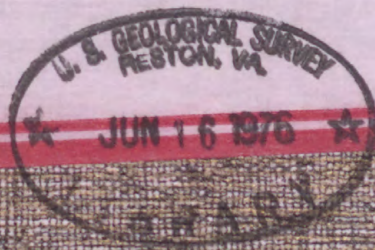
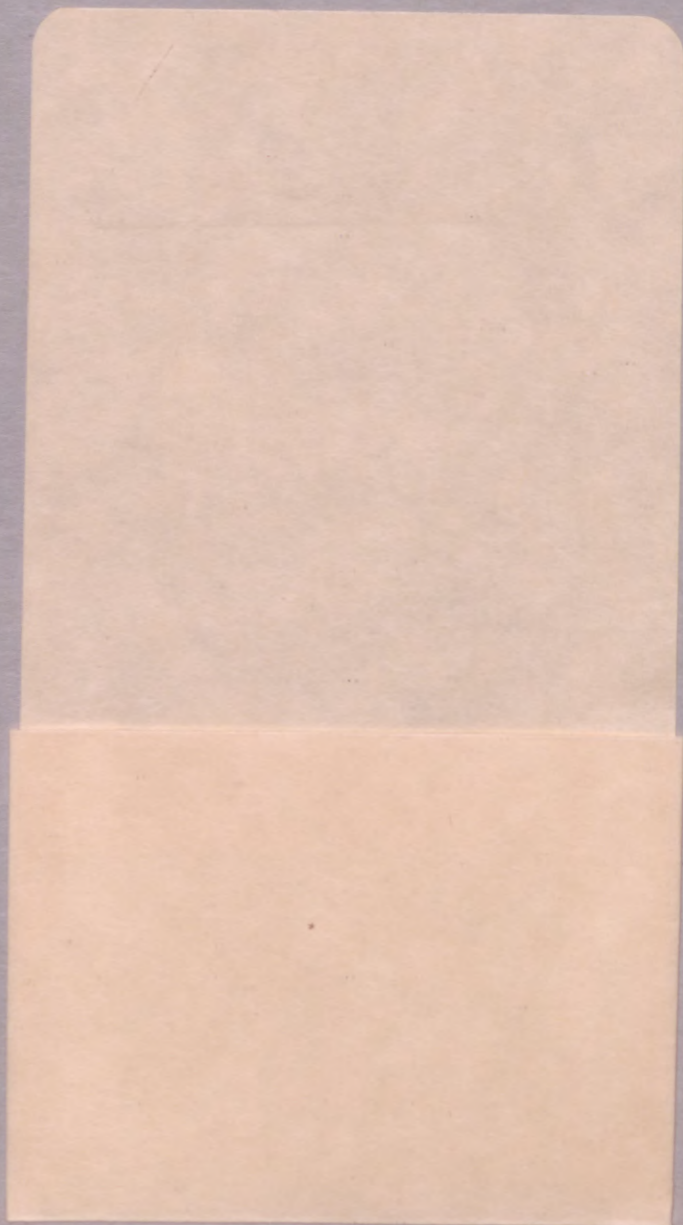


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Titanium deposits in alkalic igneous rocks

By Norman Herz

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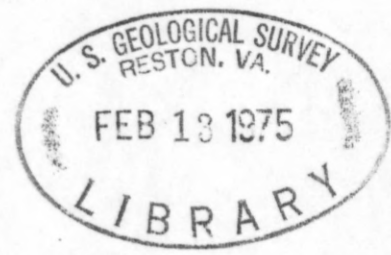
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Titanium deposits in alkalic igneous rocks

By Norman Herz 1923-
U. S. Geological Survey
Department of Geology
University of Georgia
Athens, Georgia 30601

U. S. Geological Survey
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Titanium deposits in alkalic igneous rocks

By Norman Herz

Abstract

Many types of alkalic rocks are enriched in TiO_2 relative to the average for the crust. Silicate minerals in these rocks may have high TiO_2 contents, but the oxides ilmenite, rutile, brookite, and perovskite are ^{also} characteristic primary phases. These tend to be higher in niobium than are the same minerals from other rock suites.

At Tapira, Brazil, titanium minerals in a carbonatite complex comprise tens of millions of tons contained TiO_2 . Anatase (as "leucoxene") is present in laterite lying over parent rocks containing perovskite, ilmenite, and rutile. ^{At Magnet Cove, Arkansas, and the Kola Peninsula, U.S.S.R.,} In other discovered localities of alkalic rocks, production of titanium minerals is at best economically marginal.

Introduction

Titanium is enriched in many alkalic rocks several fold beyond the normal concentration in igneous rocks (about .7-1.0 percent as TiO_2). Nockolds (1954) lists the following average TiO_2 contents of alkalic rock types:

Alkali pyroxenite	3.31%	TiO_2
Nepheline monzonite	2.49	
Essexite	2.81	
Ijolite	1.41	
Average subsilicic igneous rock (721 analyses)	1.9%	

Several silicate minerals characteristic of alkalic rocks are high in TiO_2 . Except for sphene, melanite garnets from alkalic rocks contain the highest amount of TiO_2 found in silicate minerals: melanite from ijolite in Iron Hill, Colo., has 5.08 percent, and elsewhere up to 17 percent (Deer and others, 1962, p. 91). Kaersutite, an amphibole with 5 to 10 percent TiO_2 , and titanaugite, a pyroxene with 3 to 6 percent TiO_2 , are common in but not restricted to alkalic rocks.

The principal titanium minerals found in alkalic rocks are ilmenite, titano-magnetite, sphene, perovskite, rutile, anatase, and brookite, and these commonly contain significant amounts of niobium (Nb) and rare earths (Fleischer and others, 1952).

Most titanium oxide minerals form late in the crystallization history of alkalic complexes. Chemical activities of Si, Al, and Fe, and the partial pressure of oxygen are especially important in determining whether Ti will enter silicate minerals or form independent oxides. (Philpotts, 1967). Some dikes consisting of iron-titanium oxides and apatite in alkalic rocks has been ascribed to the formation of immiscible melts (Philpotts, 1967). Based on extrapolation of experimental data, Philpotts deduced that liquids of magnetite-ilmenite-apatite composition can form immiscible melts in silicate magmas that are enriched in Na, have a dioritic composition, and are undergoing strong differentiation. Some titanium ore bodies found in alkalic rocks of the Kola Peninsula and Brazil may have formed by such a process.

Description of individual localities

The only attempted production of any significance of titanium from deposits in alkalic rocks has been at Magnet Cove, Ark.; the Kola Peninsula, U.S.S.R.; and Tapira, Minas Gerais, Brazil. These will be discussed below as examples of titanium deposits in alkalic rocks. Another potential domestic resource of perovskite and ilmenite has been described in mafic alkalic rocks and carbonatite from Iron Hill, Colo. (Larsen, 1942).

Magnet Cove, Ark.

The alkalic complex of Magnet Cove, Ark., consists of a variety of feldspathoid-rich rocks that have intruded sediments of Paleozoic age (Erickson and Blade, 1963). The complex has been dated as early Late Cretaceous, 95 ± 5 m.y. (Zartman and Marvin, 1965) as in some alkalic rocks in Brazil.

The Magnet Cove rutile deposit consists largely of phonolite that has been intruded, brecciated, and hydrothermally altered by a number of veins of different types. Rutile is contained in feldspar-carbonate-rutile veins and vein masses which range from "several inches to tens of feet" in thickness. About 15 to 20 percent of the TiO_2 in the veins is present as "leucoxene" (Fryklund and Holbrook, 1950). The average grade of the deposit is 3 percent rutile. Most of the exposed material has been weathered to a clay-rich, highly friable material; information from drill cores shows that weathering has penetrated to a depth of at least 45 m.

The estimated reserves of rutile-bearing material at Magnet Cove is 7.75 million tons containing approximately 100,000 tons of rutile concentrate containing 95 percent TiO_2 (Toewe and others, 1971). Before the deposit can be economically exploited, however, several serious problems must be solved: (1) the best present beneficiation techniques result in a recovery of under 60 percent of the contained rutile and (2) the rutile averages 2.2 percent Nb, 1.8 percent Fe, and 0.6 percent V (unpublished data and Erickson and Blade, 1963, p. 80-81). Rutile of this composition cannot be used for welding rod coatings or for the chloride process of pigment and metal manufacture.

Kola Peninsula, U.S.S.R.

Important titanium deposits are found in alkalic rocks of the extreme northwestern part of the Soviet Union, in the Kola Peninsula, and the Karelia Finnish S.S.R. Specific information on grade and tonnages is not available, although general descriptions of the geology of the mining areas do exist (Malyshev, 1957, p. 204-207; Vlasov and others, 1959; Yudin and Zak, 1970). The area is part of the Precambrian Baltic Shield and consists largely of Archean gneisses, granites, migmatites, and granulites, and Proterozoic metasedimentary and volcanic formations, gabbro-anorthosites, basalts, granites, and alkalic gabbros and granites. These are overlain by upper Precambrian and Lower Cambrian platform sediments. Paleozoic alkalic rocks, including ultrabasic-alkalic rocks 340-590 m.y. old and nepheline syenites about 290 m.y. old, intrude the Archean and Proterozoic rocks.

The ultrabasic-alkaline group of plutons consists of an earlier phase of olivinite, pyroxenite, and nepheline pyroxenite and a later group of ijolite and related rocks. The earlier ultrabasic rocks include large stocklike bodies of late magmatic perovskite-titanomagnetite ores that are enriched in rare elements (Yudin and Zak, 1970). In the largest deposit, Afrikanda, a pipelike ore body can be traced to a depth of more than 400 m. These ores are characterized by high amounts of TiO_2 , 8.5-18.0 percent, and total Fe, 11-18 percent. The rocks of this phase are generally high in major elements Ca, Mg, Na, Fe, and Ti, and in minor elements P, C, Sr, and Ba; they are deficient in Si and Al. Younger alkalic plutons caused a contact metasomatism-metamorphism of some of the perovskite-titanomagnetite bodies which produced high quality magnetite ores in places.

The younger group of alkalic intrusives consists of nepheline syenite of Hercynian age typified by the Lovozero and Khibiny massifs, and forms larger bodies than the earlier ultrabasic-alkalic rocks.

The Khibiny pluton is over 800 km² and is made up of seven distinct phases listed in order of decreasing age (Turner and Verhoogen, 1960, p. 393):

1. Syenites and nepheline syenites which have fenitized adjacent Archean gneisses.
2. Coarse aegerine-nepheline syenite, injected as a peripheral ring dike.
3. Trachytoid aegirine-nepheline syenite, forming an imperfect ring within 2.
4. Poikilitic micaceous nepheline syenite forming an imperfect ring and consisting of alkali feldspar, nepheline, mica, aegerine, and astrophyllite.
5. A massive cone sheet of nepheline-rich ijolite.
6. Foyaite (feldspathic rock) making up the central core of the pluton.
7. Dikes of leucocratic and melanocratic alkalic rocks.

The pluton is characterized by concentration of Na, K, Al, P, F, Ti, Zr, Nb, Sr, and rare earths, especially the Ce group, and is deficient in Si, Mg, Cr, V, Co, and Ni. Segregations of ore minerals have formed in the complex as distinct rock types, including one body that is 2.4 km long and 160 m thick and made up of 45-65 percent apatite, nepheline, aegerine, sphene, and titanomagnetite. Zones that are enriched in sphene are 5 to 30 m thick with an average TiO₂ content of 8-11 percent. Apatite and nepheline are presently mined in large quantities, and Yudin and Zak (1970, p. 871) suggest that large amounts of titanomagnetite concentrate with 13.5 percent TiO₂, 0.65 percent V₂O₅, and 42 percent total Fe, and sphene concentrate with 26 percent

The nearby Lovozero massif is similar in age and overall geology but different in titanium mineralogy. Niobium-rich perovskite (loparite) is in nepheline-rich syenite and trachytoid nepheline syenite and is an ore mineral of niobium (Vlasov and others, 1959; Parker and Adams, 1973).

Tapira, Minas Gerais, Brazil

Belts of alkalic rocks and widespread tholeiitic basalt are found in the southern part of Brazil (Herz, 1966). The basalt plateau of the Paraná basin is the largest of its kind, covering 1,200,000 km² with a maximum recorded thickness of 1,530 m. The peak of activity responsible for this volcanism occurred about 125 m.y. ago and the whole span of activity is 119-147 m.y. (Amaral and others, 1966).

The alkalic volcanism took place around the margin of the basalt, with most of the known occurrences to its east, intruding the crystalline Precambrian basement of the Brazilian Shield, Ages obtained

on alkalic plutons suggest two distinct times of volcanism, one early Cretaceous (122-133 m.y.) and the other late Cretaceous-early Tertiary (51-82 m.y.) (Amaral and others, 1967). Most of the volcanism, however, coincides with the younger ages, and no genetic relationship is immediately evident between the alkalic rocks and the tholeiitic basalt flows.

The Brazilian alkalic rocks are mineralogically highly variable. They include rocks of four general types: (1) nonfeldspathic rocks including ijolites and jacupirangites which consist largely of pyroxenes and nepheline. Titaniferous magnetite, apatite, and sphene are locally abundant as at Jacupiranga; (2) feldspathic rocks including nepheline syenites, tingvaites, and phonolites that consist largely of alkali feldspars, nepheline, and Na-rich pyroxenes. Sphene, apatite, and rare earth minerals are locally abundant, as at Poços de Caldas; (3) carbonatites composed dominantly of carbonate minerals (calcite and dolomite), with accessory apatite, pyrochlore, perovskite, rutile, and ilmenite. Examples include Jacupiranga, Araxá, and Tapira; and (4) feldspathic rocks (fenites) formed locally in situ around many alkalic complexes by alkali metasomatism of country rock.

The Tapira complex was discovered in 1955, during a reconnaissance study for manganese by B. P. Alves (1960). He noted strong similarities between that complex and the one just to the north at Araxa. Both are primarily carbonatites and have "explosive" intrusive characteristics such as extensive ultramylonite and breccia zones in the contact area with Proterozoic ^{OK} sericite schists and quartz-sericite schists. The intrusion itself is in the form of a ring about 6 km in diameter. Weathering of all the rocks of the complex has been intense, so few rock types can be identified with certainty. Among the types that can be identified are bostonite, which forms part of a ring in the southern part of the complex, volcanic breccia, which forms much of a ring to the southwest, and carbonatite, which is abundant throughout the central part of the complex. Large masses of other types occur including an apatite rock with abundant perovskite and subordinate ^{sphene} titanite and magnetite which forms parts of two rings, an inner one on the western side, 2,000 m long and up to 300 m thick, and another similar body on the eastern side.

The Brazilian Ministry of Mines and Energy (C.P.R.M., 1972) has extensively explored the area and estimated almost 132 million tons of ^{ore} TiO_2 reserves (measured, indicated, and inferred) averaging 21.6 percent TiO_2 . The greatest concentration of titanium minerals at Tapira is in an area about 3 by 4 km on which a lateritic cover about 100 m thick has formed. The primary titanium minerals of this deposit are perovskite, ilmenite, magnetite, and rarely rutile, but the bulk of the reserves are anatase and "leucoxene," the weathering products of the primary minerals. At least 60 percent of the total TiO_2 measured in laterite samples is present as anatase.

Perovskite occurs in veins and disseminations in the country rock; it and its weathered products form up to 5 percent of the laterite. Magnetite and ilmenite also occur in veins and in the alkalic country rock; they and their weathered products comprise from 20 to 70 percent of some laterite.

The Tapira deposit formed mainly as a result of two processes: first, development of a Ti-rich segregation in the carbonatite plug, presumably as an immiscible liquid in the melt, and second, tropical weathering which enriched the tenor of Ti in the protore minerals at the expense of Ca and Fe and perhaps also Nb. Fresh rutile from Tapira has 0.5 percent Nb_2O_5 as well as 3.5 to 6.8 percent Fe (Alves, 1960, p. 16) which puts fresh rutile from Tapira under the same economic handicap as rutile from Magnet Cove, Ark. The composition of fresh perovskite is not known but is likely to be high in niobium also.

Outlook

Titanium is enriched in many alkalic rocks. However, in many alkalic complexes, much of the Ti has gone into silicates, especially garnet and clinopyroxene; in others, where Ti does form primary minerals like perovskite and rutile, the accessory elements Nb and Fe have made the minerals unusable for chloride-process manufacture of pigment and Ti metal. Titanium at present can be considered a resource in alkalic rocks in two circumstances: (1) where tropical weathering has produced an economic titanium product by leaching out the undesirable elements, as in Tapira and elsewhere in Brazil; and (2) where Ti can be obtained as a byproduct, as in mining for niobium and for phosphate, rare earths, and aluminum in the Kola Peninsula.

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