deposits and be associated with gabbros. Because one deposit has 12 percent TiO_2, Singewald (1913b, p. 78) states, "It is quite probable that a few of the high titanium occurrences may be exceptions and do occur in metamorphosed gabbros."

Ilmenite is a common minor constituent of so many rocks that to give the occurrence of all would be impractical. A few primary deposits, such as the granites and basalts, are important in that ilmenite in them is often concentrated by weathering processes. The basalts, according to Clarke (1924, p. 460-463), contain from 0.12 to 2.93 percent TiO_2. Rankama and Sahama (1950, p. 159) give the following amounts of TiO_2 for basalts and the average igneous rock: plateau basalts 2.19 percent; all basalts 1.36 percent, and average igneous rock 1.05 percent. Granites and other acidic rocks carry only small amounts of titanium, probably as ilmenite, titanian-magnetite, or sphene; Clarke (1924, p. 439-443) shows a maximum of 0.41 percent TiO_2 for the rhyolite-granite group, and 0.67 percent TiO_2 for the trachyte-syenite group. Table 5 shows that the average titanium content of a group of igneous rocks ranges from 0.02 to 1.62 percent TiO_2.

Table 5. Average chemical composition of some igneous rocks _/

	Dunites	Hornblendites	Gabbros	Diorites, excluding quartz diorites	Granodiorites	Granites of all periods	Nephelite-syenite
No. of analyses	10	11	41	70	40	546	43
SiO_2	40.49	42.80	48.24	56.77	65.01	70.18	54.63
Al_2O_3	0.86	10.55	17.88	16.67	15.94	14.47	19.89
Fe_2O_3	2.84	6.62	3.16	3.16	1.74	1.57	3.37
FeO	5.54	9.16	5.95	4.40	2.65	1.78	2.20
TiO_2	0.02	1.62	0.97	0.84	0.57	0.39	0.86
MnO	0.16	0.24	0.13	0.13	0.07	0.12	0.35
MgO	46.32	12.48	7.51	4.17	1.91	0.88	0.87
CaO	0.70	11.67	10.99	6.74	4.42	1.99	2.51
Na_2O	0.10	1.89	2.55	3.39	3.70	3.48	8.26
K_2O	0.04	1.00	0.89	2.12	2.75	4.11	5.46
H_2O	2.88	1.73	1.45	1.36	1.04	0.84	1.35
P_2O_5	0.05	0.24	0.28	0.25	0.20	0.19	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.0	100.00

_/ From Daly, 1933, Table 1.

Deposits containing rutile and brookite.

Rutile nelsonite bodies.--Rutile nelsonite occurs only in anorthosites of Amherst and Nelson Counties, Virginia. It is similar to the other nelsonite bodies (see p. 67) except that it may contain as much as 60 percent rutile.

Disseminated rutile deposits within anorthosite.--Rutile occurs in Virginia as disseminations in the same anorthosite that contains the nelsonite bodies (see p. 67). The rutile averages 4 to 5 percent of the anorthosite where it is irregularly distributed as grains, but locally comprises 30 percent where it is segregated into "irregular wavey lines or stringers composed of disconnected rutile grains of variable size" (Watson and Taber, 1913, p. 194). The rutile is associated with all three of the silicate minerals of the anorthosite, namely feldspar, quartz, and secondary hornblende, and is often associated with ilmenite.

Watson and Taber (1913, p. 193-194) state that the rutile does not occur in any specific part of the anorthosites, and only mention that some of the anorthosite has been greatly deformed. Ross (1941, p. 19), conversely, believes that the rutile is associated with ilmenite and secondary minerals, shows zonal relationship to shear zones, and is found only in granulated feldspar.

Acid dikes and veins.—Rutile, a common minor constituent of quartz veins, pegmatites, and aplite dikes, is in places sufficiently concentrated to be an ore mineral. At Kragerö, Norway, rutile occurs within an aplite dike composed of sodic plagioclase, microcline, orthoclase, much black rutile, some quartz and a little ilmenite. The rutile is uniformly distributed near the center as grains, and irregularly distributed as schlieren throughout the entire dike. Roughly 5 to 10 percent of the total rock is rutile.

Another typical deposit is the Giftkuppe, Southwest Africa, rutile deposit in which bands of rutile less than 1 inch thick are found within a highly altered quartz-albite rock (Frommurze and others, 1942, p. 129-134).

Rutile is common in quartz veins, and although in places present in insufficient quantities to be a primary ore, it can be concentrated by weathering processes. A few occurrences within quartz veins have yielded large rutile crystals for mineralogical collections; Graves Mountain, Georgia, is an example of this.

Brookite occurrences in quartz bodies are similar to those of rutile, although the brookite usually forms crystals.

Deposits of unique geologic occurrence in Arkansas.--Rutile and brookite deposits in the Magnet Cove region of Arkansas are unique geologically. Reports on the area do not agree on the type of rock in which rutile occurs, the difference being principally the result of varying interpretations of genesis. The country rock is novaculite and aegirine phonolite porphyry which contain bodies of fine-grained material.

In the deposit of the Magnet Cove Rutile Company, rutile occurs in fine-grained, in places clayey material, between unaltered blocks of predominantly igneous rock. Ross (1941, p. 23-26) and Kinney (1949, p. 5-6) identified the fine-grained material as a volcanic agglomerate, now altered to clay, and possessing microscopically a "well-preserved glassy volcanic tuff structure, although now completely altered to the clay minerals beidellite and kaolinite ..." (Ross, 1941, p. 24). The blocks of unaltered rock, also part of the volcanic agglomerate, are monchiquite, lamprophyre, coarse-grained porphyritic rocks and blocks of calcite. Dikes of nepheline syenite, lamprophyre and a fine-grained black mafic rock also transect the rocks of the area.

Fryklund and Holbrook (1950, p. 16-36), and more recently Fryklund, Harner, and Kaiser (1953), have indicated the fine-grained rocks to be a series of feldspar-carbonate veins which cut across a country rock of aegirine phonolite porphyry. The ~~five~~ six types of veins constitute 50 to 75 percent of the deposit and have varying amounts of rutile as follows: (1) coarse-grained, biotite-apatite-calcite vein, without rutile; (2) sugary-textured albite-dolomite vein, containing up to 5 percent rutile; (3) microcline-calcite vein, containing 1 to 2 percent rutile; (4) albite-ankerite vein, with abundant rutile in large masses; (5) coarse-grained albite-perthite-carbonate vein, with less than 1 percent rutile; (6) calcite-rutile vein, containing abundant rutile disseminated in the calcite.

According to Ross and Kinney the rutile occurs in the fine-grained clayey material of the altered agglomerate, just below the large blocks of unaltered rock. Those believing in a vein method of emplacement indicate that the rutile occurs in only some of the veins.

At the Christy brookite deposit the primary "ore" lies within quartzite masses that are embedded in novcaulite and clayey material. The quartzite is generally porous and varies from light to dark gray in color; the darker colors contain more rutile and taeniolite than the lighter shades. These quartzite beds are separated by layers of relatively barren clay, ribs of barren novaculite, and unmineralized shale layers, most of which show weathering and some alteration even at depth.

Secondary

The secondary deposits are derived from primary ones by weathering processes that often result in considerable enrichment of titanium-bearing minerals. Because their unconsolidated nature makes large-scale mining inexpensive, many of the deposits are commercially valuable.

Sands of marine origin

The sands of many beaches contain local accumulations of heavy minerals that in places are rich in ilmenite or rutile, and their alteration products. These and other heavy minerals are generally concentrated in wedge-shaped black sand lenses that thin seaward. The best deposits extend from between low and high water mark to a point inland reached by the strongest storm waves, considerably above high-water mark, and often near the foot of the first dunes. Some of the larger deposits, such as those on the east coast of Australia, are thin ribbons up to 800 feet long parallel to the beach, 100 feet wide normal to the water's edge, and up to 5 feet thick (Beasley, 1948, p. 116). Small layers, however, may be only a few inches thick, and extend for only a few feet parallel to and normal to the water's edge. Individual,thin layers are often separated by barren white sand, or groups of lenses may overlap one another and form complexes extending considerable distances along coastlines. In Australia, for example, deposits are worked for 50 miles along the Queensland and New South Wales coastlines.

In addition to deposits on the present beaches, black sands also occur on raised off-shore bars, in lagoons behind barrier beaches, and beneath sand dunes that may extend inland for considerable distances from the present beaches. In Australia some of the dune complexes extend for a half mile inland from high-water mark, and contain black sand deposits which are 10 to 15 feet above high-water level (Fisher, 1948, p. 1).

Buried layers of black sand may occur down to various depths on beaches and on terraces inland from the shore. In Florida extensive deposits of buried black sand are found 50 miles inland, and to depths of 65 feet. These sands are associated with cross-bedded, highly oxidized clastic sediments that show the results of channeling associated with strong currents. The heavy mineral concentrations of these average 1 to 2 percent, with a few areas averaging 3 percent. Although this is considerably less than many beaches, it represents an average that extends throughout an entire deposit and is not confined to a single lens.

Stream sands and gravels

The sands and gravels occurring in stream beds and on river flood-plains contain accumulations of heavy minerals that may be rich enough in titanium-bearing minerals to be classed as ores. In valleys, sands and gravels may extend to considerable depth and fill the valley-bottom from wall to wall. Valley fill in Portugal is 3 to 4 miles long, a mile wide and extends to depths of 12 to 35 feet. In some of the California canyons, heavy-mineral bearing sands are found at depths of 50 feet, and average 7 to 8 percent TiO_2 (Oakeshott, 1948, p. 265). Deltas of some rivers contain important heavy mineral concentrations, such as that of the Nile River in Egypt, where the deposits are worked for their titanium minerals.

The deposits commonly occur as lenses or irregular tabular bodies parallel to the stratification of the sands and gravels. Thicknesses are generally measured in inches, and may be similar to heavy deposits in beach sands.

Residual deposits

Surface concentrations of resistant minerals such as quartz, ilmenite, and rutile are common in regions where bedrock is greatly weathered. These chemically inert, residual minerals are embedded in a matrix of unconsolidated sands, silts, and clays that grades downward into bedrock. The concentration of the residual minerals is generally greatest in the upper portion of the deposits, and decreases downward to the normal concentration within bedrock. Because of this upper zone enrichment, the deposits can be important sources of rutile and ilmenite, even though the bedrock contains only minor amounts of them. In tropical climates the residual deposits may be 100 to 150 feet thick, whereas in temperate climates 10 to 30 feet is more common. Arctic climates have very thin zones of chemical decay since mechanical disintegration is the most common phenomenon.

Clay.—Parts of northwestern United States are underlain by thick deposits of residual clay containing grains of partially altered ilmenite. The clay is derived from basalt bedrock.

Certain ferruginous clays of Oregon having a high alumina content, and commonly referred to as ferruginous bauxite, are a typical example. They contain three types of material: (1) a hard oolitic or pisolitic material; (2) a softer earthy variety containing hard porous nodules or angular fragments; and (3) a hard porous granular clay occurring largely as float and containing more alumina and less iron than the others (Libbey, Lowry, and Mason, 1946). The ilmenite and minor amounts of magnetite occur within the oolites and matrix as residual grains as much as 0.55 mm in diameter. In addition, the porous granular type contains numerous residual skeletons of magnetite with their original spatial arrangement, and also has much of the texture of the parent basalt.

Channel and grab samples of all the known deposits of ferruginous bauxite in Colombia County, Oregon, showed an average of 5.83 percent TiO_2, 38.63 percent Al_2O_3, 20.70 percent Fe, 9.36 percent SiO_2, and 19 percent ignition loss (Libbey, Lowry, and Mason, 1946, p. 259). Clay deposits elsewhere have as much as 8 percent ilmenite (in Idaho) and 7.3 percent TiO_2 (in Washington).

Bauxite.--Commercial bauxite, used as a source of aluminum, in many places contains enough ilmenite to make it a potentially valuable by-product. The processing of this ilmenite has been experimentally undertaken on bauxite ores which the Reynolds Metal Company uses at Bauxite, Ark. (Calhoun, 1950). Bauxite having 2.1 percent TiO_2 is initially treated to yield two products: (1) a red mud that is further processed for the extraction of aluminum; and (2) a waste black sand that can be processed to recover the ilmenite. This black sand is 8.5 percent of the raw product and contains 5.0 percent TiO_2 or 20.6 percent of the total titania. Experimental treatment by various methods of crushing, screening, tabling, roasting, and magnetic separation yields titaniferous products ranging from 17.8 percent TiO_2 with a recovery of 82.4 percent to 41.2 percent TiO_2 with a recovery of 35.7 percent ~~ta~~ (Calhoun, 1950, p. 15). The results from various methods are summarized below.

Method	Recovery of TiO_2 (percent)	Final product: Percent TiO_2	Percent Fe	Percent Mn	Percent of black sand
Screening, tabling and magnetic separation	35.7	41.2	20.1	8.9	3.4
	51.7	20.7	20.8	—	9.8
Crushing, tabling, roasting, and magnetic separation	68.3	40.1	18.7	5.8	7.0
	82.4	17.8	18.5	2.6	20.4

Soils.--A few soils have been cited as possible ores of titanium as a result of their unusually high titanium content. Soils throughout the world average between 0.50 and 1.50 percent TiO_2 (Barksdale, 1949, p. 6), yet certain Hawaiian soils average about 5 percent TiO_2 and in some places contain as much as 45.5 percent. The upper portion of the profile of certain Hawaiian soils is most abundant in titanium. It contains the mineral anatase along with concretions of iron oxide; analyses indicate an average of 15 to 25 percent TiO_2 and 45 to 55 percent Fe_2O_3 (Sherman, 1952).

Origin

The origin of many titaniferous deposits is subject to different interpretations. In this report, no attempt is made to give a complete and exhaustive study of the various genetic hypotheses, and only the more common theories are stated, without any evaluation of their relative merits. Most of the theories discussed in this report are taken from articles concerning titaniferous deposits, and no reference is made to the numerous theories arising from investigations on general geological or petrogenetic problems. If the reader is interested in theories of origin, or more detailed discussion of the rocks of a given area, it is suggested that he consult articles on the regional geology of the area in question. For example, in the case of the Adirondack titanium ores in anorthosite, this report gives only a limited description of the areal geology, and much fuller coverage may be found in articles on the regional geology, such as those by Balk (1931), Buddington (1939), Newland (1908), and others. The same is true for other areas, such as the Duluth gabbroic complex, the Bushveld igneous complex, the southern Appalachian piedmont, and others.

Primary titaniferous deposits

Anorthosite complexes.—Theories of origin of titaniferous bodies in anorthosite falls into two general categories: one theory postulates emplacement of the bodies as magmas, and the other postulates an origin by replacement of pre-existing rock. A typical example of a magmatic origin, the more common of the two theories, is given by Balsley (1943, p. 117) for the Lake Sanford, New York, ores. The gabbro, anorthosite, and ore are all related to the same magmatic intrusion. Anorthosite, the first rock to crystallize, left behind a magmatic residuum of gabbroic composition, which upon continued crystallization produced a solidified gabbro and an interstitial liquid of nearly pure magnetite-ilmenite. In places this liquid was injected into partly consolidated anorthosite, resulting in sharp contacts, whereas in others it remained in contact with the gabbroic minerals, forming a gradational contact. Hammond (1949, p. 120) has similar views on the origin of the Allard Lake deposits; he says, "It would seem that the ilmenite has been derived from all or part of the parent anorthosite magma, and that it has been injected into another part of the consolidated though still hot anorthosite along structural planes. The deposits, then, are high temperature, late magmatic injections containing only minor amounts of volatiles." Mawdsley (1927, p. 46) stated that the deposits at St. Urbain, Quebec were magmatic in origin, and Osborne (1928, p. 744) indicated that the ore magma was essentially a concentration of the last crystallizing constituents of the anorthosite. It was derived from one part of the anorthosite and forcefully injected into another part by breaking through and engulfing blocks of it.

The replacement theory postulates the molecule by molecule replacement of a pre-existing rock by permeating gases or liquids. In most theories the titaniferous deposits are believed related to the parent anorthosite or other host rock, in that the material may have come from the same magmatic chamber, and was emplaced by a process which has introduced titanium (and in some cases iron) into the rock while removing the host material. Gillson (1949, p. 1046) believes the ores at Lake Sanford, N. Y. are the final product of the soaking of hot anorthosite rocks by consecutively more basic solutions that eventually became high in iron and titanium. The ore is thus a replacement of both anorthosite and gabbro by these titanium-rich and iron-rich solutions. At St. Urbain, Quebec similar replacement processes have been postulated. Gillson (1932, p. 572) concludes that "the ores were formed by replacement in the already solid anorthosite and were deposited from solutions, either gaseous or liquid, which soaked through the rock." The ilmenite-magnetite dike at Iron Mountain, Wyo. is, according to Newhouse and Hagner (1951, p. 9), the result of replacement processes, although the sharp contacts with the anorthosite led earlier workers to conclude that it was a magmatic intrusion (Singewald, 1913b, p. 121; Diemer, 1941, p. 19). Newhouse and Hagner do not elaborate on the mechanism of replacement, only saying, "The replacement theory is believed to be supported by the marked change in mineralogy along the strike, dip, and plunge of an ore body, and of its individual layers... ."

Layered norite complexes.—The origin of the titaniferous deposits in the Bushveld is still open to question. According to Wagner (1928, p. 33) the titaniferous iron "ore" is not found at the base of the Norite zone, and therefore must have crystallized later than many of the silicates. Because of this late crystallization in the cooling sequence, the titaniferous deposits occur near the top of the Norite zone, where they overlie thousands of feet of earlier crystallized silicates. As an alternative, Wagner postulates the formation of the iron and titanium oxides from gases and solutions trapped in the upper part of the norite magma sheet during the crystallization of the lower portions. Bateman (1951) has proposed a theory of "late gravitative liquid accumulation", in which liquid iron and titanium oxides have trickled down through late-formed plagioclase crystals and settled as a layer upon earlier formed ferromagnesian silicates. Reunig (1928) suggests differentiation of magma at great depth, followed by separate intrusions into the complex of magmas of varying composition, although possibly the magnetites and their associated anorthosite may be the differentiation product in place of only one magma.

Junner (1930, p. 431) gives the following sequence of intrusions of magma for the complex at Freetown, Sierra Leone, but unfortunately gives no detailed information on method of emplacement. Troctolite, olivine-bearing gabbro, and norite were emplaced, and while still hot, were invaded by relatively small masses of coarse-grained gabbro, norite, peridotite, dunite, and gabbro-pegmatite. The large sheet-like anorthosite body appears to be intrusive, and was probably emplaced during the second period of activity.

Gabbroic and basic complexes.—The origin of the magnetite-ilmenite bodies in gabbros has been discussed but little. Most of the deposits appear to be primary and have crystallized from the same magma that formed the enclosing gabbro, dunite, or other basic rock. The North Carolina "ores" "are connected genetically with apophyses from the dunite and peridotite magmas that have intruded the schists along their foliation planes in the form of narrow veins or flat lenses. The ore veins are portions of these rocks rich in ferruginous material" (Bayley, 1923a, p. 260). Some of these "ores" were apparently deposited by hydrothermal processes. They are in distinct dikes or parallel-walled veins, and have titanium-bearing minerals which are younger than the associated silicates. Mineral assemblages from other parts of the world are probably similar, and in some cases may have been intruded essentially as a magma of titanium-rich composition, or may have segregated in place from a basic magma.

Nelsonite.—The problem of the Virginia nelsonite origin is similar to that of the ilmenitic bodies in anorthosites, with both magmatic and replacement theories having been advanced. Watson and Taber (1913, p. 153) believe that anorthosite magma was intruded first, followed by nelsonite magma that had segregated from the anorthosite. It is not clear whether they imply that the nelsonite magma segregated in place, or at depth, and was then intruded into partially consolidated anorthosite. Davidson, Grout, and Schwartz (1946, p. 748) indicate that the ilmenite "ore" (the nelsonite of some authors) "was in large part intruded as an irregular dike fingering into its wall", and was genetically related to the anorthosite into which it was intruded.

Ross (1941, p. 15-22) postulates a replacement origin for both the disseminated rutile deposits and the nelsonite bodies. According to this theory the titanium minerals were introduced by solutions that were derived from a deep-seated intrusive body. This mass was probably a ferromagnesian differentiate of the same primary magma whose other fraction formed the anorthosite. Mineralization occurred only in areas which showed shearing and granulation. Where iron was present, or was later introduced, ilmenite formed, otherwise rutile was the common titanium mineral deposited by the incoming solutions.

A complex process of intrusion of a granodiorite magma and nelsonite dikes into quartz monzonite, and later alteration of these rocks by solutions from the magma is envisioned by Moore (1940, p. 641-644).

Rutile-bearing acid dikes and veins.—The rutile in quartz veins, pegmatite, and aplite dikes is usually an accessory mineral and very little information is given concerning its origin. The theories on origin of the host body vary from concepts of magmatic emplacement (with the rutile as a minor constituent) to deposition from gases or liquids having only a small amount of rock-forming material.

Arkansas rutile deposits.--The geologic description of these deposits (see p. 74-75) has already indicated more than one theory on origin. The theory proposed by Ross (1941, p. 23-26) applied to the two principal deposits of the region: the Magnet Cove Rutile Company deposit, and the Christy brookite deposit. Initially there was deposition of a volcanic agglomerate consisting of large blocks of material embedded in a volcanic ash. At the Magnet Cove deposit the blocks were igneous rocks and crystalline calcite, and at the Christy deposit they were novaculite. A later period of hydrothermal activity altered the volcanic ash to clay, deposited rutile and brookite within the clays, and formed the porous, vuggy, brookite-bearing quartz masses at the Christy deposit. Surface weathering in both areas has altered the upper portions to clay with abundant small blocks of quartzite, novaculite, and igneous rock masses, and grains of both rutile and brookite.

Fryklund and Holbrook offered differing origins for the two deposits. At the Magnet Cove Rutile Co. deposit, drilling work by the U. S. Bureau of Mines in 1945 and 1948 supposedly confirms their theories. Initially an aegirine phonolite porphyry magma was intruded, after which rutile-bearing feldspar-carbonate veins were intruded into the phonolite and its associated igneous rocks. Next, hydrothermal alteration of these veins occurred throughout the entire deposit, so that now these veins contain clays even at depth. Afterwards more rutile-bearing feldspar-carbonate veins were introduced, and finally the deposit weathered to clays at the surface. The richer deposits of rutile are confined solely to the veins (Fryklund and Holbrook, 1950, p. 35).

The Christy brookite deposit was originally novaculite and interbedded fine-grained sedimentary rocks which were initially partly altered by the introduction of titanium-rich solutions. Following this alteration and partial recrystallization of the novaculite, there was the formation of the clay minerals, during which both novaculite and fine-grained sediments were further altered. Final action was a weathering of the complex to a depth of 100 feet, during which pyrite was altered to iron oxides (Fryklund and Holbrook, 1950, p. 61-62).

Miscellaneous deposits.--The New Jersey magnetite deposits are supposedly the result of enrichment by late magmatic solutions or vapors which percolated through gneisses that had formed shortly before. Bayley (1910, p. 149) says, "after partial cooling of the gneisses these were in turn intruded by ferruginous portions of the same magma that gave them birth, and these intrusions were later enriched by iron-bearing solutions or vapors originating in the same subterranean source." These solutions "made the ore lenses that now comprise the ore bodies."

Secondary titaniferous deposits

Beach sands.—The heavy mineral deposits on beaches result from natural concentration by wave and current action. Most deposits probably form during heavy storms, when large waves carry sand well above the normal high-water mark of the beach. The returning water has enough velocity to remove only the lighter mineral grains, leaving behind a residue of heavy minerals. Because longshore currents and winds in many areas cause a migration of the sands along the beach, the deposits are "wandering" unless "anchored" at one end by a cliff, headland, natural bar, or other obstacle. For example, along the east coast of Australia the prevailing direction of the waves from the southeast causes the deposits to move northward; the best deposits are consequently found south of the capes, headlands, and bays, from which they have grown southward by accretion of the northward moving material (Fisher, 1948, p. 5).

The source of the heavy minerals is an important, yet often overlooked point. Although deposits of heavy minerals are common on the coasts of all continents, commercial titanium-bearing sand deposits most commonly occur under the following conditions. The sand of the heavy deposits has been contributed to the ocean by the erosion and reworking of sediments or sedimentary rocks high in titanium minerals; this makes the heavy mineral layers second, or even third cycle deposits. The sedimentary source materials, which may include deltas, river sediments, coastal plain sediments, or even beach and dune deposits, have a larger than normal titanium mineral content because the sand in them has resulted from the erosion of lateritic soils developed on igneous and metamorphic rocks. Tropical weathering of such rocks provides large proportions of the relatively stable heavy minerals ilmenite, rutile, zircon, and relatively little of the less stable magnetite, amphiboles, pyroxenes, etc.

A few examples will suffice to show that these conditions are essential for the formation of most titanium-bearing deposits. In Florida, the heavy deposits were produced during the continuous reworking of an old, pre-Pleistocene delta that occupied approximately the area now called Trail Ridge. This delta, composed of numerous smaller coalescing deltas, was built by streams that flowed from the north and were laden with debris from the lateritic soils of the area now occupied by Georgia and the southern Appalachians (Gillson, 1949, p. 1053-1054; Thoenen and Warne, 1949, p. 7-8). The Travancore deposits of India have resulted from the reworking of bars, spits, and dunes that formed after the coast was submerged and a river bed was inundated. The river had been draining an area of thick, deep red, lateritic soils (Gillson, 1949, p. 1053-1055). In Australia, sand in the deltas of the Clarence and Richmond Rivers (draining an area of Triassic sandstone) is attacked by longshore currents and redeposited along the coast; here it is reworked by the waves and concentrated into heavy mineral pockets (Beasley, 1948; Fisher, 1948).

In Brazil, deposits of titanium-bearing minerals occur where the ocean is attacking older coastal plain sedimentary rocks, but are not as rich as deposits elsewhere in the world because of the low concentration of titanium-bearing minerals.

In many areas burial of the deposits has been accomplished by wind activity, or by slight changes in the depositional activity of the ocean. In some places the layers have been elevated above the water by recent coastal uplifts, and now occur in terraces that are protected from attack by the water. Buried deposits that occur considerable distances inland (such as in Florida) are instances in which both burial and uplift have been considerable.

Stream sands and gravels.--When appreciable quantities of titanium-bearing heavy minerals are present in streams, a source-rock high in these minerals is being actively eroded. Deposition of the minerals occurs in backwaters or pools where the stream may deposit only the heavier minerals of its load. In some cases, such as the cassiterite-bearing gravels of Malaya, or the diamondiferous gravels of Sierra Leone, the titanium minerals are uniformly distributed throughout the deposit, and were deposited during the normal processes of stream deposition.

Residual deposits.—Weathering of rock under conditions, such as in tropical climates, that favors chemical decomposition rather than mechanical disintegration provides the best residual deposits. During the chemical changes many of the silicates are altered to hydrous aluminum silicates but the more resistant minerals, such as quartz, rutile, ilmenite, and zircon, are changed only slightly. In the Oregon ferruginous bauxite, evidence indicates that the lower parts of the clay are leached of silica, magnesia, calcium, and sodium, whereas in the upper parts of oolitic and pisolitic material, a concentration, especially of iron and aluminum, is dominant. This view is held by Libbey, Mowry, and Mason (1946, p. 257) who say, "The oolitic or pisolitic section .... probably represents a zone of concentration in part by concretion, whereas the underlying sections may represent a zone of concentration largely by leaching." Supporting analyses show that the lower portions of earthy, laterized basalt contains 38.5 percent Al_2O_3, 19.1 percent Fe, and 14.3 percent SiO_2, whereas the overlying pisolitic horizon contains 33.2 percent Al_2O_3, 27.8 percent Fe, and 6.4 percent SiO_2. In another group of analyses titanium varies from 2.73 percent TiO_2 in the porous granular material, to 3.23 percent TiO_2 in the oolitic or pisolitic kind, thus showing that titanium is relatively unaffected during the weathering action.

In Hawaiian soils the concentration of titanium has posed many problems. Sherman (1952) believes that the presence of anatase rather than ilmenite in the upper soil layers indicates a secondary origin. Accordingly, he believes the titanium is carried in waters from the wet tropical rainfall forest further upslope, and is deposited on the slopes where a climate with definite wet and dry seasons predominates. The titanium dioxide accumulates in the soil probably in the same manner as does iron oxide. The process probably is as follows: during the wet season the titanium-rich solutions permeate the soil, but during the dry weather they move upward and are dehydrated to anatase in the zone of accumulation.

DESCRIPTION OF TITANIUM-BEARING DEPOSITS

The titanium-bearing deposits, arranged by countries, are described in the following section; where possible, reserves and production data are given. With the exception of the United States and Canada the countries are grouped under their respective continents. The description of the titanium-bearing deposits does not attempt to evaluate the individual properties, as information about them is often limited. Many of the reports which were used for compilation of data mention only the grade and inferred tonnages of deposits, and do not indicate the mineralogical composition of the ore, or its commercial usability.

The total reserves of titanium-bearing deposits as indicated in Table 6 are 4,947 to 5,435 million short tons of titaniferous material with 600 to 889 million short tons of contained TiO_2. Unfortunately these estimates of reserves are inadequate because: (1) many estimates are from reconnaissance surveys; (2) reserve data are lacking for some of the large, commercially valuable deposits; and (3) the titanium content is the total contained in the deposit, all of which may not be recoverable.

Table 6. World resources of titanium-bearing deposits.

Country	Millions of short tons of titaniferous material			Millions of short tons of contained TiO_2		
Australia		12.4			4.5	
Canada	117.3	-	205.3	36.7	-	75.9
Ceylon		6.4			2.8	
Finland	11.0	-	55.1	1.3	-	6.6
India		2.6			0.3	
Japan		41.6			3.5	
Madagascar		3.9			1.0	
New Zealand		247.4			4.4	
Norway	51.3	-	59.8	6.6	-	7.5
Russia	100.9	-	441.7	6.7	-	66.8
Sweden		248.0			17.0	
Tanganyika		1,344.0			170.2	
Union of South Africa		2,393.2		301.7	-	481.6
United States of America	367.4	-	373.2	43.7	-	46.7
	4,947.4	-	5,434.6	600.4	-	888.8
	4,947 to 5,435 million short tons			600 to 889 million short tons		

The principal, actively mined deposits in 1951 were as follows: Australia, sands along the east and west coasts; Canada, primary deposits of ilmenite, magnetite, and hematite in Quebec; French Cameroons, rutile from stream placers; India, ilmenite and rutile from beach deposits along the Travancore coast; Malaya, ilmenite as a by-product of the mining of alluvial deposits for tin; Norway, ilmenite from ilmenite-magnetite bodies along the southwestern coast; Senegal, French West Africa, ilmenite from beach deposits along the coast south of Dakar; Russia, ilmenite and rutile(?) from deposits in the Ural Mountains; United States of America, ilmenite and rutile from various primary deposits and from buried beach deposits in the state of Florida.

The world production of ilmenite and rutile concentrates for the period from 1941 to 1950 is given in Table 7 and totals 5,305,476 metric tons of ilmenite concentrates and 193,071 metric tons of rutile concentrates._/ No information is available on Russian production. Although

_/ Although production for Japan is given for the years 1925 through 1946, only a small percentage of the ilmenite concentrates was produced prior to 1941.

the United States was the principal producer during this period, India was one of the largest producers prior to World War II.

Table 7. World production of ilmenite and rutile concentrates, 1941-1950

Metric tons

(No information on Russia)

Country	Metric tons of ilmenite concentrates	Metric tons of rutile concentrates
Australia	74,550	101,224
Brazil	21,271 *	13,298 *
Canada	230,634	---
China (1941-1944)	4,423	---
Egypt	3,390	---
French Cameroons	---	14,714
French Equatorial Africa	---	6
India	1,625,870	9,425
Japan (1925-46, Max. 1941-45)	25,556	---
Malaya	71,593	---
Norway	696,592	656
Portugal	2,978	---
Senegal, French West Africa	38,059	---
Spain	2,605	---
United States	2,507,955	53,748
TOTAL	5,305,476	193,071

* Exports

United States of America

In the United States of America the production of titanium concentrates from 1941 to 1950 was 2,507,955 metric tons of ilmenite concentrates and 53,748 metric tons of rutile concentrates. Table 8 shows that titanium-bearing deposits of the United States contain 367 to 373 million short tons of ore and materials containing 44 to 47 million short tons of TiO_2.

Ilmenite concentrates have been commercially produced from deposits in California, Florida, New York, North Carolina, and Virginia. Rutile concentrates have been obtained from deposits in Arkansas, Florida, and Virginia. Small production for gems, for experimental purposes and minor commercial purposes, has been reported from additional deposits in Connecticut, Georgia, Pennsylvania, Rhode Island, South Carolina, and Wyoming. Deposits of possibly future significance are known in Colorado, Idaho, Minnesota, Montana, Oklahoma, Oregon, Rhode Island, Washington, and Wyoming; less important deposits occur in Georgia, Maryland, Nevada, New Jersey, Pennsylvania, Tennessee, and Texas. Minor deposits of mineralogical interest only, or unimportant occurrences of ilmenite-bearing sands are reported from Alabama, Arizona, Connecticut, Indiana, Massachusetts, Michigan, Missouri, New Mexico, South Carolina, South Dakota, Utah, and Wisconsin. These minor occurrences are not discussed in this report, but are mentioned by the following authors: Anonymous, 1944 (Michigan); Barksdale, 1949 (Alabama, Missouri, and South Dakota); Coulter, 1939 (New Mexico); Day and Richards, 1906 (Arizona, Indiana, New Mexico, South Dakota, Utah); Denner, 1943 (Massachusetts); Schrader and others, 1916 (Connecticut, South Carolina); Watson, 1915 (Alabama, South Carolina); Weidman, 1907 (Wisconsin); and Youngman, 1930b (Alabama, Missouri, Wisconsin).

Table 8. Titanium resources the United States

State	Deposit	Owner	Kind of deposit	Percentage TiO_2 (grade)	Short tons of titaniferous material	Short tons of TiO_2	Reference
ARK.	Hot Spring County	One of the deposits operated 1932-1944 (Magnet Cove Rutile Co.)	Rutile and brookiten clay and igneous rock	3.0- 4.0	2,250,000	70,000	1. Table 38.
CALIF.	San Gabriel Mountains	No production	Ti-mags in anorthosie	5.0-25.0	250,000 - 6,000,000	45,000-1,050,000	1., 2
FLA.	Near Jacksonville	National Lead Co.	Buried beach sands	0.5- 1.5	114,600,000	545,000	1. {Table 38, Chart 26.
	Near Starke	DuPont	Buried beach sands	1.3- 1.8	?	?	—
	Near Vero Beach	Fla. Ore Proc. Co.	Buried beach sands	0.8	66,700,000	560,000	1. {Table 38, Chart 26.
	Pensacola Bay area	No production	Modern beach sands	—	750,000	?	3.
	All buried beach deposits	—	—		?	13,000,000-15,000,000	4.
					TOTAL 182,050,000	1,110,000-15,000,000	
IDAHO	Latah County clay	No production	Ilmenite-bearing alnina clays	4.0	?	150,000	5.
MINN.	Lake and Cook Counties	No production	Ti-mags in gabbro ad anorthosite	3.0-25.0	94,600,000	14,400,000	6. TiO_2 content calculated.
MONT.	Teton County	No production	Ss with titaniferou magnetite	3.7-8.5	4,500,000	270,000	7.
N. Y.	Sanford Hill	National Lead Co.	Ti-mags in anorthoste and gabbro	20.0	13,700,000	(Aug. '49) 2,740,000	8. TiO_2 content calculated from various analyses
	Ore Mountain	No production	Ti-mags in anorthoste and gabbro	13.0-24.0	12,000,000	2,330,000	
	Calamity Mill Pond	No production	Ti-mags in anorthoste and gabbro	17.2	9,500,000	1,630,000	
	Cheney Pond	No production	Ti-mags in anorthoste and gabbro	12.0	800,000	96,000	
					TOTAL 36,000,000	6,796,000	
N. C.	Yadkin Mica and Ilmenite	The Glidden Co.	Ilmenite in mica sciist	35.0	750,000	260,000	1. Table 38. Allowances made for depletion by mining.
ORE.	Western Oregon	No production	Clays and laterites with ilmenite	1.0- 6.1	6,549,000	321,000	9.
VA.	Amherst and Nelson Cos.	Am. Cyanamid Corp.	Total of all nelsonite bodies	3.0-20.0	31,330,000	5,150,000	1. Table 38.
WASH.	Spokane County	No production	Ilmenite-bearing alumina clay	7.1	?	890,000	10.
WYO.	Iron Mountain	No production	Ilmenite and magnetite in anorthosite	5.0-23.0	9,150,000	1,278,000	11.
					TOTAL USA 367,429,000-373,179,000	43,735,000-46,740,000	
					367.4 to 373.2 million	43.7 to 46.7 million	

References

1. Matthews, Ralston, and Ross, 1947.
2. Oakeshott, 1950.
3. Matthews, 1945, p. 809.
4. Cannon, 1950.
5. Scheid and Sohn, 1946.
6. Grout, 1949-50.
7. Mining World, 1952, v. 14, no. 3, p. 94.
8. Balsley, 1943.
9. Libbey, Lowry, and Mason, 1946.
10. Scheid, 1946.
11. Newhouse and Hagner, 1951.

Arkansas has never been an important producer of titanium ores, and has produced only 5,188 short tons of rutile concentrates, from 1932 to 1944 (Fryklund and Holbrook, 1950, p. 14). Reserves for the state are estimated by Matthews, Ralston, and Ross (1947, Table 38) at 2,250,000 short tons of rutile "ore" containing 70,000 short tons of TiO_2.

The deposits are associated with igneous and sedimentary rocks in the Magnet Cove region of Hot Spring County, and with sands in Howard County.

Magnet Cove Rutile Company.--The only production of rutile in Arkansas has been from the deposit of the Magnet Cove Rutile Company (formerly the Titanium Alloy Manufacturing Company of Arkansas), in sec. 18, T. 3 S., R. 17 W., Hot Spring County, about 8 miles north-northwest of Malvern. This deposit of rutile-bearing clays and igneous rocks has been interpreted as either a highly altered volcanic agglomerate, or an igneous rock complex cut by partially altered, rutile-bearing veins. (see p. 47, 74-75, and 91-92).

Sampling by the U. S. Bureau of Mines and the operators indicated an average of 3 to 4 percent TiO_2, of which 15 to 20 percent is in leucoxene, and the remainder is in rutile. The open pit mine measures 2,400 by 1,000 feet at the surface, and yielded 5,188 short tons of rutile concentrates in intermittent operations from 1932 to 1944. Ore dressing difficulties probably halted operation, because beneficiation tests in 1944 indicated that recovery was only 14 to 17 percent in a 91 to 92 percent TiO_2 concentrate (Spencer, 1946, p. 5). Further beneficiation tests in 1947 showed, however, that by using flotation it might be possible to get a 46 percent recovery in a 92.2 percent TiO_2 product (Reed, 1949b, p. 8).

Christy brookite deposit.--The Christy brookite deposit has never been mined although it has been test drilled and sampled. It is located in the SW¼SW¼ sec. 16, T. 3 S., R. 17 W., Hot Spring County, 8 miles north of Malvern, and contains brookite crystals embedded in a matrix of clays and highly altered novaculite (see p. 48, 74-75 and 92). Average grade of the deposit over an area of 900 by 500 feet is about 5.8 percent TiO_2 and two small test pits show 6.9 and 7.6 percent TiO_2 (Holbrook, 1947, p. 13; Reed, 1949a, p. 2, 5). Beneficiation tests in 1944 on "ore" containing 10.6 percent TiO_2 showed that by flotation and other techniques it was possible to obtain "reasonably good recovery of titania in a concentrate analyzing 92.4 percent TiO_2" (Falconer and Crawford, 1944, p. 8-10). Samples analyzed by the U. S. Bureau of Mines contained approximately 6 percent TiO_2 and were concentrated by flotation to one product of 92.8 percent TiO_2 with a recovery of 60.6 percent, and to another of 91.2 percent TiO_2 with a recovery of 55.2 percent (Fine and Frommer, 1952, p. 4-5).

Hot Spring County, miscellaneous.--Minor deposits in the Magnet Cove region of Hot Spring County appear too small to be economically valuable. The Hardy-Walsh brookite deposit lies in two adjacent 40-acre tracts in sections 16 and 17, T. 3 S., R. 17 W., about 1 mile east of the Magnet Cove Rutile Company. Test pitting shows that the "ore" occurs in residual clays which overlie altered brookite-bearing novaculite, and contains 5.0 to 8.4 percent TiO_2 (Fryklund and Holbrook, 1950, p. 42-52).

The Mo-Ti Corporation deposit in the NW$\frac{1}{4}$ sec. 17, T. 3 S., R. 17 W., has an average grade of 1.23 percent TiO_2.

Howard County.--Northwest of Mineral Springs, Howard County, layers of ilmenite-rich sand occur in the Upper Cretaceous Tokio formation, which is 300 feet thick and contains intertonguing clays, sands, and lignites. In the Pink Green deposit in the N$\frac{1}{2}$SE$\frac{1}{4}$ sec. 12, T. 10 S., R. 28 W., the best ilmenite concentration occurs 4 to 8 feet below the surface where a cross-bedded friable sandstone contains a maximum of 12.8 percent TiO_2 and averages about 4 percent. In the Beulah Green deposit in the NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 23 and the W$\frac{1}{2}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 24, T. 10 S., R. 28 W., some titaniferous material is exposed at the surface. The largest concentration of ilmenite occurs 3 to 4 feet below the surface in quartz sands which range from 0.6 to 28.6 percent TiO_2. Testing of these deposits by the U. S. Bureau of Mines indicated that a concentrate of 54.9 percent TiO_2 could be obtained with a recovery of 92 percent (Holbrook, 1948b).

California

Reserves of titanium in California occur near Los Angeles in beach sands, and in the San Gabriel Mountains in stream placer deposits and primary deposits of ilmenite and magnetite. The reserve estimates by Matthews, Ralston, and Ross (1947, Table 38) indicate 250,000 short tons of 18.0 percent TiO_2 "ore", equivalent to 100,000 short tons of ilmenite or 45,000 short tons of TiO_2. Other estimates of the San Gabriel ilmenite deposits range from 300,000 to 6,000,000 short tons of material containing 52,500 to 1,050,000 short tons of TiO_2 (Oakeshott, 1950, p. 355). Both these estimates may be considerably in error, since very little drilling or extensive geological investigation has been undertaken. There are no estimates for the beach deposits.

The production from the California lode and beach deposits has never been large; it was 10,013 tons of concentrates in 1927 and 1928, 705 tons from 1939 to 1944, and an unknown but presumably small amount from 1946 to 1950.

Los Angeles County beach sands.—The ilmenite-bearing beach sands between Hermosa and Palos Verdes, Los Angeles County have been intermittently worked for their titanium minerals. According to Baughman (1927, p. 310) the sands along more than 3,000 feet of beach averaged 7 percent ilmenite, and in the richer portions contained 60 percent ilmenite and 40 percent magnetite. Although one source indicates that pure ilmenite concentrates were obtained by beneficiation (Tucker, 1927, p. 298), another source claims that in 1927 ilmenite shipments "amounted to about 7,640 tons, ranging from 15 to 52 percent titanium oxide, equivalent to about 3,500 tons carrying 50 percent titanium oxide" (Youngman, 1930b, p. 4). During 1927 and 1928 production from this beach and from lode deposits in the San Gabriel Mountains totaled 10,013 tons of concentrates, and during 1939 to 1944 this beach yielded 705 tons of concentrates. Reserve information, and data on these recent operations are lacking.

San Gabriel placer deposits.--During 1946 to 1950 Ferro-Titan Minerals and the Live Oak Mines intermittently operated in Sand Canyon, near Saugus, Los Angeles County. The stream sands of both Sand Canyon and Pacoima Canyon contain layers of ilmenite and magnetite-bearing black sand that is derived from the nearby ilmenite and magnetite-rich gabbro and anorthosite. These sands extend for considerable distances along the streams (half a mile and perhaps even more), and according to drill information by the U. S. Bureau of Mines and the U. S. Forest Service they average 30 to 50 feet in depth and contain from 2 to 30 percent TiO_2 (Oakeshott, 1948, p. 265). Beneficiation tests on these sands indicated that the small intergrowths of ilmenite and magnetite make it difficult to obtain high-grade ilmenite concentrates. Fine grinding and electromagnetic separation yielded one concentrate analyzing 32.6 percent TiO_2 with an 18 percent recovery, and another of 23.3 percent TiO_2 with a 73.2 percent recovery (Oakeshott, 1948, p. 262). Ferro-Titan Minerals Company recovered ilmenite as a by-product of the waste sands from a sand and gravel plant and sold the concentrates for use in roofing granules and welding rod coatings. The other plant, the Live Oak Mines, mined creek sands averaging 7.5 percent TiO_2 and produced a concentrate of 31.3 percent TiO_2 (Oakeshott, 1948, p. 263). Production from these operations is unknown, although presumably it is small.

According to Oakeshott (1948, p. 265) there are several million tons of workable sand in each canyon, although lack of systematic sampling and drilling makes these estimates only approximate.

San Gabriel primary deposits.--Minor production has been reported from various localities in the San Gabriel Mountains, where bodies of ilmenite-magnetite are associated with gabbro and anorthosite. The small intergrowths of ilmenite and magnetite that occur in these deposits make the production of high purity ilmenite concentrates difficult. A futile attempt was made in 1906 to utilize ore of the western San Gabriel Mountains at Russ Siding in Soledad Canyon. In 1927 and 1928 mining for titanium ore was undertaken on the ridge between Pole and Bear Canyons, 2.4 miles southeast of Lang Station. Samples of ore from this short lived venture analyzed 19.6 percent TiO_2, 46.1 percent iron, and 0.53 percent V_2O_5. E. I. duPont de Nemours and Co., Inc. undertook an extensive exploratory program throughout much of the range from 1927 to 1938, but abandoned the project without doing any drilling; they have not made public the results of their work. Although the San Gabriel titanium-bearing deposits are estimated to contain as much as 6 million tons of "ore", equivalent to 1 million tons of TiO_2 (see p. 110), the difficulties in ore dressing make them commercially unworkable at the present. The location and possible reserves of numerous deposits in this region are given by Oakeshott (1948).

Minor deposits.--Minor deposits of titanium-bearing minerals include beach deposits near Aptos in Santa Cruz County. Black sand layers here occur in long, irregular crescents that are 6 feet thick, 50 feet wide, and 200 feet long, and contain 16 percent TiO_2 (Youngman, 1930b, p. 3-4). Other beach sands along the coast have been investigated, but as of early 1952 no workable titanium deposits had been found.

Colorado

In Colorado, ilmenite-magnetite bodies occur in Boulder and Freemont Counties, and a perovskite-magnetite or ilmenite-magnetite body occurs in Gunnison County. An unverified titaniferous deposit reportedly occurs in Clear Creek County.

The deposits have not been operated commercially, and are not exploitable at the present (1952) because: (1) the individual titaniferous bodies are all small; (2) the tonnage of titanium-material in a given deposit is small; and (3) intergrowths of ilmenite and magnetite are so fine grained that high grade ilmenite concentrates cannot be obtained by ordinary ore dressing techniques.

At Caribou Hill, Boulder County, approximately 17 miles west by south of Boulder, basic dikes within Precambrian granites and gneisses contain small pockets and lenses of ilmenite and magnetite. These ilmenite-magnetite bodies contain magnetite with interstitial particles and small grains of ilmenite, and average 67 percent magnetite and 8.5 percent ilmenite (Singewald, 1913b, p. 125-128).

At Iron Mountain, Freemont County, about 12 miles southwest of Canyon City, lenses of ilmenite-magnetite average 25 feet in width within gabbro and anorthosite, and contain 13 percent TiO_2 and 48 percent iron (Singewald, 1913b, p. 128-135).

On the east side of Cebolla Creek, south of Powderhorn, in the southern part of Gunnison County, Singewald (1912, 1913b, p. 135-140) describes ilmenite-magnetite bodies that occur as numerous small segregations within a gabbro, and as small nests or patches within a contact metamorphosed limestone. The bodies generally contain more ilmenite than magnetite, and analyze 9 to 36 percent TiO_2. Larsen (1942, p. 14) indicates that the same deposit contains "dikelike or lenslike bodies of 'iron ore', many of them 20 feet across, made up of nearly pure magnetite and perofskite . . ." The purest portions of the "ore" consist of coarse-grained magnetite and perovskite with minor amounts of ilmenite, apatite, and biotite. An analysis of the richer material shows in part 35.05 percent TiO_2, 24.03 percent Fe_2O_3, and 14.26 percent FeO.

It was reported in 1943 that a small shipment of titanium ore was made from property near Georgetown in Clear Creek County (Mining Journal, Phoenix, 1943). No further mention of this deposit is made in the literature.

Florida

Florida, the second largest producer of titanium ores in the United States during 1950, was exceeded in production only by New York State (Cservenyak, 1953, p. 1231). All mining in 1952 was from buried beach deposits, although until 1943, modern beach deposits were also mined. The buried deposits contain ilmenite, rutile, and leucoxene in amounts up to 50 percent of the total heavy minerals. The deposits formed when the land was lower and the ocean was attacking a large delta of sediments that were derived from the highlands to the north. Reserve estimates range from approximately 180 million tons of rutile and ilmenite-bearing sand containing about 1 million short tons of TiO_2 (Matthews, Ralston, and Ross, 1947, Table 38), to 25 to 30 million short tons of ilmenite, equivalent to 13 to 15 million short tons of TiO_2 (Cannon, 1950, p. 206).

Although the buried sands usually average less than 5 percent heavy minerals, they can be mined economically on a large scale by floating dredges. Mining by dredges became feasible only during World War II when the advent of spiral concentrators made possible the treatment of low-grade sands. Buried sands are preferable to modern beach sands in large, mechanized mining operations because the buried deposits have larger reserves and more uniform distribution of heavy minerals over a large area.

National Lead property near Jacksonville.--One of the two principal deposits in Florida is about 8 to 10 miles east of Jacksonville, where the Humphreys Gold Corporation mines property owned by the Rutile Mining Company of Florida, a National Lead Company subsidiary. The buried sand here contains approximately 4 percent heavy minerals, of which 43 percent is ilmenite, 7.5 percent is rutile, and 10 percent is zircon (Michell, 1952, p. 368). Sampling work by Miller (1945, p. 71) indicated that heavy mineral concentrates from this deposit contain 26 percent ilmenite, 5 percent rutile, 3 percent zircon, 24 percent enstatite, 21 percent staurolite, and 11 percent epidote.

Operation of the property began in the summer of 1943, and by 1944 suction dredges were handling 4,000 to 5,000 tons per day of raw sand containing 5 to 11 percent heavy minerals. Concentration by Humphreys spirals and electromagnetic and electrostatic separators yielded 2,000 tons of ilmenite concentrates and 300 tons of rutile concentrates per month (Nighman and Bryson, 1946, p. 800). By 1949 the input had been increased to 8,000 tons per day of raw sand (Lenhart, 1949, p. 102).

According to Matthews, Ralston, and Ross (1947, Table 38) the deposit contains 114,600,000 short tons of rutile ore containing 545,000 short tons of TiO_2. Cannon (1950, p. 204) claims this deposit and the duPont property near Starke contain 30 million tons of heavy minerals of which 12 million tons is ilmenite, and 3 million tons is zircon.

DuPont property near Starke.--The second important deposit in Florida is in the state-owned land of Camp Blanding, east of Starke in Clay County. Humphreys Gold Corporation operates the deposit for E. I. duPont de Nemours and Co., Inc. by using suction dredges on buried heavy sands. The heavy minerals, which occur from 30 to 70 feet below the surface, usually comprise 2 to 10 percent of the total sand, and average 2 to 4 percent. They consist of 45 percent ilmenite (some partly altered to leucoxene), 14 percent zircon, and 20 percent staurolite (Meyer, 1949, p. 1176-1177). The titania content of the total sand is approximately 1.3 to 1.8 percent TiO_2, and that of the heavy minerals is 28 to 33 percent TiO_2 (Anonymous, 1952).

Mining by suction dredges began in March 1949, and by the close of 1951 the dredges were producing 30,000 tons of raw sand per day. Every hour approximately 1,100 tons of sand containing 4 percent heavy minerals is pumped to banks of Humphreys spirals, and yields 45 tons of concentrate containing approximately 80 percent heavy minerals. This concentrate, which contains 45 percent titanium minerals, 15 percent zircon, 20 percent staurolite, 5 percent sillimanite, 4 percent kyanite, and 5 percent tourmaline, is further treated by electromagnetic and electrostatic separators to yield titanium and zirconium concentrates (Anonymous, 1952). In 1951 the output was 120,000 tons of titanium concentrates with an average TiO_2 content of 65 percent (Allen, 1952, p. 54).

The only reserve estimates are by Cannon (1950, p. 204) who claims that this deposit and the Rutile Mining Company property near Jacksonville contain 30 million tons of heavy minerals, of which 12 million tons are ilmenite, and 3 million tons are zircon.

Vero Beach.--Deposits east of Vero Beach were worked from 1943 to 1947 by Riz Mineral Company, and from 1948 to 1950 by the Florida Ore Processing Company, Inc. Buried beach deposits, 3 miles inland beneath coastal dunes, and the present beach are worked. According to Miller (1945, p. 65) the rough concentrate from the dunes contains 36 percent ilmenite, 27 percent rutile, 6 percent zircon, 20 percent staurolite, and 3 percent epidote.

Matthews, Ralston, and Ross (1947, Table 38) show that this deposit contains 66,700,000 short tons of ilmenite-bearing sand, averaging 0.84 percent TiO_2 and containing about 560,000 short tons of TiO_2.

Former mining operations.--An important source of ore during 1916 to 1928 was the beach east of Jacksonville. Buckman and Pritchard, Inc., a subsidiary of National Lead Company, produced ilmenite, rutile, and monazite from the beach that extends 3 miles north and 8 miles south of Mineral City. The sands as received at the concentration plant contained 20 percent heavy minerals, that averaged 55 percent ilmenite, 6 percent rutile, 20 percent zircon, and 2 percent monazite (Martens, 1928, p. 137).

Another operation of the past was from 1940 to 1943 at Palm Bay, south of Melbourne, where Riz Mineral Company mined beach placer deposits for 12 miles along the Indian River. The sand as mined contained 28 percent heavy minerals, averaging 36 percent rutile, 36 percent ilmenite, and 11 percent zircon (Vernon, 1943, p. 142).

In 1943, the St. Johns Lumber and Development Company of St. Augustine reportedly shipped a small quantity of mixed ilmenite, rutile, and zircon concentrate (Matthews, 1945, p. 808).

Central and northeastern Florida.—Drilling by the U. S. Bureau of Mines in 1947 and 1948 (Spencer, 1948; Thoenen and Warne, 1949) has revealed extensive buried low-grade deposits of titanium-bearing sands in the central and northeastern parts of Florida. The drilling program covered ten separate areas extending from northwest of Jacksonville southward to about 10 miles northwest of Lake Okeechobee. These sands averaged 1.0 to 2.0 percent heavy minerals, with a few holes exceeding a 3.0 percent average. The average heavy mineral composition of 100 composite samples from the drill holes is: magnetic opaques, 45 percent; rutile, 4.6 percent; staurolite, 15.3 percent; and zircon, 12.4 percent. The magnetic opaque material was determined to be principally leucoxene, which, according to Thoenen and Warne (1949, p. 30) "is a mixture of rutile and fine-crystal ilmenite."

The more promising areas shown by the drilling were: (1) an area known as the Baywood Promontory near Interlachen in Putnam County; (2) the area around Cambon in Duval County, about 10 miles west of Jacksonville; (3) the area around Camp Blanding in Clay County, especially near the Gold Head State Park; (4) an area bounded by Lynne, Astor, Weirsdale, and Altoona in Marion and Lake Counties, and including part of the Ocala National Forest; (5) between Minneola and Orlando in Lake and Orange Counties; and (6) an area including Childs in Highlands County.

Pensacola Bay region.--Beach deposits in Santa Rosa, Escambia, and Okaloosa Counties, within a 25-mile radius of Pensacola, contain 750,000 tons of sand averaging 1 percent ilmenite, 0.1 percent rutile, 1.2 percent kyanite, and 0.4 percent zircon (Matthews, 1945, p. 809). Miller (1945, p. 71) shows that the heavy minerals are 14.7 ilmenite, 8.7 percent rutile, 32.8 percent kyanite, 30.7 percent staurolite, and 9.8 percent zircon, but does not indicate the total percentage in the sand.

Minor deposits.--Sands of the following areas contain layers of titanium-bearing minerals, but are probably commercially unimportant. They are: Amelia Island, Nassau County, in the extreme northeast corner of the state; Eau Gallie, Brevard County, on the Indian River north of Melbourne; on the beach near Venice, Sarasota County; the peninsula between Cape San Blas and Point St. Joseph, Gulf County, southeast of Panama City; on the shoreward side of Crooked Island along St. Andrews Sound in Bay County; and on Gulf Beach in the vicinity of Phillips Inlet, Bay County (Martens, 1928, p. 141-147).

Georgia

Occurrences of titanium-bearing "ore" in Georgia are all minor. The only recorded production was at Graves Mountain in the western portion of Lincoln County, where rutile was mined for specimens and gems during the late nineteenth century. The rutile occurs within quartzites and quartz veins, and analyzes from 97.22 to 97.64 percent TiO_2. The deposit is too small for commercial development (Watson and Taber, 1913, p. 23-27).

The following minor deposits of titanium-bearing coastal beach sands have been described by Martens (1928, p. 141-142) and Teas (1921, p. 376-377). Near the southern end of St. Simons Island, black sands containing 34 percent TiO_2 extend for half a mile southward from the lighthouse. The northern end of Long Island contains black sands which have 51 percent ilmenite and 4 percent rutile. Black sand deposits appear to be general throughout most of Sapelo Island, and are especially prominent near the southern end of the island. Two analyses of sand here show about 5 percent TiO_2.

In Idaho, where prospecting and dredging of placer deposits has been undertaken principally for monazite, testing of the Walsh Creek placer indicated that the sands and gravels contain in addition to gold and monazite some ilmenite, zircon, and garnet (Mining World, 1951, v. 13, no. 10, p. 78). Other places throughout the region are also said to contain ilmenite, and this might be an important by-product if mining for other minerals is undertaken. A preliminary investigation of the streams draining the west and southwest flanks of the Idaho batholith of central northern Idaho was undertaken by the U. S. Bureau of Mines during 1951 and 1952, but the results of this have not been published. No reserve information has been published on any of the placer deposits.

Latah County clay.—In Latah County the Deary clay deposit averages about 8 percent ilmenite and contains 150,000 short tons of TiO_2 (Scheid and Sohn, 1946).

Maryland

The only important titanium-bearing deposits in Maryland are in Harford County, where rutile deposits occur in a belt of serpentine rocks that extends northward for 5 miles from a point 1 mile northwest of Pylesville (Tomlinson, 1946, p. 322). Within this belt the Dinning rutile mine contains rutile pockets that average 8 percent TiO_2 and reportedly extend to a depth of 58 feet (Ostrander, 1946). Preliminary concentrates from this deposit contained 91 percent TiO_2. By means of improved facilities, claims state that the mine could yield 6 percent TiO_2 "ore" capable of concentration to a 93 to 96 percent TiO_2 product. There are no reserve estimates.

Minnesota

North of Lake Superior, in northeastern Minnesota, are numerous unmined deposits of ilmenite and magnetite. Recent drilling and geologic investigation show that the material is mostly low grade and would require beneficiation before it could be used. Reserves of these deposits are estimated at 94.6 million short tons of "ore" in bodies of more than 100,000 short tons each, and 81.6 million short tons of "ore" in bodies of more than a million short tons each (Grout, 1949-50, p. 85-86). Grout (1949-50, p. 93) indicates that the deposits of more than 1 million tons each average about 14 percent TiO_2, and those of less than 1 million tons average about 23 percent TiO_2. By using these grades the average TiO_2 content can be calculated at ~~11,414,000~~ 14,414,000 tons of contained TiO_2.

The deposits of ilmenite and magnetite are associated with the Duluth gabbro, a large lenticular intrusive more than 150 miles wide, and supposedly more than 10 miles thick at its center (Grout, 1949-50, p. 15). The gabbro extends for 125 miles from Duluth northeast to Greenwood Lake, T. 64 N., R. 2 E., Cook County, and has a crescentic outcrop pattern with the concave side towards Lake Superior (Singewald, 1913b, p. 93-94). The complex of layered, basic igneous rocks ranges from peridotite through gabbro to anorthosite, and contains ilmenite-magnetite bodies as bands, irregular bodies, and dikes (see p. 36 and 66 for a fuller description). The best "ores" occur in the easterly trending North and South Ranges of Cook County, especially near Poplar, Tucker, Saganaga, and Gabimichigami Lakes in the North Range and near Smoke and Jack Lakes in the South Range. Analyses of cores drilled in 1947 show 3.4 to 25.0 percent TiO_2, and 10.8 to 37.4 percent iron (Grout, 1949-50, p. 101). Examination of polished sections shows very small intergrowths of ilmenite and magnetite. Beneficiation tests indicate that generally only a small amount of ilmenite concentrates can be obtained.

The location and grade of deposits having more than a million tons of "ore" is given below, and is taken directly from a report by Grout (1949-50). Grade A is direct shipping "ore"; Grade B is "ore" that requires a concentration of about 2 to 1; Grade C requires a concentration of about 3 or 4 to 1, and Grade D requires a concentration of about 5 or 6 to 1 (Grout, 1949-50, p. 80). The tonnages are as follows:

1. Calculated from drilling

Southeast of Tucker Lake	2,300,000 tons Grade B
Between the arms of Tucker Lake	19,000,000 tons Grade D
Northeast of Smoke Lake	3,000,000 tons Grade D

2. Indicated by outcrops and exploration or magnetics

Between the arms of Tucker Lake	10,000,000 tons Grade D
$S\frac{1}{2}NW\frac{1}{4}$ sec. 1, Tucker Lake	12,000,000 tons Grade D
Sec. 2, northwest of Poplar Lake	5,000,000 tons Grade B
Sec. 2, northwest of Poplar Lake	15,000,000 tons Grade D
Secs. 5 and 6, northeast of Poplar Lake ...	2,000,000 tons Grade C
Between Smoke Lake and Jack Lake, T. 63 N., R. 4 W.	
Sec. 26	3,000,000 tons Grade B
Sec. 26	1,000,000 tons Grade C
Sec. 27	4,000,000 tons Grade D
Sec. 27	1,300,000 tons Grade D
Sec. 28	2,500,000 tons Grade C
Sec. 33	1,500,000 tons Grade B
	81,600,000 tons in the state

The adaptability of these "ores" to present-day industry is summarized by Grout (1949-50, p. 91-93) who says: "Cook County may have within easy reach of shallow surface mining something more than 90 million tons of indicated and inferred titaniferous magnetite ore; and ... some important bodies of the ore could be easily concentrated by cheap gravity methods to a product closely approaching ilmenite in composition ....

"These prospective titaniferous ores ... are probably 'marginal' ores; that is, they can be used profitably only under certain favorable conditions. The large bodies are of low grade; and the rich bodies are small ....

"When the titanium market requires ore supplies so strongly that prices make any of the following kinds of deposits attractive, further exploration and possible production will be in order. Cook County has:

1. Large tonnage of lean ores in deposits of a million to 20 million tons carrying about 25 percent Fe and 14 percent TiO_2 in position for open pit mining.
2. Small tonnages of fairly high grade ore, possibly several million tons, to be mined underground, carrying 25 percent Fe and 23 percent TiO_2, in condition to be concentrated by simple gravity methods to a product 37.5 percent Fe and 44.0 percent TiO_2.
3. Several deposits of intermediate grade and fair size."

Montana

The only important titanium-bearing deposits in Montana are in Teton, Glacier, and Pondera Counties, where the upper 25 feet of the Horsethief sandstone of Late Cretaceous age contains beds of black sandstone. These beds range in thickness from a few inches to 9 feet, and are the indurated equivalent of black sand lenses which are common in many beaches. This sandstone extends from Teton County northward through Pondera County, into Glacier County and across the border into Canada. The black sandstone lenses often have a metallic luster, and contain individual grains of magnetite, ilmenite, zircon, and sphene, and also grains of intergrown ilmenite and magnetite.

In the Blackfeet Indian Reservation of Glacier County, the beds average 4 to 5 feet in thickness and contain 6.8 to 12.8 percent TiO_2, and 27.3 to 49.3 percent Fe (Stebinger, 1914, p. 337).

In July 1945 drilling by the U. S. Bureau of Mines in the deposits northwest of Choteau, Teton County, totaled 800 feet, of which approximately 164 feet, or 20 percent, was in beds which contained more than 30 percent iron. These richer parts contained 3.7 to 8.5 percent TiO_2 (average 5.9 percent), and 30.4 to 56.2 percent Fe (average 38.8 percent). Beneficiation tests showed that it was impossible to obtain good iron or ilmenite concentrates by grinding, screening, sink-float, or magnetic separation (Wimmler, 1946, p. 6-12). The only reserve estimates are given in an article in Mining World (1952, v. 14, no. 3, p. 94) which states, "An estimated 4,500,000 ton deposit of titaniferous magnetite in Teton County, Montana, averages about 6.0 percent titanium dioxide. A similar deposit in Pondera County averages 5.0 to 8.0 percent titanium dioxide."

Nevada

In Nevada only two small deposits have been mentioned for their titanium content; one occurs in Churchill County and the other in Douglas County. There has been no production, and there are no published reserve estimates.

The Corral Canyon mine in northern Churchill County, approximately 70 miles south of Winnemucca and on the eastern flank of the Stillwater Range, contains gold-bearing quartz veins and anatase-bearing altered feldspathic dikes. The anatase is irregularly distributed and "in places it forms over 5 percent of the rock and in small segregations a much larger proportion; elsewhere it may be lacking or present only in small specks" (Ferguson, 1939, p. 19). Testing by the U. S. Bureau of Mines on samples of "ore" that were probably from this locality, and contained 2 percent TiO_2 as anatase, showed that the two best concentrates contained 63 percent TiO_2 with a 11 percent recovery, and 52 percent TiO_2 with a 36.5 percent recovery (U. S. Bureau of Mines, 1938, Rept. Inv. 3425, p. 89). The amount of "ore" is not large.

The Blue Metal Corundum property in Douglas County, approximately 20 miles west of Yerington, contains material rich in corundum and apatite, with small amounts of rutile. Concentration tests yielded a rutile product of 16.0 percent TiO_2 with a recovery of 14.8 percent (Binyon, 1946).

New York

The production in 1951 of over 270,000 tons of ilmenite concentrates (Allen, 1952, p. 54) placed New York state first in the production of titanium ores in this country. All of the ore was mined by the National Lead Company at Lake Sanford, Essex County, N. Y.

The only important area of titaniferous reserves in the state is within a 2-mile radius of Lake Sanford, Essex County, near the headwaters of the Hudson River, about 32 miles north of North Creek. In this region, where estimates of titaniferous material range from 15 to 100 million tons, the U. S. Geological Survey in 1942 estimated 43 million short tons of ore (Balsley, 1943, Table 4), equivalent to approximately 8.2 million short tons of TiO_2. Mining up to August 1949 had reduced the reserves to 36 million short tons of ore containing 6.8 million short tons of TiO_2.

National Lead Co. deposit, Lake Sanford.--This deposit in the Lake Sanford area has been variously identified in the literature as the Lake Sanford, Sanford Lake, Tahawus, MacIntyre, or Sanford Hill operation. The National Lead Company is mining the Sanford Hill deposit on the east side of Lake Sanford, where massive ilmenite-magnetite ore is associated with gabbro and anorthosite of the large Mt. Marcy anorthosite massif of the Adirondack Mountains. The ore, averaging 20 to 21 percent TiO_2 and 34 percent iron, is mined in open pits and trucked to the nearby concentration plant. This deposit, and others in this area, are also discussed on pages 35, 44, 56-58, 59-62, and 84-86.

Mining of the property began in August 1942, and by the end of August 1949 7,000,000 tons of ore had yielded 1,000,000 tons of ilmenite concentrate averaging 44 to 48 percent TiO_2, and 3,000,000 tons of magnetite concentrate averaging 56 percent iron and 9 to 10 percent TiO_2 (Meyer, 1951, p. 1223). The ilmenite concentrate finds immediate use, whereas the magnetite concentrate is at times stockpiled since the demand for it is less.

After extensive drilling in 1942 reserves for this deposit were estimated by the National Lead Company to be 15,000,000 tons of ore. The U. S. Geological Survey estimates in September 1942 showed 11,500,000 short tons of measured and 4,200,000 short tons of indicated rich ore, plus a measured 5,000,000 short tons of lean ore, for a total of 20,700,000 short tons of ore (Balsley, 1943, Table 4). As of August 1949, an estimated 13,700,000 tons of ore remained in the deposit.

Iron Mountain deposit.--The Iron or Ore Mountain deposit occurs on the southwest flanks of Mount Adams, northeast of Lakes Sanford and Jimmy. The deposit of practically pure magnetite-ilmenite extends to a depth of 150 feet in a zone that is 2,000 feet long by 50 to 200 feet wide, and is bounded by anorthosite on one side and gabbroic rocks on the other (Balsley, 1943, p. 121; Stephenson, 1948, p. 406-409). Balsley (1943, Table 4) shows 7,000,000 short tons of indicated rich "ore", and 5,000,000 short tons of inferred lean "ore" in this body of approximately 24 percent TiO_2.

Calamity Mill Pond deposit.--The Calamity Mill Pond deposit, located in an area surrounding the junction of Calamity and Henderson Brooks, is associated with anorthosite and gabbro. Reserves are 600,000 short tons of indicated and 900,000 short tons of inferred rich "ore," in addition to 8,000,000 short tons of inferred lean "ore;" average grade of "ore" is about 17.2 percent TiO_2 (Balsley, 1943, Table 4).

Cheney Pond deposit.--The least important is the Cheney Pond deposit, located approximately 600 feet south of Cheney Pond, and about 2 miles southwest of the Sanford Hill deposit. This lens of ilmenite and magnetite within gabbro is finer grained and contains more gangue than most bodies within gabbro. Singewald (1913b, p. 63) states that the deposit is 50 percent gangue and contains 8.2 to 15.8 percent TiO_2. The U. S. Geological Survey in September 1942 estimated 800,00 short tons of indicated "ore" in this deposit (Balsley, 1943, Table 4).

Miscellaneous Essex County deposits.--Far less promising than the above are numerous other occurrences of magnetite and ilmenite in Essex County. Singewald (1913b, p. 58-60) said the deposits were not economically mineable under conditions at that time because (1) they are small and scattered; (2) most are inaccessible to proper transportation faciliies; (3) most of the bodies are lean, with 25 to 50 percent gangue being common; (4) the deposits average only 13.6 percent TiO_2, and 35.4 percent iron; and (5) intergrowths of magnetite and ilmenite are very common.

The smaller Essex County deposits are as follows (Singewald, 1913b, p. 49-58). The Dalton Ore deposit, situated 1 mile northwest of Feeder Pond and 5½ miles west of Mineville, has large grains of ilmenite and contains 3.9 to 11.5 percent TiO_2. Two small openings known as the Little Pond Mines have been made north and southeast of Little Pond, and about 2 miles southeast of Elizabethtown. The deposit, averaging 15 percent TiO_2, occurs as small segregations within gabbro, and has massive ilmenite grains and ilmenite inclusions within magnetite. The Lincoln Pond or Kent Mine is three quarters of a mile southwest of the lower end of Lincoln Pond, and 5 miles northwest of Mineville; titaniferous material here contains 2.6 to 12.3 percent TiO_2. The Split Rock Mine is in a cove on the west shore of Lake Champlain, 5 miles northeast of Westport. Lean magnetite-ilmenite lenses within a highly garnetiferous gabbro contain a maximum of 15.7 percent TiO_2. The Tunnel Mountain Mines, 1 to 1½ miles southeast of Little Pond, and 3½ miles southeast of Elizabethtown, have 10.6 to 16.4 percent TiO_2 as small ilmenite grains and as ilmenite swarms within magnetite.

Minor occurrences.--Minor deposits are reported from Mineville, where titaniferous magnetite within gabbro carries 20 percent TiO_2 (Newland, 1908, p. 170). An abandoned mine at Port Leyden, Lewis County, near the site of the old iron furnace, analyzed 9.3 percent TiO_2 and 52.7 percent Fe_3O_4 (Newland, 1908, p. 168-169). Titanium-bearing magnetites of the Cortlandt series of gabbroic rocks near Peekskill contain 0.2 to 4.2 percent TiO_2 (Singewald, 1913b, p. 46-47).

North Carolina

North Carolina produced from 1944 to 1950 inclusive approximately 164,000 short tons of ilmenite concentrates, and with Virginia accounted for less than one fourth of the country's total production (Cservenyak, 1953, p. 1231). The ilmenite and magnetite bodies are associated with dark talcose schist and gneiss that are the result of metamorphism of dunite, amphibolite, olivine gabbro and other basic rocks (Bayley, 1923a, p. 260). The only reliable published reserve estimates are by Matthews, Ralston, and Ross (1947, Table 38) who indicate 1 million short tons of "ore" averaging 35 percent TiO_2, equivalent to approximately 350,000 short tons of TiO_2. Mining by 1950 had reduced these reserves to approximately 750,000 tons of "ore."

Yadkin Mica and Ilmenite Company deposit, Caldwell County.--The Yadkin Mica and Ilmenite Company, a subsidiary of the Glidden Company, operates the only titanium ore mine of the state at Richland Cove, Caldwell County, on the Yadkin River approximately 14 miles north of Lenoir. The ore body, conformable with the foliation of surrounding mica schist and gneiss, is 2,000 feet long, 20 feet thick, and has been explored for 500 feet down the dip. The ore is pure ilmenite with no magnetite, and occurs in a gangue of talc, chlorite, serpentine, and minor rutile. Estimates of composition range from 50 to 70 percent ilmenite, and from 30 to 49 percent TiO_2.

Mining began in January 1942, and in 1952 was producing per year between 25,000 and 30,000 tons of ilmenite concentrates that averaged 51 percent TiO_2. McMurray (1944) says that ore analyzing 41.4 percent TiO_2, 32.7 percent FeO, and 14.9 percent insolubles is treated by grinding and froth flotation to separate the ilmenite from the "sericite talc gangue." This produces a concentrate having 53.8 percent TiO_2, 39.4 percent FeO, and 4.8 percent insolubles, with an ilmenite recovery of 80 percent. The only published reserve information is by Greaves-Walker (1945, p. 29) who says, "It is estimated that this deposit contains a reserve of several million tons (Stuckey, J. L., personal communication)."

Titaniferous magnetite deposits.—Deposits of ilmenite and magnetite in the mountains and piedmont of North Carolina are described by Bayley (1923a, 1923b), and Singewald (1913b, p. 80-93). The ilmenite, ilmenite-magnetite, magnetite-rutile, or ilmenite-rutile bodies contain 4.5 to 39 percent TiO_2, and 25.7 to 65 percent iron. They occur as veins or dikes cutting through dark talc-bearing schist, chlorite, and serpentine, and outcrop in lines or belts parallel to the regional structure (Bayley, 1923a, p. 250, 258-259). They are similar to other titanium-bearing ores in gabbros (see p. 36, 65-66, and 88), except that they have been altered by metamorphism. The best deposits are in a 30-mile long belt which trends northeasterly across Guilford County, northwest of Greensboro, and passes into Davidson and Rockingham Counties on either side. Three old workings in this belt provide information about the character of the rocks. They are the Tuscarora Mine, half a mile north of Friendship; the Trueblood Plantation Workings, northeast of the Tuscarora Mine and on the south side of Brushy Creek; and the Dannemora Mine about 3 miles west of Summerfield on the north side of the Haw River. Other deposits, all small, are found in Alleghany, Ashe, Avery, Caldwell, Catawba, Davie, Lincoln, Macon, Madison, Mitchell, and Yancey Counties.

Beach and placer deposits.—During 1946 the E. I. duPont de Nemours and Co., Inc. prospected the beach and under-water deposits of Albermarle Sound for ilmenite, and in July 1951 the National Lead Company was drilling beach sands in Dare County in search of ilmenite. According to Engineering and Mining Journal (1952, v. 153, no. 3, p. 138) the "North Carolina Board of Conservation and Development granted a 10-year lease to Burnup and Sims, Inc., of West Palm Beach, Florida, for exclusive mining privileges of ilmenite and other mineral sand deposits along shoreline and under waters of Albermarle Sound."

A residual rutile deposit 3½ miles east of Hayesville, near Shooting Creek in Clay County was under development in 1941, and supposedly was a source of rutile shipments in 1921 (Matthews, 1943b, p. 813). The rutile occurred over several hundred acres, which, according to Gillson (1949, p. 1061), averaged "about 50 lb of ilmenite and rutile to the yard". The property was condemned in 1941 by the Tennessee Valley Authority for its Chatuge Dam project.

Oklahoma

The Wichita Mountains contain bodies of ilmenite and magnetite that are associated with anorthosite and gabbro in Kiowa and Comanche Counties. Trenching and sampling indicate that the titaniferous bodies are limited in size, discontinuous, and lean. Ilmenite occurs as "small crystals with rectangular outline," as irregular elongated grains, and as intergrowths up to 1 millimeter long within magnetite. Although selected hand samples contain 10.9 to 16.0 percent TiO_2, two samples of typical titanium-bearing material contain 4.4 and 5.2 percent TiO_2 (Merritt, 1940). There are no reserve estimates.

Oregon.

Although titanium minerals occur in Oregon in sands along the coast and in ferruginous laterites developed on basalts, titanium ore has never been produced. Reconnaissance surveys by Twenhofel discovered about 25,000 short tons of ilmenite and chromite in the beach sands. Investigation of laterites revealed 6.5 million short tons of material that contained 321,000 short tons of TiO_2.

Coastal sands.--Black sands are abundant along the coast of Oregon, and contain considerable ilmenite and chromite in addition to other heavy minerals. South of Coos Bay the deposits contain a large proportion of chromite relative to ilmenite, but north of the bay the chromite to ilmenite ratio decreases. North of Tillamook Head ilmenite is in excess of chromite, and no appreciable amoumt of the latter mineral is present (Twenhofel, 1946b, p. 62). Although in 1943 chromite concentrates were commercially produced from sand along the southwestern coast, the production of ilmenite concentrates was found impossible. This confirmed previous studies by the U. S. Bureau of Mines that claimed the economic separation of ilmenite concentrates from these sands would not be feasible (Dasher and others, 1942, p. 19).

The better beach black sand deposits on the coast south of Coos Bay are listed by Twenhofel (1943, p. 7) as follows: (1) near the mouths of Myers Creek and Pistol River; (2) in the bay between Cape Sebastian and Crook Point; (3) around the mouth of Rogue River; (4) near the mouth of Euchre Creek, south of the headland of Sisters Rocks; (5) in the bay south of the Heads at Port Orford; (6) south of Cape Blanco, where Griggs (1945, p. 124) notes 5.6 percent ilmenite; and (7) around the mouth of Five Mile Creek. The terraces east of this area contain numerous prospects and mines which in places contain as much as 65 percent combined ilmenite and chromite, such as at the Butler and Madden Mines (Twenhofel, 1946a, p. 201-205).

Information on reserves and grade of some of the better beach deposits north of Coos Bay is given by Twenhofel (1946b, p. 17-52) as follows: (1) Heceta Beach, south of Sutton Creek, 3,500 tons of ilmenite and chromite; (2) near China Creek at Muriel O. Ponsler Memorial Wayside Park, 12.4 to 46.9 percent ilmenite and chromite; (3) Newport Beach adjacent to the municipal pavilion, 2,750 tons of ilmenite and chromite; (4) Big Creek Bay, just north of Newport, 12,800 tons of ilmenite and chromite; (5) dune deposits on the south side of Yaquina Bay, 6,300 tons of ilmenite and chromite; (6) north side of Netarts Bay, 44 percent ilmenite and chromite; (7) Trestle Bay on the mouth of the Columbia River, 15,000 to 30,000 cubic yards of sand which contains 15 percent ilmenite; and (8) Sand Island in the mouth of the Columbia River, "thousands of tons of magnetic black sands."

Ferruginous laterite deposits.--Ferruginous laterites are developed on the basalts in parts of western Oregon, and may contain appreciable amounts of titanium. The high content of titanium resulted from Tertiary weathering and decomposition of the upper portion of Miocene basalts, during which the more soluble magnetite and silicates were removed, but the more resistant ilmenite was relatively unaffected (see p. 51, 79-80 and 99). The laterites contain 1.49 to 6.11 percent TiO_2 in Columbia, Multnomah, and Washington Counties, and 1.00 to 5.25 percent TiO_2 in Marion and Polk Counties (Libbey, Lowry, and Mason, 1945, p. 22-23, 75-81).

The U. S. Geological Survey and the U. S. Bureau of Mines in a preliminary investigation in Columbia County near St. Helens during the summer of 1945 discovered approximately 950,000 short tons of laterites (more than half of which is inferred), with an average composition of 5 percent TiO_2, 31 percent Al_2O_3, 21 percent Fe, and 12 percent SiO_2 (Libbey, Lowry, and Mason, 1946, p. 258-259). A breakdown by deposits is as follows (Bell, 1945): (1) Yankton area, 225,000 short dry tons of laterite containing 11,200 short tons of TiO_2; (2) Alder Creek, 669,000 short dry tons of laterite containing 35,600 short tons of TiO_2; and (3) Cater Road, 56,000 short dry tons of laterite containing 2,800 short tons of TiO_2.

Washington County supposedly contains more than 5.6 million short tons of ferruginous bauxite which analyzes 4.85 percent TiO_2, 34.69 percent Al_2O_3, 23.12 percent Fe, and 9.48 percent SiO_2 (Libbey, Lowry, and Mason, 1946, p. 246).

Pennsylvania

Prior to the opening of the Virginia rutile deposits in 1901, Pennsylvania was the principal source of rutile in this country, with a production of a few hundred pounds of rutile annually. Most of it came from Chester County, where it was uncovered as chunks in plowed fields. The primary deposits from which the rutile originated were minor concentrations in the lower Paleozoic limestones and quartzites (Watson and Taber, 1913, p. 21-22).

Minor deposits of titaniferous magnetite containing 3 to 6 percent TiO_2 occur in Bucks County south of Easton near the town of Durham (Bayley, 1941, p. 77).

Rhode Island

A large deposit of ilmenite-magnetite occurs at Iron Mine Hill in the town of Cumberland, about 3 miles east of Woonsocket in the northeastern corner of Rhode Island. Numerous attempts were made during the nineteenth century to use the ore as a source of iron, but all were unsuccessful because of the high titanium content.

The titaniferous body is 1,200 feet long, 500 to 600 feet wide, and is apparently associated with coarse-grained gabbro which crops out about 350 yards away (Johnson and Warren, 1908, p. 6-8). The principal material in the deposit is cumberlandite, a mixture of olivine and labradorite embedded in a fine-grained matrix of ilmenite and magnetite. The opaque minerals have a maximum diameter of 2 mm and for the most part are largely intergrown with one another (see p. 37). Nine analyses of "ore" show an average of 9.8 percent TiO_2 and 33.4 percent iron (Singewald, 1913b, p. 44). It is doubtful if this "ore" could be successfully beneficiated by ore dressing, for preliminary investigation by the U. S. Bureau of Mines shows that by grinding to 100 mesh the "ore" can be separated from the gangue, but that even finer grinding will not suffice to separate the ilmenite from the magnetite.

Texas

Only two deposits in Texas have been cited as sources of titanium, but neither is commercially important. The Mueller prospect in the Medley district of south central Jeff Davis County, about 20 miles southwest of Fort Davis, contains minute crystals and patches of rutile that are disseminated through hard silicified tuffs and ashes and locally concentrated in shear zones. Beneficiation tests by the U. S. Bureau of Mines on samples analyzing 11 to 34 percent TiO_2 showed that by flotation and gravity it was possible to concentrate a sample containing 34 percent TiO_2 to an 87 percent TiO_2 product and with a recovery of 67 percent (U. S. Bureau of Mines, 1942, Rept. Inv. 3628, p. 32-33). Vogel (1942, p. 7) believes, however, that "there is no sufficient ore in sight in this prospect to warrant commercial development."

The second deposit, at Baringer Hill in Llano County approximately 100 miles northwest of Austin, is a large pegmatite dike formerly on the west bank of the Colorado River but now beneath the lake made by Buchanan dam.

Virginia

Although Virginia and North Carolina accounted for less than one fourth of the country's titanium ore production in 1950, Virginia was the largest producer in this country prior to 1942. Titanium ores are now mined only in Amherst and Nelson Counties, in an area that is approximately midway between Lynchburg and Charlottesville, and about 75 miles west of Richmond. Reserves in 1947 were estimated at 26,000,000 short tons of ilmenite ore, and 5,330,000 short tons of rutile ore, both containing a total of 5,150,000 short tons of TiO_2 (Matthews, Ralston, and Ross, 1947, Table 38).

American Cyanamid Co. Piney River deposit.--The Piney River deposit of the Calco Chemical Division of the American Cyanamid Company was the only active mine in 1952. It is located on the south side of Piney River between Roseville and Roses Mill. The deposit is one of the dikelike bodies of nelsonite which occurs within an anorthosite zone that trends northeasterly across Amherst and Nelson Counties, and is approximately 19 miles long by 2 to 6 miles wide. For furthur geologic information see p. 42, 67, and 89.

The property was first developed in 1930 by the Southern Mineral Products Corporation, and was acquired in 1945 by the American Cyanamid Company. The ore body of nelsonite contains ilmenite, apatite, rutile, and accessory silicates; average grade is 17 percent TiO_2 in the weathered surface zones, and about 14 percent TiO_2 in the fresh portions (Gillson, 1949, p. 1050). Open pit mining on the upper oxidized layers of the deposit yielded approximately 170,000 tons of crude ore per year prior to 1949 (Cross, 1949, p.123). Initial concentration of the ground nelsonite ore in Humphreys spirals is followed by bulk flotation to separate the ilmenite and apatite from the silicates. Final separation of the ilmenite from apatite is achieved by selective flotation as a froth concentrate. Although the literature contains no information of the amount of titanium in these concentrates, previous methods produced concentrates with 42.5 percent TiO_2 (Bevan, 1942).

Reserve estimates are made by Bevan (1942) who says there are "4,000,000 or more tons of titanium dioxide" in the deposits, and by Barksdale (1949, p. 16) who says, "This deposit, to a depth of 400 feet, contains 24,000,000 tons of nelsonite carrying more than 4,400,000 tons of titanium dioxide."

Roseland rutile deposit.--An important producer of rutile was the deposited owned by the American Rutile Company on the east bank of the Tye River, a quarter of a mile south of Roseland. Mining of this body began in 1902, and ceased in July 1949 when the ore body was exhausted. The ore, which averaged 6 to 10 percent TiO_2, consisted of rutile and ilmenite that was disseminated throughout the same anorthosite body that contains the nelsonite (see p. 67, 72, 89). By concentration a product with 86 to 99 percent TiO_2 was obtained.

Amherst and Nelson Counties, miscellaneous deposits.--The disseminated rutile bodies and nelsonite dikes of Amherst and Nelson Counties provide a potential source of titanium. One of the better deposits in this area occurs on the Warwick Farm on the north side of Piney River, about 1½ miles northwest of Roses Mill. Starting in 1907 the General Electric Company extracted rutile for a few years from two large nelsonite bodies on this property (Watson and Taber, 1913, p. 173). Other noteworthy deposits and development work are as follows: several nelsonite bodies were developed in 1889 on Hat Creek in the vicinity of Bryant Post Office; the Giles Tract (three fourths of a mile northwest of Roseland) and the Quinn place (1 mile north of Roses Mill) were explored in 1894; the Camden Farm (2 miles northeast of Bryant) and the region around Davis Creek both contain lean nelsonite bodies; and exploration work in 1903 on the Shelton Farm (on the west side of Tye River 1 mile above Roseland) and on many properties between Bryant and Roses Mill exposed many lean ore bodies (Watson and Taber, 1913, p. 48-49).

In the Lovingston district (northeast of the central portion of the Amherst and Nelson County area) several nelsonite bodies have been mentioned for their titanium content. Watson and Taber (1913) give the following information on a few of them. On the Dillard Farm, 2 miles southwest of Lovingston, a nelsonite dike contains 16 percent TiO_2 (p. 125). A large dike crops out just over the crest of the ridge half a mile west of Lovingston (p. 126). Prospecting has revealed nelsonite bodies along the ridge 1 3/4 miles southwest of Lovingston (p. 128). Hornblende nelsonite on the Shipman Farm, 3 miles north of Lovingston, contains 13 percent TiO_2 (p. 136).

Goochland and Hanover Counties.--Two deposits of rutile were discovered in 1910 northwest of Richmond. One occurs on the Bowe and Brown Farms near Gouldin and Waldelock in Hanover County, and the other on the Nuckols Farm, Goochland County between Peers and Johnson Springs. Rutile occurs in these as 15 to 20 pound masses in soils that overlie pegmatite dikes that contain rutile, minor ilmenite, and rarely apatite (Watson and Taber, 1913, p. 248-261). There are no reserve estimates.

Roanoke County, Bush-Hutchins deposit.--In Roanoke County nelsonite bodies containing ilmenite, rutile, and apatite, occur on the Bush and Hutchins Farms, 2 miles east of Vinton and 4 miles east of Roanoke. Mining in 1943 produced 8 cars of ore which were shipped to the Interlake Iron Company, Toledo, Ohio, and which contained 14.16 percent TiO_2 and 26.01 percent Fe. Drilling by the U. S. Bureau of Mines showed that nelsonite continues to a depth of 150 feet below the surface, has a maximum thickness of 100 feet, and contains 9.1 to 16.0 percent TiO_2 (Hickman, 1947, p. 2-3). There are no reserve estimates.

Minor deposits.--Numerous, small, unimportant, titanium-bearing deposits are found in other counties throughout the state. Rutile is associated with the kyanite schists at Willis Mountain in Buckingham County (Watson and Taber, 1931, p. 264-265). In Campbell County numerous angular fragments of ilmenite and quartz occur on parts of the Hudson Farm on Highway no. 120, about 7 miles south of Lynchburg (Steidtmann, 1931, p. 39). Minor occurrences of rutile and ilmenite, similar to those in Hanover and Goochland Counties, have been noted in both Carroll and Grayson Counties (Pegau, 1950, p. 51-52). Minor amounts of rutile occur in kyanite-bearing schists of Charlotte County, approximately 12 miles northwest of Charlotte Courthouse (Watson and Taber, 1913, p. 262-263). Quartz veins containing rutile and ilmenite occur in Franklin County 1 mile west of Teels Mill and approximately 15 miles southeast of Roanoke (Watson, 1922, p. 447). Kyanite-bearing quartzites at Baker Mountain in Prince Edward County contain 2 to 3 percent rutile as scales and crystals that can be readily concentrated (Pegau, 1950, p. 52). The lower 15 feet of the Lower Cambrian Unicoi formation has one-quarter to 6-inch layers of black sandstone on the Robinson Gap Road, about 3 miles southeast of Buena Vista. These lithified placer deposits contain approximately 50 percent rutile and ilmenite (Bloomer and DeWitt, 1941, p. 745-747).

Washington

Deposits of titanium-bearing minerals in Washington are minor, and to date no production has been reported. Near Elma, in Grays Harbor County, beds of black sand are 1 to 4 feet thick, cover 2 to 3 acres, and reportedly contain 22 percent TiO_2 and 50 percent Fe; a reconnaissance survey indicates that reserves of "ore" are "known 5,000 tons, probable 10,000 tons, and possible 20,000 tons" (Glover, 1942, p. 7). Minerals Yearbook for 1941 claimed that plans were being made to work this titanium "ore" (Matthews, 1943a, p. 806). Youngman (1930b, p. 17) indicated that black sand deposits at Sedro-Woolley in Skagit County contained 11 percent TiO_2 and were mined in 1920 for their iron.

In Spokane County the Excelsior clay deposit, 11 miles southeast of Spokane, contains 7.3 percent TiO_2, 8.2 percent Fe_2O_3, and 31.1 percent Al_2O_3 (Sohn, 1952). A U. S. Geological Survey open-file report shows that this deposit contains 890,000 short tons of TiO_2 (Scheid, 1946).

Wyoming

Deposits of ilmenite and magnetite were discovered in the Laramie Range of Albany County, Wyoming, in 1853, but have not been extensively worked, although a few shipments were made in 1897 and 1898 to a smelter in Pueblo, Colorado. Recent estimates by the U. S. Geological Survey (Newhouse and Hagner, 1951, Table 2) showed that the largest of the deposits contains 9,150,000 short tons of "ore"; calculations based on titanium content of this "ore" indicate that it probably contains approximately 1,300,000 short tons of TiO_2. There are no other reliable reserve estimates.

Iron Mountain deposit.--The largest of three closely associated deposits is the Iron Mountain body, located 47 miles by road northeast of Laramie, in secs. 22, 26, and 27, T. 19 N., R. 71 W., Albany County, Wyoming. Iron Mountain (elevation 7,450 feet) rises 660 feet above a transecting creek, and contains outcrops of magnetite-ilmenite bodies for 5,000 feet along its rugged, northward-trending crest. The ilmenite-magnetite occurs within and near the eastern margin of a light-colored, medium- to coarse-grained anorthosite. Individual ilmenite-bearing bodies are 50 to 300 feet wide and occur as "lenses or tabular-shaped masses frequently arranged in discontinuous and overlapping en echelon bodies" (Newhouse and Hagner, 1951, p. 5). The dikelike shape and sharp contacts of the titaniferous bodies against the anorthosite are characteristic of these bodies, the mineralogy and geology of which are discussed on pages 36, 56-58, 62, and 85-86 of this report.

The "ore" has been divided into three grades on the basis of the volume percentage of the silicates (Newhouse and Hagner, 1951, p. 11-12). Grade one consists of massive ilmenite-magnetite with a maximum of 35 percent by volume of silicates, and contains 16 to 23 percent TiO_2; grade two consists of ilmenite-magnetite with 35 to 65 percent by volume of silicates, and contains 10 to 16 percent TiO_2; and grade three consists of ilmenite-magnetite with 65 to 85 percent by volume of silicates and contains 5 to 10 percent TiO_2. The grade of "ore" is important in beneficiation, since the richer material contains large grains of pure ilmenite and magnetite, whereas the leaner material has many inclusions of ilmenite within magnetite. Preliminary crushing and magnetic separation tests by Singewald (1913b, p. 124-125) indicated that the character of the intergrowths in the leaner material makes it difficult to obtain good titanium concentrates. A change in the chemical composition of the opaque minerals was found to accompany a change in the grade of the "ore", and led Newhouse and Hagner (1951, p. 14) to conclude that the poorer grades of "ore" contained a larger ratio of iron to titanium within the ilmenite than did the richer grades.

Reserves for the Iron Mountain area have been determined by Newhouse and Hagner (1951, Table 2) on the basis of their geologic map and drilling and assaying by the U. S. Bureau of Mines (Frey, 1946b). Total reserves are 9,150,000 short tons of "ore", divided as follows: northern block ("ore" above 6,900 feet), 5,200,000 short tons; southern block ("ore" above 6,600 feet), 3,450,000 short tons; small lenses and masses, 500,000 short tons. A breakdown by grade is given in table 9.

Table 9. Estimated reserves at Iron Mountain, Wyoming

	Short tons			
	Grade 1 Percent TiO_2 16 to 23 Fe 42 to 50 V_2O_5 0.50	Grade 2 Percent TiO_2 10 to 16 Fe 30 to 42 V_2O_5 0.36	Grade 3 Percent TiO_2 5 to 10 Fe 18 to 30 V_2O_5 0.17	Total for all grades
Northern area				
Indicated	1,200,000	1,280,000	700,000	3,180,000
Inferred	70,000	780,000	1,170,000	2,020,000
Southern area				
Indicated	1,700,000	320,000	200,000	2,220,000
Inferred	430,000	430,000	370,000	1,230,000
Small miscellaneous				
Masses				
Indicated	100,000			100,000
Inferred	100,000	100,000	200,000	400,000
Totals				
Indicated	3,000,000	1,600,000	900,000	5,500,000
Inferred	600,000	1,310,000	1,740,000	3,650,000
				9,150,000

Shanton and Taylor deposits.--The Shanton deposit, 4 miles southeast of Iron Mountain in the NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 8, T. 18 N., R. 71 W., is essentially similar to Iron Mountain. Analyses of massive "ore" show 20 percent TiO_2, and 52 percent iron (Newhouse and Hagner, 1951, Table 1). The Taylor deposit in the SE$\frac{1}{4}$ sec. 35, T. 21 N., R. 71 W., contains massive "ore" with 31 percent TiO_2 and 47 percent iron (Newhouse and Hagner, 1951, Table 1), and lean "ore" with 5 percent TiO_2, 32 percent iron, and 13 percent P_2O_5 (Diemer, 1941, p. 14). There are no reserve estimates for either of these deposits. More detailed descriptions of these deposits are given by Diemer (1941), Frey (1946a), Newhouse and Hagner (1951), and Singewald (1913b).

Canada

Canada became one of the foremost producers of titanium ore in the world when shipments began in July 1950 from a large ilmenite-hematite ore body at Allard Lake, Quebec. For many years small shipments have been made from two smaller deposits in Quebec at Ivry and St. Urbain. Total Canadian production (all from Quebec) from 1941 to 1950 inclusive was 230,634 metric tons of ilmenite concentrates. Most of the Canadian deposits contain ilmenite in association with anorthosite and gabbro massifs. Estimates of reserves range from 117.3 to 205.3 million short tons of "ore" containing 36.7 to 75.9 million short tons of TiO_2.

Quebec

Quebec contains the largest and most important titaniferous deposits in Canada. The principal deposit is the newly opened Allard Lake deposit; minor production has occurred at Ivry and St. Urbain.

Allard Lake.—The Allard Lake deposit is owned by the Quebec Iron and Titanium Corporation, a jointly owned subsidiary of the Kennecott Copper Corporation and the New Jersey Zinc Company. It is located on Tio and Ano Lakes, 3 miles east of Allard Lake, a mile south of Petit-Pas Lake, and 28 miles north of Havre St. Pierre. This latter town is on the north shore of the Gulf of Saint Lawrence, about 400 miles downstream from Quebec City, and north of Anticosti Island. The ore consists of ilmenite with approximately 15 percent hematite as microscopically small blades, and usually averages 35 to 36 percent TiO_2 and 36 to 40 percent Fe. It occurs as large dikes and lenses within a larger anorthosite and gabbro complex (see p. 34, 59-62, and 85-86). The largest ore body is 3,600 feet long by 3,400 feet wide, covers 136 acres, and extends to at least 300 feet in depth; a smaller one measures 1,240 feet by 740 feet on the surface and extends to 200 feet in depth (Knoerr, 1952, p. 75).

The presence of commercial quantities of titanium ore was indicated in the summer of 1941 during a geological reconnaissance of this area by J. A. Retty (Retty, 1944). Kennecott Copper Corporation explored a large area surrounding the deposit more completely in 1944, and in 1946 and 1947 outlined the known ore bodies by more detailed exploration and drilling. Development work began in 1948 by the Quebec Iron and Titanium Corporation, and by July 1950 the first shipment of ore was made from the docks at Havre St. Pierre. Ore at present is mined at Allard Lake and shipped by rail 27 miles to Havre St. Pierre where it is crushed preparatory to loading in vessels, but eventually ore crushing facilities will be installed at Allard Lake. From Havre St. Pierre the ore is shipped to Sorel, 50 miles downstream from Montreal, where electrical furnaces produce a "non-specification" steel and a slag which contains 70 percent TiO_2.

The September 1951 rate of production at Allard Lake was 2,800 tons of ore per day, and at Sorel 200 tons of titanium-rich slag and 100 tons of pig iron (Knoerr, 1951, p. 75). During the first complete year of operation in 1951 the mine produced 383,000 short tons of ore and shipped 372,000 short tons to the refinery at Sorel (Eng. and Mining Jour., 1952, v. 153, no. 5, p. 134); average grade was 35 to 36 percent TiO_2 and 40 to 42 percent Fe. Future plans call for the mining of 3,000 tons of ore per day at Allard Lake, and an annual production at Sorel of 175,000 long tons of "non-specification" steel, and 250,000 long tons of slag containing 70 percent TiO_2.

Estimates of reserves of all the deposits at Allard Lake range from 112 million short tons of ore containing 32 percent TiO_2 (Hammond, 1949, p. 119), to 200 million short tons averaging 35 percent TiO_2 (Goodwin, 1951, p. 53).

St. Urbain, Charlevoix County.--Scattered titaniferous deposits occur west of St. Urbain, Charlevoix County, approximately 8 miles north of Baie St. Paul, and 60 miles northeast of Quebec City. Total production of ilmenite concentrates from 1924 to 1950 inclusive has been 180,206 short tons, with a maximum production of 69,437 tons in 1943. There are no reserve estimates.

The deposits of ilmenite with minor hematite lie within an oval anorthosite mass that is 18 miles long by 9 miles wide. One deposit contains as much as 20 percent rutile in places. The richest bodies are approximately 2 miles southwest of St. Urbain in an area 1½ miles in diameter near the boundary between the St. Urbain Range and the St. Jerome Range. Two smaller deposits, about a quarter of a mile apart, lie 8 miles north of St. Urbain and three fourths of a mile west of Lake Ontario, and another small deposit occurs 2 miles farther east of these.

Analyses of material from some of the deposits are as follows (Robinson, 1922, p. 41-53): General Electric Mine (the only rutile-bearing deposit), 41.6 to 53.4 percent TiO_2 and 28.5 to 44.5 percent Fe; Bouchard's Mine, 32.9 percent TiO_2 and 36.9 percent Fe; Coulomb Mine, 35.5 to 41.0 percent TiO_2 and 51.5 to 55.1 percent FeO; the Furnace Mine, 38.0 to 40.5 percent TiO_2 and 44.1 to 45.5 percent Fe; and the Glen Prospect, 38.3 percent TiO_2 and 55.4 percent FeO. Deposits on the Quebec Seminary Lands, 18 to 19 miles north of St. Urbain, contain approximately 32 percent TiO_2 and 64 percent FeO. Deposits for which no analyses are available include the Bignell Prospect, a deposit on Lot 641 in the St. Thomas range, and a deposit in the Decharge range on the east bank of the river Gouffre.

Although E. I. duPont de Nemours and Co., Inc. investigated the area in 1930 and 1931 they never did any development work.

Ivry Mine.--The Ivry Mine, Beresford Township, Terrebonne County, is located 2 miles west-southwest of the Ivry railroad station, near St. Agathe, and approximately 55 miles northwest of Montreal. During 1912 to 1918 approximately 16,000 tons of concentrates were shipped to Niagara Falls, N. Y. to make ferrotitanium, and between 1927 and 1935, 500 tons of concentrates were shipped for experimental purposes.

The deposit of ilmenite with small, included laths of hematite consists of three separate bodies within massive anorthosite of the Morin series. Analyses indicate that the titaniferous portions contain 18.2 to 19.9 percent Ti, and 42.8 to 48.0 percent Fe (Osborne, 1936, p. 77).

Terrebonne Titanium Company.--In the latter part of 1951 interest was shown over the supposedly large titanium ore body of the Terrebonne Titanium Company near the village of St. Marguerite, about 55 miles from Montreal. Tests of material collected from the surface to depths of 250 and 450 feet contained an average of 17.1 percent TiO_2 and 22.4 percent Fe (American Metal Market, 1952). Since the location of this deposit is not accurately given, it may be the same as the Ivry deposit.

Saguenay River deposit, Chicoutimi district.—Bodies of ilmenite and magnetite occur on the north bank of the Saguenay River in Bourget Township, Chicoutimi district, about 1½ miles west of St. Charles Village and 15 miles below the outlet of Lake St. John. The bodies are irregularly distributed as dikes and lenses within anorthosite and gabbro and crop out over an area of about 2,200 by 1,500 feet. Preliminary magnetic separation tests indicate that mechanical separation is difficult because the magnetite and ilmenite form such fine intergrowths.

Denis (1925, p. 87) stated that five samples contained 7.4 to 13.4 percent Ti and 33.8 to 52.1 percent Fe, and Dulieux (1913, p. 88) indicated that the deposit contains about 5 million tons of "ore" with an average grade of 16.7 percent TiO_2 and 50.5 percent Fe.

Bay of Seven Islands region.—Ilmenite-magnetite bodies occur near the Bay of Seven Islands (also called Sept-Iles Bay) on the northern shore of the St. Lawrence River, approximately 320 miles northeast of Quebec City. The lenses of magnetite and ilmenite are a maximum of 80 feet long and 15 feet thick, but more commonly average about 2 feet thick. They occur only within the gabbroic portions of an anorthosite-gabbro complex. The deposits have never been mined.

The deposits occur in two groups, one along the St. Marguerite River, and the other along the Riviere des Rapides. The best deposit on the St. Marguerite River is approximately half a mile below the falls at Clarke City and contains roughly 10,000 tons of "ore" averaging 20 percent TiO_2 in rich, small, disconnected bodies (Faessler and Schwartz, 1941, p. 720). Another smaller deposit occurs half a mile above the dam and contained in two samples 15 and 19 percent TiO_2, and 39 and 58 percent Fe (Robinson, 1922, p. 65).

Along the Riviere des Rapides the best deposit occurs at the Molson mine, about three fourths of a mile above the mouth of the river. Concentration tests on material from this mine show "that it is not feasible to obtain a substantially titanium-free concentrate from this ore; but that a very pure ilmenite product can be made by magnetic separation" (Robinson, 1922, p. 64). The deposit is estimated by Faessler and Schwartz (1941, p. 721) to contain 300,000 tons of "ore" carrying 21 to 26 percent TiO_2 and 50 to 52 percent Fe. Other deposits of minor importance on this river include the ~~Ontarde~~ Outarde Falls deposit 1½ miles above the Molson Mine, and the Gagnon deposit near the mouth of the river (Robinson, 1922, p. 64).

Minor deposits.--Minor occurrences of titanium-bearing deposits in Quebec that were described by Robinson (1922, p. 58-72) are as follows: Beauce County at Beauceville; Chicoutimi County in Kenagami Township; Hull and Pontiac Counties in Bristol, Clarendon, Hull, Litchfield, and Templeton Townships; Lake St. John County on the Ile D'Alma; St. Maurice County at St. Boniface be Shawinigan; Terrebonne County, the Desgrosbois deposit in Beresford Township; along the north shore of the St. Lawrence River near the mouth of the Chaloupe River, 60 miles east of the Bay of Seven Islands; and near the mouth of the Thunder River where it empties into the St. Lawrence River, about 75 miles east of the Bay of Seven Islands. It is reported (Anonymous, 1951b, p. 33) that sands along 2,000 feet of beach between Pointe Natashquan and Mt. Joli (on the north shore of the St. Lawrence, north of the eastern end of Anticosti Island) contain 30 million tons of sand which yield more than 6.5 percent magnetic concentrates. Samples at the mouth of the Natashquan River reportedly contained 19 percent Fe and 5 percent TiO_2.

Ontario

Titanium ores have not been produced in Ontario, and the only large deposit is located in the Rainy River district. Small titaniferous magnetite bodies are found at Hinchinbrooke and Bedford Townships of Frontenac County, at Glamorgan and Minden Townships in Haliburton County, at Tudo and Lake Townships in Leeds County, at Angus Township in the Nipissing district, and at Blithfield and Horton Townships in Renfrew County (Robinson, 1922, p. 72-83).

Seine Bay deposit, Rainy River district.—In the Rainy River district of southwestern Ontario a narrow belt of ilmenite-magnetite deposits extends for 14 miles along the northern shores of Seine Bay and Bad Vermillion Lake, not far from Mine Centre. The hornblende gabbro with which the bodies are associated has intruded the greenstone, schist, felsite, and agglomerate of the Keewatin series. The flattened, lenticular ilmenite-magnetite bodies have a maximum length of 100 feet, a maximum width of 62 feet, and are parallel to the regional foliation of the host rock. Preliminary beneficiation tests showed that it was impossible to obtain either good titanium or iron concentrates from ore which analyzed 6 to 26 percent TiO_2 and 33 to 45 percent Fe (Parsons and others, 1934). Analyses of 21 samples from outcrops and drill cores show 6.8 to 28.1 percent TiO_2 and 25.0 to 50.0 percent Fe (Robinson, 1922, p. 85-86). There are no reserve estimates and there has never been any production.

Miscellaneous deposits

In Alberta, titaniferous magnetites occur in sandstones near Burmis, just east of Crowsnest Pass, and are probably the northern continuation of the iron-bearing sandstones of Montana.

In Newfoundland large deposits of titaniferous magnetite occur at Steel Mountain, Porte aux Basques, and reportedly contain 4 to 16 percent TiO_2 and 65 percent Fe (Gmelin Institut, 1951, p. 62; Imperial Mineral Resources Bureau, 1922, pt. 3, p. 101).

Africa

Production in Africa from 1941 to 1950 inclusive was 41,449 metric tons of ilmenite concentrates in Egypt and Senegal (French West Africa), and 14,720 metric tons of rutile concentrates from French Cameroons and French Equatorial Africa. Reserve information is available for only a few of the deposits and indicates that the continent contains an estimated 3,741 million short tons of "ore" containing 473 to 653 million short tons of TiO_2.

The principal deposits occur in Egypt, French Cameroons, French West Africa, Madagascar, Mozambique, Sierra Leone, and the Union of South Africa; minor deposits occur in Algeria, Belgian Congo, French Equatorial Africa, Gold Coast, Nyasaland, Tanganyika, and Uganda.

Algeria

It was reported that the Keddarans Mine of the Palestro district in Algeria produced 1,475 metric tons of titanium-zirconium concentrates in the first four months of 1942 (Matthews, 1943b, p. 817), but no further information about this could be found. Sand dunes near Biskra in northeast Algeria are reportedly rich in ilmenite and magnetite, yet no indication of grade or tonnage is given (Bellair, 1940). Numerous bodies of ilmenite and titaniferous magnetite are associated with various basic intrusives in Algeria, but so little work has been done on them, that their value cannot be determined (Dalloni, 1939, p. 35-67).

Belgian Congo

In the Belgian Congo ilmenite and rutile are commonly associated with gold and diamond deposits. Mineable concentrations of rutile occur in vein and alluvial deposits southwest of Lake Albert, and in the Katanga region of southern Congo (Huge and Egoroff, 1948, p. 35). Minerals Yearbook for 1937 says "a Kilo-Moto subsidiary has recovered white pigment from titanium-tin concentrates mined in the northern part of the Belgian Congo" (Tyler, 1938, p. 684); no further information could be obtained about this deposit.

Egypt

The production of ilmenite concentrates in Egypt has been small and intermittent, totaling only 3,390 metric tons from 1941 to 1950 inclusive. The only reserve information is a very generalized statement by Herlihy (1946, p. 346) who says in speaking of the entire country, "there are hundreds of thousands of tons of ilmenite."

The only production comes from sands of the Nile River delta, near the mouths of the Damietta and Rosetta branches. The mined sand contains 40 to 45 percent ilmenite, 20 to 25 percent titaniferous magnetite, 10 to 12 percent zircon, and minor amounts of other heavy minerals (U. S. Bureau of Mines, 1945, Mineral Trade Notes, v. 21, no. 4, p. 16-17). A preliminary electromagnetic separation of the sand at the mine site is followed by further treatment at Alexandria and yields concentrates of ilmenite, magnetite, and zircon.

A titanium-bearing deposit occurs near the well of El Ranga on the Red Sea Coast at 24° 25' N., and 35° 13' E., about 475 miles southeasterly from Cairo. According to Hume (1937, p. 850) the titaniferous iron deposit occurs within a hypersthene-gabbro country rock, and contains approximately the same amount of ilmenite as other titaniferous iron ores throughout the world. Selected hand samples "assayed 94 and 86 percent $FeOTiO_2$, 3 and 8 percent Fe_3O_4, and 49.75 and 46.10 percent TiO_2" (U. S. Bureau of Mines, Mineral Trade Notes, v. 21, no. 4, p. 17).

French Cameroons

Residual and placer deposits of rutile in the French Cameroons have produced 14,714 metric tons of rutile concentrates (92 to 95 percent TiO_2) in operations from 1941 to 1950 inclusive. Unfortunately there is very little information about individual operations, as most reports are of a general nature. Residual deposits are the most common source of rutile, and usually contain ilmenorutile, magnetite, and as much as 50 to 70 pounds of rutile per cubic yard of decomposed surface material (Haugou, 1935). Those regions which are richest in rutile are: Banyo, Dschang, Eseka, Mbati, and Yaounde.

French Equatorial Africa

In French Equatorial Africa (formerly French Congo) 6 metric tons of rutile concentrates were produced in 1950. The only information on deposits (Brustier, 1923, p. 152-153) indicates that rutile and ilmenite are very common in streams and residual deposits.

French West Africa

Beach sands along the coast of Senegal, French West Africa, have produced 38,059 metric tons of ilmenite concentrates between 1941 and 1950. Titanium-rich deposits include coastal sands and residual deposits in Senegal, Ivory Coast, and Dahomey, and primary deposits in Dahomey. Reserve estimates are lacking for all the deposits.

Senegal beach deposits.--Detailed information is lacking about mining operations, but probably all production has been in sands that occur along the beach that extends 150 miles southward from Dakar. In this sector the following three areas contain significant amounts of black sand: (1) Layers of black sand are abundant on the beach near Rufisque (about 10 miles east of Dakar). One rich, persistent layer occurs 3 to 4 feet beneath the surface of the beach, and is one half to $1\frac{1}{2}$ feet thick. (2) Between Joal and Palmarin (50 and 60 miles southeast of Dakar), black sand deposits occur within small, inland sand dunes that are associated with an old delta of the Saloum River. (3) At Casamance (approximately 150 miles south of Dakar) typical, rich deposits of heavy mineral occur along the beaches (see p. 49-50, 76-77, and 99-97).

Information on mining operations indicates that the sand ore generally contains 40 to 60 percent ilmenite, 20 to 25 percent quartz, and 15 to 40 percent zircon (Arnaud, 1945, p. 97). The only analysis within the past 20 years shows that the ore contains 32 to 43 percent TiO_2, 5 to 9 percent FeO, and 23 to 26 percent Fe_2O_3 (Legoux and Faucheux, 1935, p. 192). The only information of treatment is by Blondel (1934, p. 382) who stated that after the sand was dried on concrete floors in the sun, it was magnetically separated to yield an ilmenite concentrate of 52 percent TiO_2.

Senegal, minor deposits.—Minor deposits in Senegal include: (1) black sands in the beaches between Dakar and St. Louis, and (2) concentrations with over 50 percent ilmenite in placer deposits of the Kétiou-Kô River, near the crossing of the road from Bafoulabé to Nioro (Legoux, 1939, p. 93).

Ivory Coast.—Beach sands along the western portion of the coast of Ivory Coast contain numerous deposits of heavy minerals, especially between the mouths of the Cavalle River on the west and the Sassandra River on the east. At three rich beaches within this area the sands average 33 percent TiO_2, 10 percent FeO, 41 percent Fe_2O_3, 6 percent ZrO_2, and 5 percent SiO_2 (Aubert de la Rue, 1927, p. 205). In Bondoukou, near the Gold Coast border in northern Ivory Coast, a sample from a residual sand deposit analyzed 19 percent TiO_2 after a preliminary panning.

Dahomey.—According to information by Chermette (1938) it appears that deposits in Dahomey have not been exploited, and are all small. The best deposit is at Couffo, close to the railroad and the sea. Weathered clays with disseminated ilmenite and hematite average only 35 percent TiO_2, and would require concentration if developed. Three deposits at Birmi, Djougou, and Gouboco are approximately 250 miles north of the coast and consist of rutile-bearing residual deposits that have resulted from weathering of underlying gneiss and amphibolite. In northwestern Dahomey, near Diapaga, the Mardaga titaniferous iron deposit occurs in a gabbroic intrusive and averages 15 percent TiO_2. Although Chermette (1938, p. 63) states that it contains "more than a hundred thousand tons of ore", it probably cannot be used because it is more than 200 miles from the railroad.

Gold Coast

Very little is known about titanium-bearing deposits in Gold Coast. Titaniferous magnetite deposits reportedly occur at Pudo, near Navrongo in the Northern Territories. Ilmenite and rutile occur in diamond-bearing gravels of the Birim Valley in southern Gold Coast (Anon., 1938(?)a).

Madagascar

The only production of titanium ores from Madagascar was during World War I when rutile was mined from quartz veins in western Ambatofinandrahana. Enough rutile was mined to manufacture approximately 200 tons of smoke-screen material (Lacroix, 1920, p. 30). Reserves, all in the inferred category, are approximately 3,890,000 short tons of titaniferous material containing 1,045,000 short tons of TiO_2.

In southern Madagascar, near Betroka, a deposit of ilmenite and hematite averages 27 percent TiO_2 (Lacroix, 1920, p. 30), and according to Barksdale (1949, p. 23) contains 3,500,000 tons of "ore". Other writers (Coffignier, 1922, p. 661; Robinson, 1922, p. 96) state that a certain deposit (location not given) was discovered in 1912 and contained 3,500,000 metric (?) tons of "ore" averaging 40 percent TiO_2; possibly these references all concern the same deposit.

A residual deposit of ilmenite and magnetite occurs in the valley of the Vongoa, about 12 miles northeast of Miandrivazon in the Betisiriry region. Estimates in 1913 indicated the presence of approximately 28,715 short tons of "ore" containing 1 to 20 percent TiO_2 (Guigues, 1951, p. 74). Titaniferous magnetite also occurs as follows: (1) in the labradorites of the Volovolo in the Bekily region; (2) south of Beamale in the Betroka region; (3) at Ankatrafay approximately 1 mile east of Androngovato; (4) at Lavaililia; (5) at Ianakafy in the Benenitra region; and (6) near the headwaters of the Beleza River, about 2 miles east of Andranomanitsy (Besaire, 1948).

The Island of Reunion, off the east coast of Madagascar, contains titaniferous sands (ilmenite and titaniferous magnetite) that carry as much as 24 percent TiO_2 in the heavy portions (Blondel, 1934, p. 383).

Mozambique

In Mozambique two deposits of titaniferous magnetite occur near Moatize (about 25 miles northwest of Tete, on the road to Blantyre, Nyasaland), and according to Legraye (1940, p. 170) contain "tens of millions of tons of ore". Both the ilmenite-magnetite lenses occur within anorthosite and gabbro that have intruded the gneiss of the Swaziland series.

The Mawili deposit, about 11 miles north of Moatize, contains 10 to 13 percent TiO_2 and 50 percent Fe, but has such fine intergrowths of ilmenite and magnetite that it is impossible to obtain ilmenite or iron concentrates by electromagnetic separation.

The Kakanga deposit is closer to Moatize, and although smaller than the Mawili, is amenable to magnetic separation because ilmenite and magnetite occur as large, individual grains. Preliminary testing yielded two concentrates: (1) a non-magnetic concentrate with 43 percent TiO_2, and (2) a magnetic concentrate that weighed slightly more than half of the sample treated, and contained about 8 percent TiO_2.

Nyasaland

Stream gravels of Nyasaland carry abundant ilmenite, and numerous primary deposits contain ilmenite and magnetite. In the Port Herald Hills region ilmenite- and rutile-bearing primary and residual deposits contain over a million tons of ilmenite. Some of the titaniferous products can be concentrated to 50 percent TiO_2 (Cooper, 1947, p. 8). Commercial development does not appear likely however, since the deposits are scattered over too large an area.

Sierra Leone

Sierra Leone has no recorded production of titanium concentrates, but does contain reserves of titanium minerals. The largest deposit occurs on the Sierra Leone Peninsula near Freetown. This large norite body (25 miles long, by 8 to 9 miles wide) contains ilmenite-magnetite bands that analyze 15 to 18 percent TiO_2 (see p. 63-64 and 87 for a fuller description). Preliminary testing indicates that magnetic separation yields an ilmenite concentrate containing 48 percent TiO_2 (Pollet, 1951).

The black sands on the beaches near York and Hastings are derived from the norite body and contain as much as 46.8 percent TiO_2. In 1931 they reportedly yielded approximately 10 tons of ilmenite concentrates (50 percent TiO_2) as a by-product of mining for tin.

In the Nimi Koro Chiefdom of ~~Western~~ eastern Sierra Leone, a by-product of diamond mining in gravels of the Gbobore stream near Fotingaia is a heavy concentrate that is rich in ilmenite (Pollet, 1937). When the Tonkolili River was prospected for tungsten, it was discovered that each cubic yard of raw gravel yielded approximately 5½ pounds of ilmenorutile (Imperial Institute, 1944, Bull., v. 42, no. 1, p. 45).

Tanganyika

In Tanganyika the largest titanium-bearing deposit occurs on Liganga Mountain in Eastern Upangwa, near Njombe in the southern highlands. Titaniferous magnetite bands within anorthosite and gabbro average 12.7 percent TiO_2. Reconnaissance mapping indicates that these deposits and another one approximately 9 miles south of Tandala contain 1,344 million short tons of "ore" (Stockley, 1945, p. 270).

In the Uluguru Mountains at the upper Mbakana Brook, about 6 miles south-southeast of the Hundussi crest, "blocks of rich titanic iron-ore" extend for "about sixty miles along the road" and contain 25.3 percent TiO_2 (Imperial Mineral Resources Bureau, 1922, pt. 2, p. 50).

Union of South Africa

Although reserves of titanium in the Union of South Africa are approximately 2,393 million short tons of material containing 302 to 482 million short tons of TiO_2, none of it has been commercially utilized.

Transvaal province.--The largest deposits occur in the Transvaal, where ilmenite-magnetite layers are associated with the Bushveld lopolith, a large saucer-shaped body of basic igneous rocks (see p. 39-40, 63-64 and 87). The deposits of ilmenite, magnetite, and maghemite occur as "persistent sheets or ... short stout lenses of solid iron ore following one or more horizons in the upper part of the norite zone of the Bushveld Igneous Complex" (Wagner, 1928, p. 21). The layers range in length from a few tens of feet to 10 miles, and in thickness from 1 to 10 feet, although at Magnet Heights some bodies are as much as 20 feet thick.

The most accessible outcrops are on the southern side of the massif 10 to 15 miles north of Pretoria, near the railroad to Pietersburg. From this point the outcrops can be traced westerly, and then northwesterly to the Pilansberg (approximately 80 miles northwest of Pretoria), from whence they swing northeast towards the Crocodile River, 25 miles away. East of the river the beds are missing because of a large fault. Near Potgieterust, 130 miles north-northeast of Pretoria the bands once again crop out. To the south of Potgieterust, in the Middleburg and Lydenburg areas, the bands strike south for almost 100 miles, and then swing westerly along the southern side of the massif.

The titanium-bearing layers contain 8 to 24 percent TiO_2 and 52 to 60 percent Fe, but cannot be used commercially as a source of titanium concentrates. The fine-grained character of the ilmenite, and the presence of numerous, small lamellae of ilmenite within magnetite makes it impossible to concentrate the greater part of this material into either titanium- or iron-rich fractions.

Reserve estimates for the Magnet Heights area (100 miles east-north-east of Pretoria) show 560 million short tons of "ore". The entire complex contains 2,376.6 million short tons of "ore" (assuming a depth of 1,000 feet and an average ore thickness of 4 feet) with 300.1 to 478.2 million short tons of TiO_2 (Wagner, 1928, p. 34).

Other occurrences in the Transvaal are minor. Small offshoots of the main Bushveld complex occur at Dwarsfontein #145 and Brakfontein #219 where material contains 18 percent TiO_2. At Kaffirskraaf, 14 miles west-southwest of Heidelberg, there are considerable amounts of material with 13 percent TiO_2 (Wagner, 1928, p. 35-36). An old gabbroic intrusive in the Pongola beds of Eastern Transvaal near Piet Retief contains disconnected veins and lenses of titaniferous magnetite that contain 5 or 6 percent TiO_2 (Wagner, 1928, p. 41).

Natal.--In central Natal a norite body near the junction of the Tugela and Mabula Rivers occupies an area 3 miles square, and contains layers of anorthosite and titaniferous magnetite. Most of the ilmenite and magnetite within these 40 to 50-foot thick layers contains numerous intergrowths; analyses show 9 to 20 percent TiO_2 and 42 to 54 percent Fe (Du Toit, 1918). Rough estimates by Wagner (1928, p. 40) indicate the presence of 15 million long tons of "ore."

Preliminary investigation of beach sands at Durban Bay on the coast of Natal reveals that the sands contain 5 to 90 percent of heavy minerals. The heavy portion contains 83 percent ilmenite, 8 percent zircon, and minor amounts of other heavy minerals. By electromagnetic separation it is possible to obtain an ilmenite fraction that contains more than 40 percent TiO_2 (Partridge, 1938).

<u>Southwest Africa</u>.—In 1936 and 1937 a small rutile deposit in the Omaruru and Karibib areas produced 74 tons of rutile concentrates analyzing 95 to 96 percent TiO_2. The deposit occurs on the southeast slope of the Giftkuppe Inselberg (a low steep-sided hill standing on a level plain) at 21° 41' S., 15° 57' E., about 6 miles by road south of Kanona Siding, and 18 miles east-northeast of Karibib. Crystals of rutile occur within bands and pockets that are enclosed by quartz-albite country rock (see also p. 73). Estimates of reserves in 1937 were about 128,000 tons of "ore" averaging 4 percent TiO_2; from this about 5,000 tons of rutile concentrate could be recovered (U. S. Bureau of Mines, 1948, Mineral Trade Notes, v. 26, no. 1, p. 31).

Northeast of Windhuk in Otjisongati, titanium-rich quartz pegmatites of the Onjati Mountains near the headwaters of the Swakop River contain good crystals of rutile, apatite, magnetite, and molybdenite. Some of the rutile occurs as needle-shaped crystals as much as 12 inches long (Gmelin Institut, 1951, p. 57).

In Khan-Grube, south of Arandis, large veins of sphene occur in the metamorphosed parts of the rock. Titanium-bearing pegmatites occur in the area around Rehoboth.

Uganda

Ilmenite and rutile occur at numerous places in Uganda (Uganda Geological Survey, 1942, p. 18), but since no attempt is made in the literature to describe the kind or grade of the deposits, they will not be enumerated here.

Asia

Production of titanium ores in Asia during the period of 1941 to 1950 has been 1,701,886 metric tons of ilmenite concentrates from deposits in China, India, and Malaya, and 9,425 metric tons of rutile concentrates from deposits in India. Production figures from Japan are available only for the period 1925 to 1946 and totaled 25,556 metric tons of ilmenite concentrates from low-grade deposits in Japan, in addition to an unstated amount from Korea. Although compilation of reserve data from individual countries in Asia indicates a total of only about 51 million short tons of "ore" and 6.6 million short tons of contained TiO_2, little significance can be attached to these figures because some of the larger deposits, such as Travancore, India, and the Malayan tin deposits are not included.

Ceylon

The best potential deposits in Ceylon are ilmenite-bearing black sands of the coast, and contain an estimated 6.4 million short tons of titaniferous minerals, equivalent to about 2.8 million short tons of TiO_2. There is no record of production, although in 1951 and 1952 the Ceylon Government was attempting to interest companies in mining and milling the sands for the production of ilmenite concentrates (Mining Journal, 1952, v. 238, no. 6081, p. 364).

The deposit at Pulmoddai, on the northeast coast approximately 35 miles north of Trincomalee, is the largest black sand deposit in Ceylon and averages 240 feet in width, 2 to 6 feet in thickness. The deposit along 6½ miles of beach contains an estimated 5.6 million short tons of black sand with 74 percent ilmenite, 15 percent rutile, and 9 percent zircon (Ceylon, Records of Department of Mineralogy, 1944, p. 4, 8). One analysis of the "ilmenite" shows that it contains 62.5 percent TiO_2, 16.5 percent Fe_2O_3, and 5.9 percent FeO (Ceylon, Records of Department of Mineralogy, 1944, p. 4), and must therefore be partially altered (see p. 14, 20, and 49-50). A similar deposit along 3 miles of the coast near Tirukkovil on the southeast coast, 45 miles south of Batticoloa, contains 560,000 short tons of ilmenite (Ceylon, Records of Department of Mineralogy, 1944, p. 8).

Deposits on the west coast of Ceylon average 10 to 30 percent ilmenite, and in a few places contain as much as 50 percent. The best deposits are as follows: (1) near the mouth of the Kelani River, north of Colombo; (2) near the mouths of the Kalu and Modaragam Rivers; (3) at Kudremalai Point, 40 miles south of Mannar; (4) at Negombo; and (5) at Induruwa on the southwest coast.

China

In China the only titanium-bearing deposits cited in the literature are titaniferous magnetite deposits in the Luanping and Chen Te districts of Jehol Province, Manchuria. These deposits produced 4,423 metric tons of ilmenite concentrates (35.3 percent TiO_2) during three years of operation by the Japanese during World War II (U. S. Bureau of Mines, 1948, Foreign Minerals Survey, v. 2, no. 7, p. 65). This production required the mining of 197,359 metric tons of ore analyzing 10.2 percent TiO_2 and 45.1 percent Fe. One of these deposits at Chi-chia-tzu (41°10'N., 117°42'E.) contains coarsely granular ilmenite and magnetite within gabbro and anorthosite, and averages 12 percent TiO_2 and 53 percent Fe (Tsuru, 1934, p. 318). Because numerous microscopically small laths of ilmenite are included within the magnetite, neither pure ilmenite nor magnetite concentrates can be readily obtained.

India

India was the world's largest producer of titanium ores, until insufficient shipping during World War II decreased exports. All production has come from beach sands of Travancore State, and between 1941 and 1950 totaled 1,625,870 metric tons of ilmenite concentrates and 9,425 metric tons of rutile concentrates. The only reserve estimates are from reconnaissance surveys of smaller coastal deposits and some of the primary deposits of the interior. Total reserves are 2.6 million short tons of titaniferous material containing 329,000 short tons of TiO_2. Reserve estimates are lacking for the Travancore beach deposits.

Travancore State deposits.--The commercial Travancore deposits occur on two important beaches; one, Manavalakurichi (8°8'N., 77°18'E.), is near Colachel and Cape Comorin; the other beach is about 80 miles farther north, near Quilon.

At Manavalkurichi (often simply called "MK") mining in 1906 was initially for monazite, and not until 1922 was ilmenite recovered. Deposits occur along an arcuate coastline for a distance of 6,000 feet, and are being worked on both the barrier bar and the mainland beach. This latter beach contains the best ore in a layer 6 to 8 feet below the surface. The black-sand ore averages 50 to 70 percent ilmenite, and can be concentrated to a product that contains about 52 percent TiO_2 (Barksdale, 1949, p. 25-26). Because of the extensive mining activity, the deposits were reportedly nearing exhaustion in 1942 (Krishnan and Roy, 1942, p. 13).

The deposits near Quilon were initially mined in 1932, and by 1934 were producing the bulk of the Indian ilmenite. The deposits occur in an offshore bar which extends for 15 miles from the mouth of Neendakara Inlet to the mouth of Kayankulum Inlet, and passes in front of the mouths of the Panular and Pallikal Todu Rivers. The beach sand on the seaward side of the bar often contains as much as 80 percent heavy minerals, whereas buried black sand layers in the dunes behind the beach contain only 40 to 50 percent heavy minerals (Gillson, 1949, p. 1056). Both types of deposits are hand mined by natives who transport the sand in baskets to the nearby concentrating plant. Wet-tabling, followed by magnetic and electrostatic treatment yields an "ilmenite" concentrate with 60 percent TiO_2 (Barksdale, 1949, p. 26). Other concentrates include rutile, zircon, monazite, and garnet.

Bauxite deposits.--An important potential source of titanium is the sludges which result from the processing of bauxites and laterites for aluminum compounds. Indian bauxites average 10 percent TiO_2 and may contain as much as 14 percent TiO_2. The waste sludges and red muds that are produced during the extraction of the aluminum compounds contain 30 to 47 percent TiO_2 (U. S. Bureau of Mines, 1950, Mineral Trade Notes, v. 30, no. 3, p. 26).

Beach deposits of lesser importance.--Although the Quilon and "MK" deposits are the only producers of titanium ore in India, other beaches along the coast contain black sands that are rich in ilmenite. According to the U. S. Bureau of Mines (1946, Mineral Trade Notes, v. 22, no. 2, p. 21-24) the reserves of the important areas are: (1) the Chowghat-Ponnani Coast, 1,025,470 short tons of sand containing 49 percent ilmenite; (2) near the mouths of the Vaippar and Kallar Rivers in the Tinnevelly district, 35,750 short tons of sand containing 49 percent ilmenite; (3) near Tranquebar on the Madras coast, 100,360 short tons of sand containing 50 percent ilmenite; and (4) along the Malabar coast deposits with as much as 50 percent ilmenite. Large deposits of ilmenite sand supposedly occur in the Ratnargiri district of Bombay State (Mining World, 1952, v. 14, no. 2, p. 65), but there is no indication that they are commercially exploitable.

Ilmenite and titaniferous magnetite deposits.--Ilmenite and titaniferous magnetites are common in many primary deposits of the interior. A deposit of ilmenite and magnetite occurs west of Calcutta in Singhbhum and Mayurbhanj at approximately 22° N., and 86° E., and contains as much as 28 percent TiO_2 (Krishnan and Roy, 1942, p. 11). According to Dunn and Dey (1937, p. 124) the deposit contains about a million long tons of "ore", much of which is high in vanadium. In the Nellore district of Madras, about a mile northeast of Gulimcherla Village, Rapur Tq., ilmenite occurs within a pegmatite in large masses that often weigh 30 to 50 pounds and contain as much as 50 percent TiO_2 (Swanimathan, 1928). Another pegmatite close to the Patrugunta mica mine near Gundar contains 29 percent TiO_2. In Mysore State titaniferous iron deposits in the Channagiri Taluk supposedly contain several hundred thousand tons of "ore" averaging 11.6 percent TiO_2 (Imperial Mineral Resources Bureau, 1922, pt. 4, p. 38). The same kind of material also occurs in the Nuggihalli schist belt of the Channarayapatna Taluk. Quartz veins at Kancharia in Rajputana produced a few tons of ilmenite, but as the raw material contained only 3 percent ilmenite, the undertaking was not profitable (Krishnan and Roy, 1942, p. 12). Ilmenite also occurs in Bihar near Supur, and in the foothills northwest of Manbazar.

Rutile deposits.--Rutile is common in the crystalline rocks and the coastal sands of India. Rutile occurs in large crystals in the Narnaul district of Patiala State, Punjab; in quartz veins of the Motidongri Ridge south of Rajputana; in the mica schist of Singhbhum; and in the kyanite rocks of Dhalbhum and Mayurbhanj (Krishnan and Roy, 1942, p. 11).

Indo-China

Indo-China contains ilmenite in numerous river and beach sands (Dupouy, 1913), and also has large quantities of titaniferous sands on the Bay of Camranh in South Annam (Blondel, 1934, p. 383); unfortunately none of these has been carefully investigated.

Japan

During mining operations from 1925 to 1946 Japan produced 25,556 metric tons of titanium concentrates containing 26 to 45 percent TiO_2 and 32 to 55 percent Fe; the largest production was during World War II (Staatz, 1947, Table 4). The principal source of titanium is iron sands which occur throughout the four main islands, and are especially abundant in southern Hokkaido and northern Honshu. Although some sources claim that the reserve of titanium "ore" in these sands is about 200,000,000 tons (Barksdale, 1949, p. 27; Anon., 1927, p. 937) recent work indicates a reserve of about 41.6 million short tons of iron sands containing 1 to 17 percent TiO_2 and averaging 8 or 9 percent (Staatz, 1947, p. 3, 12).

Most mining occurs on beaches, although some placer deposits and older, uplifted beaches are also mined. Although most of the sands are mined for magnetite or other iron-bearing minerals, a few contain sufficient ilmenite to make them valuable as possible ores of titanium. The presence of 4.14 to 12.98 percent TiO_2 in iron concentrates of sands mined only for iron (Staatz, 1948), indicates that all the sands contain titanium, probably as fine-grained intergrowths of ilmenite within magnetite.

The iron sand mines that were operated principally for the extraction of titanium ores were as follows: on the island of Hokkaido, the Hokkai mine in Hokkaido Prefecture; on the island of Honshu, the Odaka, Omika, Ozawa, Takachiho, and Tomioka mines in Fukushima Prefecture, the Hiragata and Ibaraki-Taga mines in Ibaraka Prefecture, and the Kameji mine in Shimane Prefecture; on the island of Shikoku, the Iyo, Kuroshima, and Tencho mines in Ehime Prefecture, and the Iyahama mine in Kochi Prefecture. Reserve estimates are available only for the Odaka mine. In 1947 it contained 8,480 metric tons of sand with 18 percent TiO_2 and 55 percent Fe (Staatz, 1947, Table 8).

The Kengamine mine in Fukushima Prefecture on the island of Honshu is the principal primary deposit of titanium "ores", and contains titaniferous magnetite "ore" within gabbro. The mine is considered unimportant, production has been only minor, and the reserves are unknown.

Korea

Titanium ore was mined in Korea only during World War II, when a minor amount of ilmenite concentrates was produced by the Japanese. The location of the productive deposits is unknown.

On Shoenpeito Island (37°35'N., 125°45'E.), in Kokai Province, an ilmenite-magnetite body measures 600 by 1,000 feet and is interbedded with hornblende schist. The body contains magnetite grains that enclose small laths and blebs of ilmenite, and averages approximately 21 percent TiO_2 and 52 percent Fe (Ichimura, 1931). "Ore" from the Porumdo ilmenite-magnetite deposit (37°39'N., 126°12'E.) contains 25 percent ilmenite (Gallagher and others, 1947, p. 50). Titaniferous deposits at Komasan and Konan-san are associated with anorthosites, and one at Kansen-ri occurs in veins cutting gneiss. Occasional analyses of placer deposits always show a high ilmenite content, although the feasibility of working such deposits is doubtful, since the very important farming activities are confined mostly to the valley bottoms.

Malaya

Shipments of ilmenite concentrates from Malaya during 1941 to 1950 were as follows: 44 metric tons in 1941, zero from 1942 to 1945 inclusive, and 71,549 metric tons from 1946 to 1950 inclusive. There are no reserve estimates of titaniferous material.

Titanium concentrates are produced only as a by-product of the tin-mining industry, and come mostly from the important tin producing states of Perak and Selangor. The minerals in the placer and residual deposits are derived from the nearby granite. Mining by large dredges is followed by a preliminary concentration, and yields a mixture of cassiterite, ilmenite, topaz, tourmaline, and, in places, monazite (Scrivenor, 1928, p. 32). Washing of this rough concentrate by skilled Chinese laborers produces a tin-bearing concentrate and an ilmenite-rich residue called "amang". Some of the amang is magnetically concentrated to a pure ilmenite fraction, but much of it is stockpiled. Large amounts are never treated, as indicated by the 358,700 metric tons of amang stockpiled at various mines throughout the country in 1938 (Fermor, 1940, p. 76-77).

Turkey

In Turkey a beach deposit on the Black Sea near Sile, Istanbul contains appreciable amounts of black sand where bordered by cliffs of lava and tuff. An analysis shows that the sands contain 32.6 percent ilmenite, 32.4 percent magnetite, and 18.7 percent zircon (Egeran, 1941).

Central and South America

The only important producer of titanium ores in Central and South America is Brazil, which from 1941 to 1950 exported 13,298 metric tons of rutile concentrates and 21,271 metric tons of ilmenite concentrates. Chile reported a production of 5 tons of titanium concentrates in 1944. There are no accurate reserve estimates for any of the countries.

Argentina

In the province of Buenos Aires, Argentina, ilmenite and magnetite-bearing beach sands along the Atlantic coast near Mar del Plata, Mar del Sur, Miramar, and Necochea contain 1 to 12 percent titanium and 2 to 23 percent iron. Although the deposits supposedly have a maximum width of 3,500 feet and contain 13,600,000 tons of sand and 352,000 tons of recoverable iron concentrates per mile of length (Youngman, 1930b, p. 21-22), they are low grade.

In the province of Catamarca, west of Albigasta in the Sierra de Ancasti, a body of titaniferous magnetite occurs as a magmatic segregation within gabbro and contains 17 percent TiO_2, 66 percent FeO, 9 percent Fe_2O_3, and 5 percent SiO_2. Reserves are unknown (Imperial Mineral Resources Bureau, 1922, pt. 7, p. 116).

Brazil

The producing titaniferous deposits of Brazil are rutile deposits in the states of Ceara, Goyaz, and Minas Gerais, and ilmenite-and rutile-bearing coastal beach deposits in the states of Rio de Janeiro, Espirito Santo, and Bahia. Exports began in 1925, and from 1941 to 1950 amounted to 13,298 metric tons of rutile concentrates and 21,271 metric tons of ilmenite concentrates. It is impossible to give accurate estimates of reserves.

Very little information is available for minor occurrences of rutile in the states of Matto Grosso, Pernambuco, and Sao Paulo, and ilmenite in the state of Sao Paulo at Cananea, Iguape, and S. Sebastiao.

Ceara.--In the state of Ceara, alluvial and residual deposits that are derived from granites and gneisses contain about 1 percent rutile as crystals with 88 to 96 percent TiO_2 and measuring a quarter to $3\frac{1}{2}$ inches in diameter. The deposits were initially operated in 1940. Mining is on a small scale by individual laborers who pick out the rutile crystals, as they dig into the gravels (Chambers, 1942, p. 6; U. S. Bureau of Mines, 1945, Mineral Trade Notes, v. 21, no. 5, p. 19-20).

Goyaz.--In the state of Goyaz stream gravel and bench deposits of the Araguaia, Paranaiba, and Tocantins Rivers contain silver-gray to black, and red fragments of rutile. These contain 92 to 98 percent TiO_2, and can be obtained in concentrates of 92 to 97 percent TiO_2. The better deposits occur at Pirenopolis and Rio das Almas; smaller deposits are at Anapolis, Bomfin, Caldas, Campo, Corumba, Formoso, Ipameri, Morrinhos, Pouso Alto, and Trindade. Most production has been a by-product of alluvial mining for gold and diamonds (Jobim, 1941, p. 65; Leao, 1938(?), p. 85-87; U. S. Bureau of Mines, 1941, Foreign Minerals Quarterly, v. 4, no. 1, p. 49).

Minas Gerais.--Rutile occurs in residual and alluvial deposits in the state of Minas Gerais. One group of deposits occurs on a line that extends from Lima Duarte to Ayuruoca and passes through Andrelandia and Arantes; another line of deposits passes through Araxa. The titanium content of the rutile varies from 69 to 97 percent TiO_2, with the lower grades containing considerable admixed ilmenite (Abreu, 1936a). In 1941, approximately 65 percent of the rutile production came from Lima Duarte, 30 percent came from Andrelandia, and the remainder came from Araxa, Ayuruoca, and Bom Jardin (Jobim, 1941, p. 65). Other areas which contain rutile deposits are Araguaris, Livramento, and Uberlandia.

Coastal deposits.--Black sands along the coasts of Rio de Janeiro, Espirito Santo, and Bahia contain concentrations of ilmenite and rutile. Ilmenite concentrates obtained from minor mining operations contained 53 to 61 percent TiO_2, and rutile concentrates contained as much as 95 percent TiO_2 (Gillson, 1951, p. 692). Large-scale production from these deposits has been lacking because the deposits are small, they are in remote locations, good transpprtation is lacking, and the roads are in poor condition. These deposits are discussed below, starting with the southern end.

In the state of Rio de Janeiro 22 deposits occur along the 12 miles of beach that extends south from the Barra do Itabapoana River (the boundary between the states of Rio de Janeiro and Espirito Santo). The deposits average 32 percent heavy minerals, with 55 percent ilmenite (57 percent TiO_2), 5 percent rutile, and 25 percent zircon (Gillson, 1951, p. 689-690).

In the state of Espirito Santo deposits at Boa Vista de Siri and Maratayses (south of Barro do Itapemirim) are rich in monazite. One of the most important sections of the Espirito Santo coast occurs along 45 miles of coast from Barra do Itapemirim to a few miles north of Guarapary, and contains the following deposits from south to north: Caju, Piuma, Paraty, Ubu, Mahiba, Ubahy, Meahipe, Lima, Guarapary, and Ponta da Fruta. Two companies mine sand from some of these deposits, process the material near Guarapary, and ship from Vitoria. A shipment of 500 tons in 1942 contained ilmenite with 53.9 percent TiO_2, 28.5 percent Fe_2O_3, 6.68 percent FeO, 0.05 percent Cr_2O_3, and 0.45 percent V_2O_5 (Gillson, 1951, p. 692). Reserve estimates for the sands of Guarapary Municipality are 32,180 metric tons of concentrates (U. S. Bureau of Mines, 1937, Mineral Trade Notes, v. 4, no. 6, p. 24). Deposits along the 20 miles of coast north of Vitoria are: (1) the Carapebus deposit which was worked from 1910 to 1912 and contains ilmenite with 58 percent TiO_2; (2) the Capubal and Jacareipe deposits which are on a long raised bar; and (3) the Boa Vista de Nova Almeida deposit which is supposedly of insignificant size. Within 9 miles north of Ara Cruz occur, (1) the Sahi deposit which contains sands that can be concentrated to 53 percent TiO_2, and (2) 4 miles farther north the Barra do Riacho deposit. The northernmost deposits in the state of Espirito Santo are near the mouth of the Rio Doce, where titaniferous magnetite sands of the delta can be concentrated to a product with 37 percent TiO_2.

Low-grade deposits occur approximately 10 miles upstream near Lagoa Juparana and Regencia.

In the state of Bahia the best deposits occur on the southern coast not far north of Caravellas. The Guaratibal deposit is an elevated bar and contains ilmenite with 61 percent TiO_2 and 32 percent Fe_2O_3; insufficient reserves make development unlikely. A modern beach deposit at Comoxatiba, 25 miles farther north, contains layers of sand as much as 6 feet thick. One analysis of ilmenite from this showed 57 percent TiO_2 (Gillson, 1951, p. 692).

A few promising deposits occur near the "hump" of Brazil. Near the village of Cunhau, 30 miles south of Natal, black sands occur along both sides of the channel, along the beaches north and south of the village, and in the large dune complex between the sea and the sea cliff. Ilmenite and zircon comprise 85 percent of the heavy minerals. The ilmenite contains 56 percent TiO_2, 22 percent Fe_2O_3, and 18 percent FeO.

British Guiana

In the Berbice district of British Guiana, rutile occurs in placers, and in one sample analyzed 95 percent TiO_2 (Youngman, 1930b, p. 23-24).

Chile

According to the U. S. Bureau of Mines (1945, Mineral Trade Notes, v. 20, no. 33, p. 26) 5 metric tons of rutile concentrates were produced in 1944 at the Oxido de Titanio mine near La Seraba and exported to Argentina.

Mexico

Prior to 1947 a deposit of ilmenite was reportedly discovered west of Victoria, capital of the state of Tamaulipas. A description of the deposit says "the contact vein is ... about 30 feet thick, 2,500 feet deep ... two miles long and ... contains 50 million tons of ore averaging 40 to 45 percent TiO_2" (U. S. Bureau of Mines, 1947, Mineral Trade Notes, v. 25, no. 3, p. 21). These estimates of tonnage and grade may be high. A large deposit of rutile supposedly occurs in the Pacific coast state of Oaxaca, near the village of Pluma Hidalgo, and minor deposits occur in Baja California, Guerrero, San Luis Potosi, and Sinaloa.

Uruguay

In Uruguay, veins of titaniferous iron "ore" are reportedly associated with a gneissic granite "a few thousand feet west of the highway to Florida in an open field." The veins are 2 to 8 feet wide, and have been exposed by two pits and some short shafts. Analyses of the "ore" indicate a titanium content of 12 to 23 percent TiO_2, and an iron content of 45 to 56 percent Fe (U. S. Bureau of Mines, 1940, Foreign Minerals Quarterly, v. 3, no. 4, p. 14).

Europe

Production of titanium ores in Europe from 1941 to 1950 was 702,175 metric tons of ilmenite concentrates from deposits in Norway, Portugal, and Spain, and 656 metric tons of rutile concentrates from one deposit in Norway. The largest titanium-bearing deposits occur in Finland, Norway, Russia, and Sweden. Reserves are 411.2 to 804.6 million short tons of ore containing 31.6 to 97.9 million short tons of TiO_2.

Bulgaria

Extensive beds of titanium-bearing black sand occur on the west shore of the Black Sea near Bourgas, Bulgaria. They reportedly occupy 8 square miles, have an average thickness of 3 to 7 feet, and contain 10 percent TiO_2 and 50 percent Fe (U. S. Bureau of Mines, 1938, Foreign Minerals Quarterly, v. 1, no. 1, p. 30).

Finland

Finland has no production of titanium ores, although in 1950 plans were underway to mine magnetite-ilmenite ore at Otanmäki. Reserves have been determined for only this deposit, and range from estimates of 11 to 55 million short tons of ore with about 12 percent TiO_2.

Otanmäki.--The Otanmäki deposit was discovered in 1938 in central Finland, south of Oulunjärvi and southwest of Kajana. The magnetite-ilmenite ore occurs as elongated lenses and veins within a deformed amphibolite, and averages 12 percent TiO_2 and 35 percent Fe. Tests indicate that it may be possible to produce an iron concentrate with 66 percent Fe and 5 percent TiO_2, and a titanium concentrate with 47 percent TiO_2. This titanium product is obtained by flotation of the iron concentrate tailings and weighs approximately 14 percent of the raw ore weight. Reserve estimates range from 11.0 million short tons of ore to a depth of 200 meters (Magnusson, 1950), to 55.1 million short tons of ore (Stigzelius, 1952, p. 127).

Minor deposits.--Small and unimportant titaniferous magnetite bodies are as follows (Palmunen, 1925). A mine near Attu, on the island of Runholm, parish of Parainen in southwest Finland, contains a deposit of titaniferous magnetite and almandite garnet enclosed in hornblende gabbro. A small mine at Kitula, village of Kirju, parish of Suomusjärvi, contains ilmenite and magnetite, monoclinic pyroxene, hornblende, a little chlorite, and many sulfide minerals. Two small deposits, one at Riuttamaa, parish of Köyliö, and the other at Susimäki, estate of Jonkka, parish of Vampula 5 miles east of the first, contain about 50 percent of ilmenite and magnetite within olivine gabbro. A contact metamorphic deposit at Vuorijärvi, parish of Kuolajärvi, contains large crystals of intergrown ilmenite and magnetite within limestone.

Germany

Ilmenite-bearing black sand beach deposits are common on the Frisian Islands of Germany in the North Sea off the coast of Denmark and Germany. On Wangeroog many black sands average 60 to 70 percent heavy minerals, and contain in addition to other heavy minerals about 48 percent ilmenite and 12 percent magnetite. According to Trusheim (1935) the sands are an important reserve for the future, although the difficulties of beneficiation were demonstrated in the 1870's when an unsuccessful attempt was made to smelt sands from the Isle of Sylt.

Greenland

Although Greenland has been described as containing titaniferous deposits (Moos, 1938; Ramberg, 1948), there is no indication that any of the deposits are commercial.

Hungary

In Hungary, titaniferous magnetites occur southeast of Szarvasko in the Bükk Mountains, and are especially rich on the north side of Vaskapu. Concentrations of ilmenite and magnetite vary from 8 percent in gabbro to 90 percent in isolated masses within gabbro peridotite. The richer bodies average as much as 23.2 percent TiO_2. Analyses of the titaniferous magnetites show 32 to 41 percent TiO_2, and 38 to 48 percent Fe (Szentpétery, 1937).

Italy

The best sources of titaniferous material in Italy are the iron-bearing beach sands along the coast. The best deposits are on the Tyrrhenian Sea shore between Civitavecchio and Salerno, and contained approximately 1,650,000 short tons of "ore" in 1940 (U. S. Bureau of Mines, 1946, Mineral Trade Notes, v. 23, no. 3, p. 13-14). Various companies began mining the sands in 1939, and although no analyses are given, the character of the concentrates provides information about the sands. Three concentrates from the sands were as follows: (1) an iron concentrate with 5.8 percent TiO_2 and 62 percent Fe; (2) a titanium concentrate with 35 percent TiO_2 and 24 percent Fe; and (3) a zircon concentrate with 40 percent Zr.

Reports concerning deposits on the east coast of Italy at Margherita di Savoia in Foggia indicate an estimated 880,000 short tons of iron, but do not state the amount of titanium.

Norway

The steady production of titanium concentrates in Norway from 1941 to 1950 has totaled 696,592 metric tons of ilmenite concentrates and 1,656 metric tons of rutile concentrates. The important deposits are primary bodies associated with anorthosite and gabbro. Reserve estimates, mostly in the inferred category, vary considerably, and show 51.3 to 59.8 million inferred short tons of "ore" carrying 6.6 to 7.5 million short tons of TiO_2.

Ekersund Soggendal region.--The most important area is near Ekersund and Soggendal, on the southwest coast of Norway, south of Stavenger, where bodies of ilmenite and magnetite or hematite occur as veins or segregations within anorthosite and gabbro. Correlation of data from the individual deposits of Blaafjeld, Haaland, Hegdal, Koldal, Kyland, Lakesdal, and Storgangen is difficult because some of the deposits apparently have more than one name, and because conflicting information often exists for a given deposit.

The A/S Titan Company has been mining titanium ore from this region since 1921, and in 1950 was mining a deposit that was apparently called Baafjeld by some authors and Storgangen by others; it may even be possible that the two ends of the same deposit have different names. This deposit is 150 feet wide, approximately 5,000 feet long, and contains 33 million short tons of 17 percent TiO_2 ore (Magnusson, 1950). Although some sources claim that the deposits of this region average 40 to 45 percent TiO_2 (Barksdale, 1950, p. 20; Thornton, 1927, p. 36) it seems probable that only the concentrates are this rich, and that the average grade of ore is considerably less. The concentration plant of the A/S Titan Company has an approximate annual capacity of 85,000 tons of ilmenite concentrates (43 percent TiO_2 and 35 percent Fe), and 18,000 tons of iron concentrate (3 percent TiO_2 and 66 percent Fe)(Magnusson, 1950).

The Lakesdal deposit, which is supposedly also worked by A/S Titan, contains 275,000 short tons of ore with 35 percent TiO_2 (Thornton, 1927, p. 36).

Kragerö rutile deposit.—The only important rutile deposit is at Kragerö on the southeast coast of Norway, approximately 90 miles south of Oslo. The rutile occurs in large, even grained, white dikes of a rock called kragerite (mostly albite and rutile), and constitutes approximately 5 to 10 percent by weight of the dike. Shipments from this mine have averaged about 100 tons per year for the past 15 years. There are no reserve estimates.

Lofoten and Vesteraalen Islands.--The largest of the numerous titaniferous magnetite deposits that occur on the Lofoten and Vesteraalen Islands is at Selvåg, on the island of Langö. The Selvåg deposit contains 16.5 million short tons of ilmenite and magnetite, and averages 4 percent TiO_2 and 32 to 35 percent Fe (Imperial Mineral Resources Bureau, 1922, pt. 6, p. 124-125).

Rödsand deposit.--Titaniferous magnetite bodies occur in the vicinity of Rödsand on the southeast shore of Tingvoldfjord in Nordmöre, southern Norway. Ilmenite-magnetite veins and lenses within a foliated gabbro contain 6.0 to 7.5 percent TiO_2 and 35 percent Fe. Mining from five to seven of the lenses yields 145,000 tons of ore that is treated in a nearby concentration plant to produce 45,000 tons of titanomagnetite concentrate (3 percent TiO_2 and 65 percent Fe), and an unknown amount of ilmenite concentrate (44 percent TiO_2 and 35 percent Fe). Reserves are 250,000 to 4,400,000 short tons of ore carrying 6 percent TiO_2 (Imperial Mineral Resources Bureau, 1922, pt. 6, p. 122-123; Magnusson, 1950).

Söholt and Solnördal deposits.--Two closely related deposits occur on the north and south sides of the Lia Mountains, and contain approximately 14 percent TiO_2 and 50 percent Fe. The deposit on the south side of the mountains is at Söholt in Örskoug, north of Storfjord.

The Solnördal deposit on the northern side, near Skodje, contains an estimated 1.1 to 5.5 million short tons of "ore" (Imperial Mineral Resources Bureau, 1922, pt. 6, p. 124). The deposit is a magmatic segregation in gabbro, and reportedly contains 12 to 15 percent TiO_2 and 35 to 48 percent Fe. Preliminary tests indicated that for each ton of magnetite concentrate (3 percent TiO_2 and 65 percent Fe), there is obtained 0.4 ton of ilmenite concentrate analyzing 44 percent TiO_2 and 35 percent Fe (Magnusson, 1950).

Minor deposits.--Numerous minor deposits of titanium-bearing "ore" are cited in Gmelins Handbuch (Gmelins Institut, 1951, p. 44-46). Most of the information on which this is based dates from the early nineteen hundreds.

Portugal

Production of ilmenite concentrates from placer deposits in the Castelo Branco district of Portugal has totaled 2,978 metric tons from 1941 to 1950 inclusive.

A large valley north of Belmonte, approximately 150 miles northeast of Lisbon, contains ilmenite and cassiterite-bearing gravels to a depth of 12 to 50 feet. The gravels are mined by a floating dredge, and the cassiterite and ilmenite extracted in a nearby washing plant. This rough concentrate is trucked to a smelter at Belmonte, where the tin is smelted and the ilmenite concentrate extracted by magnetic methods. The production of the ilmenite concentrate is only of minor importance, as the operation is conducted mainly for the extraction of the tin.

At São Torpes beach near Sines, about 60 miles south of Lisbon, a beach deposit of iron-titanium sand extends for about 3 miles along the shore. The deposit is about 60 feet wide, half a foot thick, and in the richer portions contains more than 40 percent TiO_2 and 48 percent iron oxides (Castro, 1947).

Russia

Although Russia contains numerous deposits of titanium-bearing "ores," and is probably mining some of them, information is difficult to obtain because: (1) most of the literature is in Russian; and (2) very little of it is more recent than 1935 to 1940. Although much of the following information comes from Russian literature and maps, a thorough study of the Russian material would undoubtedly provide more details. Estimates of reserves are 100.9 to 441.7 million short tons of "ore" with 6.7 to 66.8 million short tons of TiO_2. The largest deposits are in the Ural Mountains.

Kola Peninsula and Karelia.—The northernmost deposit on the Kola Peninsula is above the Arctic Circle near Yurkino, about 40 miles southwest of Murmansk, and is not cited in the literature, but is listed as a "Titan" deposit on an economic map of the Murmansk district (Leningrad, Geografo-ekonomicheskii Nauchno-issledovatel'skii, Murmanskii filial, 1935).

Economic maps and atlases show more "Titan" deposits near Kirovsk (also called Khibinogorsk) in the region of the Khibine and Lovozero Tundras (Leningrad, Geografo-ekonomicheskii Nauchno-issledovatel'skii institut, 1934; Leningrad, Geografo-ekonomicheskii Nauchno-issledovatel'skii institut, Murmanskii filial, 1935; Tsentral'nogo Ispolintel'nogo Komiteta i Soveta Narodnykh Komissarov Soyuza SSR, 1939). This area has many large active apatite mines that contain as much as 2 percent sphene and 2 percent titaniferous magnetite (Polkanov, 1937, p. 104-106). According to Tyler and Petar (1934, p. 87) a large deposit of titanium ores was discovered about 40 miles from the large apatite mine at Khibinsk.

The Afrikanda pyroxenite mass, near Okhto-Kanda and about 45 miles southwest of Kirovsk and the Khibine massif, contains "considerable titanium", although no indication of grade or tonnage is given (Polkanov, 1937, p. 41-50; Tsentral'nogo Ispolintel'nogo Komiteta i Soveta Narodnykh Komissarov Soyuza SSR, 1939).

Titaniferous magnetites of the Pudozhgora district on the east shore of Lake Onega (about 200 miles northeast of Leningrad) contain 9 to 11 percent TiO_2 and 30 to 45 percent iron. The deposits cover an area of 75,000 square feet, and to a depth of 275 feet contain 406,000 short tons of "ore" averaging 10 percent TiO_2 (Engineering and Mining Journal, 1948, v. 149, no. 6, p. 96; Gmelin Institut, 1951, p. 49; Suirokomski, 1926).

A deposit near Koikorie (Koykory), west of Lake Onega and about 45 miles southwest of Povents, contains parts that are rich in magnetite and ilmenite-magnetite, although no indication of grade is given (Suirokomski, 1926).

The Valimaki deposit is on the north shore of Lake Laatokka (Lake Ladoga) and was formerly in Finland; it contains titaniferous magnetite "ore" with 23 percent Fe, and an unknown amount of titanium.

Ural mountains.--general.--The titanium-bearing ore deposits of the Ural Mountains are shown in Table 10, and the more important deposits described below. The reserves of the deposits listed in this table total 100 to 145 million short tons of "ore" (91 to 131 million metric tons), with 6.1 to 15.5 million short tons of TiO_2 (5.5 to 14 million metric tons). Other estimates of reserves in the Ural Mountains are: (1) Suirokomski (1926, p. 69), 110 to 165 million short tons of "ore" with 11 to 16 million short tons of TiO_2; (2) Shimkin (1949, p. 184-185), 441 million short tons of "ore" with 66 million short tons of TiO_2; (3) Panteleev and Malyshev (1934), 144 million short tons of "ore" with 11 to 15 million short tons of TiO_2.

The Ilmen Mountains in the southern part of the Ural chain contain the largest titanium-bearing deposits in Russia. In the region around Miass, 50 miles west of Chelyabinsk, pegmatites contain crystals of ilmenite that weigh as much as 17 pounds, and placer deposits contain abundant ilmenite and zircon.

Kusinka deposit.--One of the richest deposits in the Zlatoust mining area of the Ilmen Mountains is the Kusinska, sometimes called the Magnitnoye, Kusa, or Kusin; it lies about 8 or 9 miles west of the city of Kusa. Ilmenite and magnetite ore occurs in 6- to 12-foot wide dikes within a gabbro mass several hundred feet wide and over a mile long. The ore of approximately 14 percent TiO_2 and 54 percent Fe can be concentrated to an iron product with 7 percent TiO_2 and 64 percent Fe, and to a titanium concentrate with 42 percent TiO_2 and 37 percent Fe (Kulibin, 1935). Estimates of reserves range from 4.4 million short tons of ore containing 53 to 63 percent Fe (Imperial Mineral Resources Bureau, 1922, pt. 6, p. 165) to 66,796,000 short tons of ore containing 10 to 15 percent TiO_2 (Panteleev and Malyshev, 1934, p. 222-223).

Table 10. Titaniferous deposits of the Ural Mountains, Russia. Reserves in metric tons.

("Ore" used in non-commercial sense to describe titaniferous aggregates)

Name	Location	Type of deposit	Grade and reserves	Source
Bilimbaevskoye (Galashkinskoye)	57°30'N., 59°35'E. 30 miles south of Nizhny Tagil.	Titaniferous magnetite inclusions in peridotite.	3,100,000 tons of ore, 3-4 percent TiO_2.	1 2 p. 227-228 3 p. 65
Chernorechenskoye	ca 55°18'N., 59°45'E. 4 or 5 miles east or SE. of Magnitnoye deposit.	Titaniferous magnetite dikes within gabbro.	700,000 tons of ore, 10-16 percent TiO_2.	2 p. 224 3 p. 67
Denezhkin Mtn.	60°25'N., 59°25'E. Sverdlovsk Oblast, near Permsk Obl.	Titaniferous magnetite ore veins in banded gneiss.	---	3 p. 65
Kachkanar	58°50'N., 59°30'E.	Titaniferous magnetite ore as schlieren and inclusions.	31,000,000 tons of ore, 2-5 percent TiO_2.	1 2 p. 228-230

Table 10. Titaniferous deposits of the Ural Mountains, Russia. Reserves in metric tons (Continued).

("Ore" used in non-commercial sense to describe titaniferous aggregates)

Name	Location	Type of deposit	Grade and reserves	Source
Kaslinskaya Dacha	114 km N. of Chelyabinsk. South of Ufalei. 15-20 miles N. of Kyshtym.	Rutile in placers and pneumatolytic deposits. Titaniferous magnetite in serpentine and gneiss.	--	3 p. 63
Kopanskoye	55°08'N., 59°20'E. 20 miles WSW. of Zlatoust.	Titaniferous magnetites within coarse-grained gabbro.	16,000,000 tons of ore, 7-13 percent TiO_2.	1 2 p. 224-225
Kornilivskoe	57°37'N.	Titaniferous magnetite. Crops out over several thousand square meters.	6-13 percent TiO_2.	2 p. 176-177
Kusinska (Magnitnoye, Kusa, or Kusin)	55°20'N., 59°40'E. 8-9 miles E. of City of Kusa.	Titaniferous magnetite dikes in an intrusive gabbro.	20 to 60 million tons of ore. 10-14 percent TiO_2.	1 2 p. 222-223 3 p. 66-67 4

Table 10. Titaniferous deposits of the Ural Mountains, Russia. Reserves in metric tons (Continued).

("Ore" used in non-commercial sense to describe titaniferous aggregates)

Name	Location	Type of deposit	Grade and reserves	Source
Matkal'skoye	30 miles southwest of Zlatoust.	Titaniferous magnetite ore schlieren in gabbro. Very coarse-grained.	10-15 percent TiO_2, 40 percent Fe.	2 p. 69-73
Pervoural'skoye	56°50'N., 60°00'E. Near City of Pervoural'skoye.	Titaniferous magnetites as schlieren and disseminated inclusions.	10,000,000 tons of ore, 1-5 percent TiO_2.	1 2 p. 225-226
Shaitan Dacha	53°50'N., 59°05'E. Near City of Magnitogorsk.	Titaniferous magnetites resulting from differentiation of a gabbroic magma.	Supposedly 100 million tons of ore with 8 percent TiO_2, but not verified.	3 p. 66
Spornoe	57°40'N.	Ilmenite-magnetite schlieren.	100,000 tons of ore, 5-8 percent TiO_2, 60 percent Fe.	2 p. 138-143

Table 10. Titaniferous deposits of the Ural Mountains, Russia. Reserves in metric tons (Continued).

("Ore" used in non-commercial sense to describe titaniferous aggregates)

Name	Location	Type of deposit	Grade and reserves	Source
Ufalei area	80 miles NW. of Chelyabinsk, and 50 miles south of Sverdlosk.			
Ivanovskoye		Clayey lumpy titaniferous magnetite deposit.	15 percent TiO_2, 63 percent Fe.	3 p. 68
Turtashskoye		Veins and stocks of titaniferous magnetite within diorite.	10-18 percent Fe.	3 p. 68
Rutile deposit		Grains and crystals of rutile in deposits which resemble the rutile apatite deposits of Norway.	---	3 p. 68

Table 10. Titaniferous deposits of the Ural Mountains, Russia. Reserves in metric tons (Continued).

("Ore" used in non-commercial sense to describe titaniferous aggregates)

Name	Location	Type of deposit	Grade and reserves	Source
Yubryshka Mtn.	61°00'N., 59°00'E. Approximately 3,000 feet high.	Titaniferous magnetite disseminated inclusions in a gabbroic intrusion.	10,000,000 tons of ore, 6 percent TiO_2.	1 2 p. 230-232 3 p. 65
Unnamed	58°10'N., 59°55'E. Approximately 15 miles N. of Nizhny Tagil.	Listed as "Titan" deposit on map, no further information.	---	1
Unnamed	56°35'N., 60°25'E. At town of Mramorskii 22 miles SSW. from Sverdlovsk.	Listed as "Titan" deposit on map, no further information.	---	1
Unnamed	55°00'N., 59°50'E. 12 miles W. of Miass.	Listed as "Titan" deposit on map, no further information.	---	1

Table 10. Titaniferous deposits of the Ural Mountains, Russia. Reserves in metric tons (Continued).

("Ore" used in non-commercial sense to describe titaniferous aggregates)

Name	Location	Type of deposit	Grade and reserves	Source
Unnamed	$54^{\circ}55'$N., $60^{\circ}00'$E. 6 miles SW. of Miass.	Listed as "Titan" deposit on map, no further information.	---	1
		TOTAL	91-131 million tons of ore 5.5-14 million tons of TiO_2	

References:

1. Tsentral'nogo Ispolintel'nogo Komiteta i Soveta Narodnykh Komissarov Soyuza, SSR, 1939.
2. Panteleev and Malyshev, 1934.
3. Suirokomskii, 1926.
4. Shimkin, 1949.

Kopanskoye (Satkinskaya Dacha) deposit.--The Kopanskoye or Satkinskaya Dacha deposit is the second most important in the Zlatoust area, and is approximately 12 miles northeast of Satka and 20 miles southwest of Zlatoust. The ilmenite and magnetite-bearing bodies occur within a coarse-grained gabbro as "vein like masses" 2 to 15 feet thick. The zone of mineralization is about 6 miles long, and drill work has indicated "ore" to a depth of 500 feet. The deposit averages 7 to 13 percent TiO_2 and contains 17.6 million short tons of titaniferous material (Panteleev and Malyshev, 1934, p. 224-225). In spite of the large reserves, the deposit is not commercially attractive since the "ore" is very heterogeneous and requires extensive hand sorting (Gmelin Institut, 1951, p. 48).

Ukraine.--In the Ukraine, titanium deposits occur near Gatzkova in the Voldarsky district, approximately 190 miles north of Odessa (Tyler and Petar, 1934, p. 87). Ilmenite-bearing quartz and kaolin sands near Gakovske and Rudno-Gakovske in the Zitomir district contain a total of about 984,000 short tons of ilmenite, equivalent to approximately 492,000 short tons of TiO_2 (Gmelin Institut, 1951, p. 49). Black sands on the Sea of Azov at Belosarajakaja, Portovaja, Ganzukovskaja, and Nogajskaja, contain 14 to 38 percent TiO_2; reserves are 352,000 short tons of heavy sands, equivalent to 122,000 short tons of TiO_2 (Gmelin Institut, 1951, p. 49). Other titanium-bearing sands, containing 25 to 65 percent magnetite and titanomagnetite, occur in the delta of the Mius (Miusliman), and near Chutor Najdenovka; these latter sands carry 24 to 31 percent TiO_2.

Minor deposits.--Bauxites of the Tikahvinskoe region (59°40'N., 33°35'E., approximately 100 miles east of Leningrad) reportedly contained as much as 6.5 percent TiO_2 (Suirokomski, 1926, p. 59), although recent information indicates that most of the high-grade material has been mined out (E. C. Fischer, personal communication, September 1951).

The following information is from Suirokomski (1926, p. 69-72). In southern Russia, gabbro in the Volynski and Kiev regions contains as much as 4.5 percent TiO_2. In the Caucasus, a deposit at Elizauetpol, near Alabashly, supposedly contains 1 to 14 percent TiO_2. In the Kirgiz Steppes, east of the Caspian Sea in Central Asia, titaniferous magnetite in the western part of Tur-achyr contains a maximum of 15.3 percent TiO_2. Siberia reportedly contains titaniferous magnetites in the Nerchinski mining area of Trans Baikal. This area, at approximately 52° N., 117° E. is north of the eastern edge of Mongolia, not far from the southern border of Siberia.

Spain

Sands in Coruna Province and a deposit in Huelva ~~County~~ Province have produced 2,605 metric tons of ilmenite concentrates from 1941 to 1950 inclusive.

The deposit in Coruna Province of northwestern Spain consists of beach sands at the mouth of the Allones River (about 12 miles west of Carballo), and averages approximately 10 percent TiO_2, mostly as the mineral ilmenite. The sand is concentrated to a product that contains 50 to 52 percent TiO_2 (U. S. Bureau of Mines, 1945, Foreign Minerals Survey, v. 2, no. 1, p. 23).

Nothing is known about the deposits near Almonte in Huelva Province, except that it was discovered in 1948, and produced 63 metric tons of concentrates in 1949 (U. S. Bureau of Mines, 1949, Mineral Trade Notes, v. 28, no. 2, p. 29; 1951, Mineral Trade Notes, v. 32, no. 5, p. 32).

Other deposits of titanium-bearing sands are reported from Corino in northern Coruna Province, along the Sil River in Orense Province of the Galicia district, and from beaches in the Balearic and Canary Islands. Titaniferous magnetite reportedly occurs near Olot, in the Pyrenean foothills north of Barcelona (Chemical Age, 1944, p. 234).

Sweden

Titanium ores are not produced in Sweden, although there are many large deposits of titaniferous magnetite. Most of these do not contain free ilmenite, and thus are not commercially exploitable for their titanium. Estimates of reserves, mostly in the inferred category, show 248.0 million short tons of "ore" containing 17.0 million short tons of TiO_2.

Järvsö deposit.—In Kramsta, near Järvsö Station in Hälsingland, low-grade titanomagnetite deposits in a gabbro massif average 5 percent TiO_2 and 20 percent Fe. Concentration tests show that about 18 percent of the ore can be extracted as an iron concentrate with 6.2 percent TiO_2 and 64 percent Fe, and 3.6 percent can be extracted as an ilmenite concentrate with 38 to 40 percent TiO_2. Reserves are approximately 27 million short tons of "ore" (Magnusson, 1950).

Routevare deposit.—The Routevare deposit, the second largest in Sweden, lies in mountainous, uninhabited country along the Norwegian border, about 90 miles southwest of Kiruna. The nearest village (Kvikkjokk, 250 inhabitants) is 10 miles south-southeast, the nearest highway is 28 miles away, and the nearest railroad is 65 miles distant. The deposit of magnetite and free ilmenite occurs as lenses in anorthosite, and contains 11 percent TiO_2 and 46 percent Fe. Preliminary concentration tests in 1910 showed that 50 percent of the "ore" yielded an iron concentrate with 5 percent TiO_2 and 65 percent Fe, and that 20 percent gave an ilmenite concentrate with 14 to 20 percent TiO_2.[/] According to Magnusson (1950) reserves of "ore" are 33 million short tons.

[/] Most of foregoing from O. H. Ödman, personal communication, Nov. 12, 1951

Taberg deposit.—The best known Swedish deposit is at Taberg, about 7 miles south of Jönköping in Småland, southern Sweden. The deposit is a mountainous knob which rises about 300 feet above the surrounding countryside and is approximately 3,000 feet long by 1,500 feet wide. The deposit consists of olivine and magnetite with numerous fine-grained ilmenite inclusions (see p. 38), and can be concentrated to an iron concentrate of 50 percent Fe and 13 percent TiO_2; no ilmenite concentrate is obtainable. Reserve estimates are 165 million short tons of ore (Magnusson, 1950) with 6 percent TiO_2 and 32 percent Fe.

Ulvö Island deposits.—Deposits of titaniferous magnetite are numerous on the Ulvö Islands in the archipelago of Ångermanland. The best deposit, on South Ulvön, occurs as horizontal layers of ilmenite and magnetite within a large diabase dike. Because all the ilmenite occurs as fine-grained inclusions within the magnetite, the only concentrate recoverable by magnetic separation carries 18 percent TiO_2 and 53 percent Fe. The deposit contains 22 million short tons of titaniferous material with 8 percent TiO_2 and 25 percent Fe (Magnusson, 1950).

Australia

Australia, one of the world's largest producers of rutile, has produced from 1941 to 1950 inclusive 101,224 metric tons of rutile concentrates and 74,550 metric tons of ilmenite concentrates. Compilation of available reserve information on individual deposits, shows that in September 1949 beach and placer deposits contained 8,531,000 short tons of heavy minerals with 3,907,000 short tons of ilmenite and 2,093 short tons of rutile. Actual reserves are probably more, as data are lacking for many deposits. Total reserves, including the lode deposits, are 12,418,000 short tons of "ore" containing 4,536,000 short tons of TiO_2.

In 1950 the principal mining activity was along a hundred miles of east coast from North Stradbroke Island, Queensland, to Byron Bay, New South Wales; additional small production was reported from sands of Western Australia. In the past, other east coast beach deposits, and deposits on the Island of Tasmania were also worked. Ilmenite concentrates from the east coast deposits are not marketed because the presence of as much as 7 percent Cr_2O_3 makes them undesirable for the manufacture of pigments. Preliminary studies indicated, however, that some of the concentrates could be treated to yield a product with as little as 0.2 percent Cr_2O_3, although the recovery was low (Fisher, 1949, p. 5). The ilmenite from beach deposits in the western part of the country contains very little chromium, and could possibly be used for pigment manufacture.

The east coast beach and dune deposits of rutile, ilmenite, and zircon-bearing black sands are typical heavy mineral deposits, and are discussed in the general section of this report (see p. 49-50, 76-77, 94-97). The deposits of New South Wales and Queensland average 34 percent ilmenite, 24 percent rutile, 39 percent zircon, and 3 percent of other minerals (garnet, monazite, tourmaline, leucoxene, etc.). Along the southern part of the New South Wales coast the amount of rutile and zircon is slightly higher (zircon to rutile to ilmenite ratio is 5 to 3 to 2), whereas north of North Stradbroke Island, Queensland, the ilmenite increases to 60 or 70 percent, and the zircon to rutile to ilmenite ratio becomes 2 to 2 to 6 (Fisher, 1949, p. 8, Table 4).

New South Wales.--Mining for rutile and ilmenite began in New South Wales at Byron Bay in 1934 and by 1951 had expanded to include several deposits along 40 miles of beach immediately south of the Queensland border. Production from 1941 to 1950 inclusive was 62,035 metric tons of rutile concentrates, and 43,286 metric tons of ilmenite concentrates. The coastal deposits are listed in Table 11 and are the only titanium ore producers in the state.

Small deposits of titaniferous magnetite occur as irregular stratified bodies in tuffs and sandstones near the Williams and Karuh Rivers, about 50 to 75 miles northwest of Port Stevens. A reconnaissance survey of 26 of these deposits showed 2,263,000 short tons of "ore" containing 2 to 16 percent TiO_2, equivalent to 207,000 short tons of TiO_2; the largest single deposit contains only 100,000 short tons of TiO_2 (Imperial Mineral Resources Bureau, 1922, pt. 5, p. 27-28).

Table 11. Deposits of titanium-bearing sands in New South Wales

Location	Miles south of Qld. border	Description of deposit	Name of organization working the deposit	Dates	Results of investigation or mining	Reference
Fingal	2-3	Modern beaches	Porter and Derrick (Nat. Lead Co.).	1939-40	Produced about 6,000 tons of heavy mineral concentrates. No reserve estimates.	1 p. 12
		Buried deposits behind the coastal dune.	Bureau of Mineral Resources	July 1949	Testing proved 31,700 tons of heavy minerals in deposits which averaged 441 lbs. per cubic yard. No production.	1 p. 12
Cudgen Headland to	8	Modern beach, and buried material under first coastal dune.	Tweed Rutile Syndicate & Titanium Alloy Div. of Nat. Lead Co.	Up to the end of 1948	Total production was 80,000 tons of concentrates, containing 21,000 tons of rutile and 18,000 tons of ilmenite. No reserve estimates.	1 p. 12

Table 11. Deposits of titanium-bearing sands in New South Wales (Continued).

Location	Miles south of Qld. border	Description of deposit	Name of organization working the deposit	Dates	Results of investigation or mining	Reference
Norries Head	16	Dune complex between ocean and Cudgen Creek. 15 lines of dunes, up to 1,600 feet wide.	Alluvial Gold Ltd.	?	Testing by deep boring indicated the presence of "considerable reserves".	1 p. 12
Norries Head	16	Dune complex, 2,000 feet long by 900 feet wide.	Zinc Corp.Ltd.	?	Contains 150,000 tons of heavy minerals in deposits that average 300 lbs. of heavy minerals per cubic yard. Contains 40,000 tons of rutile.	1 p. 12

Table 11. Deposits of titanium-bearing sands in New South Wales (Continued).

Location	Miles south of Qld. border	Description of deposit	Name of organization working the deposit	Dates	Results of investigation or mining	Reference
Cudgera Headland to New Brighton	18 28	Modern beach, and dune complexes not exceeding 400 feet in width.	Metal Recoveries Pty., Ltd.	Up to the end of 1948	Mining from dune deposits at Crabbes Creek, and from beach deposits between Crabbes Creek and New Brighton, has yielded 6,500 tons of rutile and 4,800 tons of ilmenite. No reserve estimates.	1 p. 13
Byron Bay area						
Tallow Beach	37	Low-grade deposits under and behind coastal dune.	Zircon Rutile, Ltd.	Up to the end of 1948	Concentration by tables at Seven Mile Beach and by spirals at Tallow Beach. Final separation plant at Byron Bay. Total production of 16,000 tons of rutile and 11,000 tons of ilmenite.	1 p. 13
Seven Mile Beach	42	Modern beach.				

Table 11. Deposits of titanium-bearing sands in New South Wales (Continued).

Location	Miles south of Qld. border	Description of deposit	Name of organization working the deposit	Dates	Results of investigation or mining	Reference
Byron Bay area						
Seven Mile Beach	42	Fossil beach, 15 ft. above sea level. 1,200 ft. long, by 300 ft. wide. ½ mile inland from modern beach.	J. Scott Moffatt (Mineral Sands Co.)	?	Contains approximately 4,000 tons of heavy minerals with 33 percent rutile, 17 percent ilmenite, and 49 percent zircon. No production.	1 p. 13
Broadwater to Ballina to Evans Head	49 to 50	Modern beach	---	?	The average of samples from natural beach concentrates in this area contained 12 percent rutile, 10 percent ilmenite, and 71 percent zircon.	2 p. 430
	55	Modern beach, and dune complex extending up to 3 miles inland	Titanium Alloy Manuf. Co. (now Natl. Lead).	?	Boring in this area "proved considerable tonnages of low-grade material."	1 p. 13

Table 11. Deposits of titanium-bearing sands in New South Wales (Continued).

Location	Miles south of Qld. border	Description of deposit	Name of organization working the deposit	Dates	Results of investigation or mining	Reference
Yamba to Angourie	80 83	Modern beach	Porter and Derrick	1935-39	Produced about 17,000 tons of concentrate.	1 p. 14
Angourie	83	?	Bureau of Mineral Resources & Assoc. Minerals	1948	"testing ... proved disappointing."	1 p. 14
Wooli	120	?	Porter and Derrick	1935-39	Produced 11,000 tons of mixed concentrates.	1 p. 14
Woolgoolga	145	?	Coff's Harbor Minerals	1943-44	Produced 1,997 tons of mixed concentrates.	1 p. 14
One mile southeast of Swansea	300	Modern beach	J. Scott Moffatt	Before 1948	Deposit of limited extent only. Table concentrating plant installed.	1 p. 14

Table 11. Deposits of titanium-bearing sands in New South Wales (Continued).

Location	Miles south of Qld. border	Description of deposit	Name of organization working the deposit	Dates	Results of investigation or mining	Reference
Due east of Swansea	300	Modern beach deposit on arc-shaped bay.	---	--	Heavy minerals occur in a narrow deposit approximately 1 foot thick and 3 miles long.	1 p. 14
Terrigal	327	Beach(?)	---	--	Average composition of deposit is 40 percent ilmenite, 20 percent rutile, and 40 percent zircon.	1 p. 14

References:

1. Fisher, 1949.

2. Anon., 1939.

Queensland.—The production of rutile and ilmenite in Queensland did not begin until 1941, and from 1941 to 1950 totaled 39,189 metric tons of rutile concentrates and 31,106 metric tons of ilmenite concentrates. Although deposits of heavy mineral sands occur along 180 miles of coastline north of the New South Wales border, the sands are exploited only in the 50 miles from the border to North Stradbroke Island. The important deposits are shown in Table 12.

A minor occurrence of ilmenite and rutile in the Boyne River, 22 miles west-southwest of Kingaroy and 110 miles northwest of Brisbane, could yield approximately 7 tons of 60 to 70 percent TiO_2 concentrates (Cribb, 1943). Tailings from the Tableland Tin Company dredges at Mount Garnet (approximately 22° S., 144° E.) in northern Queensland contain ilmenite, and granites at Mount Perry (25°00'S., 151°25'E.) contain rutile in veins that are less than 8 inches wide (Fisher, 1949, p. 12).

Table 12. Deposits of titanium-bearing sands in Queensland

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
Fraser Island	178					
Hook Point	?	Modern beach deposits extending 2 miles north of Hook Point.	--	--	Contains 65 percent heavy minerals with 64 percent ilmenite, 16 percent rutile, and 17 percent zircon.	2 p. 225
Indian Head	?	Modern beach, 2½ miles long and 120 feet wide.	--	--	Contains 87,000 tons of heavy minerals with 56 percent ilmenite, 17 percent rutile, 25 percent zircon.	2 p. 225
Middle Rock	?	Narrow belt of frontal dunes, ¼ mile long, 40-50 feet wide.	--	--	Minor concentration of sand with 45-67 percent heavy minerals, in layers with maximum thickness of 2 feet.	2 p. 242

Table 12. Deposits of titanium-bearing sands in Queensland (Continued).

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
Fraser Island						
Waddy Point	?	Old beach terrace, 100-600 feet west of high-water mark.	--	--	Deposits up to $2\frac{1}{2}$ feet thick, contain 5-73 percent heavy minerals.	2 p. 242
Inskip Point	165	Modern beaches, extend for 8 miles south from Point, Maximum 2 feet thick.	--	--	Contains maximum of 87 percent heavy minerals, with 57-66 percent ilmenite, 10-24 percent rutile, and 15-27 percent zircon.	1 p. 9 2 p. 239
Double Island Point	155	Frontal dunes, black sands up to 4 feet thick, 60 feet wide, and 1 mile long.	--	--	Contains 16-69 percent heavy minerals, with 64-70 percent ilmenite, 11-20 percent rutile, and 12-22 percent zircon.	1 p. 9 2 p. 225

Table 12. Deposits of titanium-bearing sands in Queensland (Continued).

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
Paradise Caves, at Noosa Headland	128	Old high dunes, black sands 2-6 feet thick, for 3/4 mile south from cave.	—	—	Boreholes show a minimum of 6 feet of overburden. Averaged 47 percent heavy minerals with 63-68 percent ilmenite, 12-18 percent rutile, 13-19 percent zircon.	1 p. 9 2 p. 225
Moreton Island	70	Modern beaches; deposits maximum of 65 feet wide and 3 feet thick.	J. Scott Moffatt (holds leases)	1949	Heavy minerals are 56 percent ilmenite, 19 percent rutile, and 23 percent zircon.	1 p. 9 2 p. 243
North Stradbroke Island	54	Old beach deposits between foredune and the higher dunes inland.	Zinc Corp. Ltd.	?	Contains 600,000 tons of heavy minerals, in deposits averaging 8 percent heavy minerals, with 46 percent ilmenite, 26 percent rutile, and 26 percent zircon.	1 p. 10
One to 4 miles south of Point Lookout	54-51					

Table 12. Deposits of titanium-bearing sands in Queensland (Continued).

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
North Stradbroke (continued)						
"Main part of island"	?	High dunes, west of the swamp. Deposits are up to 100 feet deep.	Zirconium & Titanium Industries Pty., Ltd. (Zinc Corp., Subsidiary)	?	Scout boring indicates 200 million tons of sand with 2 percent heavies by volume, equivalent to 6 million tons of concentrate with 43 percent ilmenite, 27 percent rutile, and 28 percent zircon.	1 p. 10
13 to 17 miles south of Point Lookout	42-38	Coastal dunes, with black sand lenses up to 125 feet wide, and 1 foot, 4 inches to 4 feet 6 inches thick.	---	---	Contains 9 to 51 percent heavy minerals, with 34 percent rutile, 29 percent ilmenite, and 33 percent zircon	1 p. 10 2 p. 225

Table 12. Deposits of titanium-bearing sands in Queensland (Continued).

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
N. Stradbroke (continued)						
"Southeastern end of Is."	?	"Beach concentrates."	Titanium and Zirconium Industries Pty., Ltd.	Start in Aug. 1950	Production reached 35 tons of concentrates per week by end of 1950. Initial concentrates made by Humphrey spirals. Final rutile and zircon concentrates produced at Dunwich.	3 p. 144
"Northeastern end of Is."	?	"Sand dunes bordering the beach"				
The Spit, Southport	18	?	Mineral Deposits Syndicate	?	Mining for production of rutile and zircon concentrates	1 Table 3

Table 12. Deposits of titanium-bearing sands in Queensland (Continued)

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
Surfers Paradise to	14	Belt of low dunes as much as 1,200 feet wide; best deposits occur near beach.	Mineral Deposits Syndicate	During 1948	Mining for production of rutile and zircon concentrates.	1 p. 10 4 p. 121
Broad Beach to	13		Associated Minerals			
North Burleigh	11		Bureau of Mineral Resources	?	Boring showed 49,900 tons of heavy minerals. Deposits averaged 16 percent heavies with 36 percent rutile, 25 percent ilmenite, and 37 percent zircon.	1 p. 11

Table 12. Deposits of titanium-bearing sands in Queensland (Continued)

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
North Burleigh to Burleigh	11 to 8	Beach sands near the foredune, and buried deposits inland from and close to the foredune.	Mineral Deposits Syndicate	During 1948	Mining for production of ilmenite, rutile, and zircon concentrates.	1 p. 11 4 p. 126
			Bureau of Mineral Resources	1948	Reserves of 93,600 tons of heavy minerals, containing 34 percent rutile, 26 percent ilmenite, and 38 percent zircon.	1 Table 5 ~~Table 5~~
Tallebudgera Creek to Palm Beach to Currumbin Creek	7 6 5	Beach deposits near the foredune. Deposits are thicker in the northern part of the beach.	Bureau of Mineral Resources	1948	Drilling indicated sands contained 31,300 tons of heavies, in deposits averaging 15 percent heavies with 34 percent rutile, 23 percent ilmenite, and 40 percent zircon.	1 Table 5 4 p. 127

Table 12. Deposits of titanium-bearing sands in Queensland (Continued)

Location	Miles north of the NSW border	Description of deposits	Name of organization working the deposit	Dates	Result of investigations or mining	Reference
Vicinity of Flat Rock Creek	4	Beach deposits. Some seams near the fore-dune are up to 4 feet thick.	Bureau of Mineral Resources	1948	Contained 7,250 tons of heavies, in deposits averaging 13 percent heavies with 36 percent rutile and 23 percent ilmenite.	1 Table 5 4 p. 128
Tugun to Bilinga Bilinga to Coolangatta Creek	3 2 1	Beach deposits and buried sands under the foredune.	Rutile Sands Pty., Ltd.	1948	Contained 26,800 tons of heavies, in deposits averaging 18 percent heavies with 32 percent rutile, 25 percent ilmenite and 41 percent zircon.	1 Table 5 4 p. 129

References:

1. Fisher, 1949.
2. Connah, 1948.
3. Pearson, 1951.
4. Beasley, 1948.

Western Australia.--The first production of ilmenite concentrates in Western Australia was in 1949, and during 1949 and 1950 totaled 158 metric tons of concentrates from deposits at Cheyne Bay.

At Cheyne Bay, on the southern coast approximately 60 miles east-northeast of Albany, testing by the Western Australian Geological Survey on dredge claim number nine proved 45,000 short tons of heavy minerals, approximately one-third of which is in the dunes behind the beach. The heavy minerals on the beach average 68 percent combined ilmenite and leucoxene and 4 percent rutile, and in the dunes 73 percent ilmenite and leucoxene and 2 percent rutile (Fisher, 1949, p. 15).

Investigation by the Western Australian Geological Survey indicates that beach deposits on Doubtful Island Bay (34°15'S., 119°30' E.), 115 miles east-northeast of Albany contain 45,000 short tons of heavy minerals in sands which average 20 percent heavy minerals, and have a composition like those at Cheyne Bay (Fisher, 1949, p. 16).

Ancient beach deposits at Wonnerup, on the west coast, 5 miles east of Busselton (33°38'E., 115°21' E.) contain 400,000 tons of heavy minerals with 87 percent ilmenite, 2 percent rutile, and 6.5 percent zircon (Fisher, 1949, p. 15).

At Gabanintha (25°24'S., 115°43'E.), 21 miles southeast of Nannine, a two-mile long, low-ridge of titanium-bearing magnetite and hematite contains according to a reconnaissance survey 1,680,000 short tons of "ore" with 12.7 percent TiO_2 and 52.1 percent Fe (Imperial Mineral Resources Bureau, 1922, pt. 5, p. 52).

Northern Territory.—In the Northern Territory heavy mineral deposits occur on beaches near Record Point and Reef Point in Port Essington, 120 miles east of Port Darwin. Beaches on Bowen Bay, near Cape Fourcrey, Bathhurst Island, 70 miles northwest of Port Darwin, contain 40 percent ilmenite, 31 percent rutile, and 27 percent zircon (Fisher, 1949, p. 16).

South Australia.—In South Australia residual deposits of rutile occur in the vicinity of Blumberg, Williamstown, and Mt. Crawford (hundreds of Barossa, Para Wirra, and Talunga) approximately 25 miles northeast of Adelaide (Anon., 1917, p. 85-86; 1938b, p. 78; Fisher, 1949, p. 15; Watson and Taber, 1913, p. 35-37). Near Mount Jagged minor deposits average 5 percent TiO_2, and at Mount Painter small quantities of rutile [redacted] and sphene occur as massive segregations within granitic rocks. At Radium Hill the titaniferous iron "ore" forms the bulk of the "ore shoots," and contains 60.7 percent TiO_2, 28.6 percent Fe, and 0.8 percent V_2O_5 (Alderman, 1925).

Tasmania.—Tasmania contains numerous alluvial deposits of ilmenite and rutile, most of which are of minor importance (see Anon, 1928). One deposit at Naracoopa, on King Island, produced 550 metric tons of ilmenite concentrates in 1933. A terrace here extends along the beach northward from the mouth of the Fraser River, and contains 45,000 metric tons of ilmenite, abundant cassiterite, and minor amounts of gold, monazite, zircon, and molybdenite. The magnetic fraction of heavy minerals from this deposit contains 12 to 45 percent TiO_2 (Fisher, 1949, p. 14; Anon., 1928).

Victoria.--Low-grade deposits in the valley of the Acheron River, Victoria, 45 miles east-northeast of Melbourne, average only 1.5 percent heavy minerals, yet might be commercially developed as the ground is suitable for dredging and contains 198,000 short tons of heavy concentrates. Concentrates contained 84.5 percent ilmenite with 52 to 55 percent TiO_2 and less than 0.03 percent Cr_2O_3 (Fisher, 1949, p. 14).

At Cape Everard (37°47'S., 149°15'E.) a low-grade beach deposit contains 2,200 short tons of heavy minerals with 62 percent ilmenite and 11 percent rutile (Fisher, 1949, p. 14).

New Zealand

The only sources of titanium in New Zealand are black sands of the Taranaki coast on North Island, and black sands at various points on South Island. North Island contains approximately 247 million short tons of iron sand with about 4 million short tons of TiO_2. None of the sand deposits has been mined.

On North Island the iron sands extend 330 miles from Wanganui in the south to Kaopara Heads in the north, with the best deposits at Patea, New Plymouth, Waitara, and Wanganui. The Patea deposits consist of terrace, beach, and dune deposits with 14,280,000 to 50,400,000 short tons of iron sands (Hutton, 1940, p. 193; Mason, 1945, p. 228) equivalent to approximately 1,400,000 short tons of TiO_2. At Fitzroy, New Plymouth, near the mouth of the Waiwakaiho River, beach and dune deposits contain 1,250,000 short tons of sand of which only 560,000 short tons is titanomagnetite (Hutton, 1945, p. 293, 297). Because the titanomagnetite contains approximately 8.75 percent TiO_2, the total TiO_2 in the deposit is probably about 47,400 short tons. By using similar calculations the deposit at Waitara which contains 35,245,000 short tons of sand and 8,610,000 short tons of titanomagnetite (Beck, 1947, p. 312) probably carries about 730,000 short tons of TiO_2, and the deposit at Wanganui which contains 160,535,000 short tons of sand with 25,544,000 short tons of titanomagnetite (Fleming, 1946, Table 2) carries approximately 2,173,000 short tons of TiO_2. Other large deposits occur at Makau, Awakino, Manakau Heads, and Muriwai.

Neither pure magnetite nor ilmenite concentrates can be obtained from these sands as the titanium is either within the lattice of the titanian magnetite, or within the lattice of hematite included within the magnetite (Hutton, 1945). Analyses, probably of concentrates, show 8 to 10 percent TiO_2, 53 to 60 percent Fe, and 0.3 to 0.5 percent V_2O_5 (Mason, 1945, p. 228).

South Island contains considerable quantities of iron sands that are amenable to concentration since they contain separate grains of ilmenite and magnetite (Mason, 1945, p. 228). Most of the sands do not occur in commercial concentrations. Reserve information is lacking.

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