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PROSPECTING FOR AND MINING MONAZITE SAND.

NORTH CAROLINA GEOLOGICAL SURVEY.

J. A. HOLMES, STATE GEOLOGIST.

BULLETIN No. 9.

MONAZITE, AND MONAZITE DEPOSITS IN NORTH CAROLINA.

BY

HENRY B. C. NITZE,

ASSISTANT GEOLOGIST.

WINSTON:
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RALEIGH, N. C., June 1st, 1895.

To His Excellency, HON. ELIAS CARR,
Governor of North Carolina.

SIR:—I have the honor to submit for publication as Bulletin 9 of the Geological Survey, a preliminary report on Monazite and Monazite Deposits in North Carolina, by Mr. Henry B. C. Nitze. The publication of this bulletin will serve as an answer to the many enquiries received by the Survey for information on this subject.

Yours obediently,
J. A. HOLMES,
State Geologist.

MONAZITE.

By H. B. C. Nitze.

BRIEF DESCRIPTION OF THE MINERAL.

Monazite is essentially an anhydrous phosphate of the rare earths cerium, lanthanum, and didymium (Ce, La, Di), PO_4. It also contains, almost invariably, small percentages of thoria (ThO_2) and silicic acid (SiO_2), which may be present in combination as thorite or orangite ($ThSiO_4$), or the thoria may exist as the phosphate, either in combination with the cerium, etc., or as an isomorphous mixture. Other occasional accessory constituents are the yttrium and erbium earths, zirconia, alumina, magnesia, lime, iron oxides (Fe_2O_3 and FeO), manganous oxide, tin and lead oxides, fluorine, titanic acid, and water, usually in fractional percentages.

It is a subtranslucent to subtransparent mineral, light yellow, reddish yellow, brownish, or greenish in color, and has a resinous luster. It is brittle with conchoidal to uneven fracture. Its hardness is from 5 to 5.5, and its specific gravity from 4.9 to 5.3. It crystallizes in the monoclinic system.

HISTORICAL SKETCH AND NOMENCLATURE.

The following names have been applied to the mineral by independent discoverers and workers: Turnerite, monazite, mengite, edwardsite, eremite, cryptolite, monazitoid, phosphocerite, urdite, and kårarfveite. It was not long, however, before the identity of these newly described mineral species was recognized, and at the present time the general name in use is monazite.

The name "turnerite" was given in 1823 by A. Levy[1] in honor of the English chemist, E. H. Turner, in whose collection the first specimens were found. The locality of these was Dauphiny. They had been classed as sphene, on account of their color, accompani-

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[1] The Annals of Philosophy, London, 1823, vol. 5, p. 241.

ment (adularia and lamellary crichtonite), and the locality; but Levy found their hardness to be less than that of sphene, and a good cleavage in one direction. He gives as the primary crystallographic form an oblique rhombic prism with differment dimensions from that of sphene. G. vom Rath[1] has also called attention to the fact that titanite (sphene) may be confounded with tnnerite from general resemblance. In the fifth edition of his Mineralogy (American edition, Boston, 1844) Phillips says that monazite is occasionally known among mineralogists under the name of "pictite," which is one of the early names for titanite, with which it was doubtless confounded.

The date 1823, then, may be taken as that of the earliest recognition of a new mineral species which was later shown to be identical with monazite. Thus, in 1866, J. D. Dana[2] demonstrated the identity between turnerite and monazite by similarity of crystal form and physical properties. No chemical examination of turnerite had yet been made at that time. In 1870 this was substantiated by G. vom Rath,[3] and although he recognized the priority of Levy's name, turnerite, he did not feel justified in abandoning the name monazite, inasmuch as the latter belonged to a chemically as well as a crystallographically known mineral, while the composition of turnerite was not yet so well known. In 1873 Des Cloizeaux,[4] by the orientation of the optical axes, and Pisani,[4] by the chemical determination of P_2O_5 and Ce_2O_3, concluded that monazite and turnerite were the same species. In 1876 Trechmann[5] showed that the optical properties of turnerite and monazite were the same. In 1826 Menge discovered some crystals in the Ilmen mountains, near Miask, Siberia, which he held for a variety of zircon. Fiedler[6] gives the more exact locality of these specimens as being not in the Ilmen mountains proper, but in their southern extension, in the so-called Tscheremtchanka. The first scientific description of these was given by Breithaupt[7] in 1829. He gave it the name, "monazite" (monazit, monacite), from the Greek,

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[1] Poggendorff, Annalen, 1864, vol. 122, p. 407.
[2] Am. Jour. Sci. vol. 42, 1866, p. 420.
[3] Poggendorff, Annalen, Erg.- Bd. 5, 1871: p. 413; Sitzungsber. Bayer. Akad. Wiss., 1870, vol. 2, p. 271.
[4] Zeitscher. Deutscher. geol. Gesell., Berlin, vol. 25, 1873, p. 568.
[5] Neues Jahrbuch, 1876, p. 593.
[6] Poggendorff, Annalen, 1832, vol. 25, p. 332.
[7] Schweigger-Seidel, Journal der Chemie u. Physik, 1829, vol. 55, part 3, p. 301

meaning "to be solitary." In 1831 H. J. Brooke[1], in describing specimens from Menge's locality in the Urals, gave the name mengite, in honor of the discoverer.

Prof. C. U. Shepard[2] in 1837 gave a description of "edwardsite," a new mineral from Norwich, Connecticut, which he named in honor of the governor of the State. Later in the year[3] he described another new mineral from Watertown, Connecticut, under the name of "eremite," after the Greek, meaning "solitude," but he did not then recognize its identity with edwardsite. Prof. J. D. Dana published in 1838 his crystallographic measurements of eremite, which agree with those of monazite.[4] In 1840 Gustav Rose[5] proved the identity, crystallographically and physically, of edwardsite and monazite. And in the second edition of his Mineralogy (1844) Shepard places both edwardsite and eremite under the head of monazite.

In 1842 Rose[6] gave a detailed description of the Russian monazite.

Woehler,[7] in 1846, discovered some small needle-like crystals invisibly included in the apatite of Arendal, Norway. They were of a pale-yellow color, specific gravity approximately 4.6, and, according to analysis, were composed of phosphate of cerium, but contained no thoria, and in this he distinguished the mineral from monazite, calling it "cryptolite," from the Greek, meaning "concealed." Although the forms of these crystals are different in appearance from that of ordinary monazite, Mallard,[8] in 1887, by careful goniometric measurements, established the identity of the two minerals.

Hermann,[9] in 1847, applied the name "monazitoid" to certain brown colored bent and broken crystals, of the specific gravity 5.28, from Lake Ilmen, near Miask, which contain less phosphoric acid (only 18.7) than monazite, besides some tantalic acid (3.75 to 6.27 per cent). Kokscharow[10] believed that monazitoid was simply impure

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[1] Poggendorff, Annalen, 1831, vol. 23, p. 362; Philos. Mag. and Annals, vol. 10, p. 187.
[2] Am. Jour. Sci. (1), 1837, vol. 32, p. 162; Poggendorff, Annalen, 1838, vol. 43, p. 148.
[3] Am. Jour. Sci. (1), 1837, vol. 32, p. 341.
[4] Am. Jour. Sci. (1), vol. 33, 1838, p. 70.
[5] Poggendorff, Annalen, 1840, vol. 49, p. 223.
[6] Reise nach dem Ural und Altai, vol. 2, p. 87 and 482, Berlin, 1842.
[7] Poggendorff, Annalen, 1846, vol. 67, p. 424.
[8] Bull. Soc. Min., 1887, vol. 10, p. 236.
[9] Jour. prakt. Chemie, vol. 40, 1847, p. 21; Annuaire de Chemie, 1848, pp. 146.
[10] Materialien zur Mineralogie Russlands, vol. 4, 1862, pp. 7-34.

monazite, the tantalic acid having been derived from columbite and samarskite, with which the crystals are intergrown.

Blomstrand[1] analyzed specimens from probably the same locality as Hermann's monazitoid, but found no tantalic acid.

In 1850 Watts[2] described a new mineral occurring in the cobalt ore of Johannisberg, Sweden, which he showed to be a phosphate of cerium (including lanthanum and didymium). He proposed the name "phospho-cerite." Its physical and chemical characters identify it beyond doubt with monazite.

Forbes and Dahll,[3] in 1855, described a mineral occurring in the granite of Urda, near Nöterö, Norway, under the name of "urdite," which E. Zschau[4] determined to be monazite.

F. Radominski,[5] in 1874, found a mineral inclosed in albite at Kårarfvet, near Falun, Sweden, which resembled monazite, but on analysis was found to contain a notable quantity of fluorine (4.35 per cent), and for that reason he proposed to class it as a separate species under the name "kårarfveite." Blomstrand[6] made an analysis of specimens from the same locality, and found only 0.33 per cent. fluorine. He concluded that it was but an impure form of monazite.

CRYSTALLOGRAPHY.

MORPHOLOGICAL.

The primary form of monazite and its equivalents, turnerite, edwardsite, and mengite, was early stated to be the oblique rhombic prism of the monoclinic system. The crystallographic studies of the mineral by Koksharow, Des Cloizeaux, Websky, Dana, Vom Rath, and others have shown the occurrence of the following forms:

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[1] Zeitschr. für Kryst., vol. 20, 1892, p. 367, Lunds Universitets Årskrift, 1888 (24).

[2] Quart. Jour. Chem. Soc. London, 1850, vol. 2, p. 131.

[3] Nyt Mag. Naturvidenskaberne, vol. 8, 1855, p. 227; Am. Jour. Sci., vol. 22, 1856, p. 262

[4] Allg. deutsche naturh. Zeitung, Dresden, 1857, p. 208; Am. Jour. Sci,, II, vol. 25, 1858 p. 410.

[5] Compt. Rend., 1874, vol. 78, p. 764.

[6] Zeitsch. für Kryst. vol. 19, 1891, p. 109; Geol. Föreningens Förhandl. Stockholm, 1889, vol. 2, p. 174.

Observed forms of monazite.

Pinacoids.	Prisms.	Hemi-domes.	Hemi-pyramids.
oP	∞P	$+ P\bar{\infty}$	$+ P$
$\infty P\bar{\infty}$	$\infty P\bar{2}$	$- P\bar{\infty}$	$- P$
$\infty P\grave{\infty}$	$\infty P\bar{3}$	$-7P\bar{\infty}$	$+\frac{1}{2}P$
	$\infty P\grave{2}$	$-\frac{3}{5}P\infty$	$-\frac{1}{2}P$
		$P\grave{\infty}$	$+ P\bar{2}$
		$2P\grave{\infty}$	$+2P\bar{2}$
		$\frac{1}{2}P\grave{\infty}$	$+3P\bar{3}$
			$+2P\grave{2}$
			$-2P\grave{2}$

Of these, the more common forms are the ortho- and clino-pinacoids and domes, the unit prism, and the unit pyramids. The basal pinacoid is rare, having been observed only on crystals from the Urals[1] and from Alexander County, N. C.[2]

Among the rarer forms are: $-\frac{3}{5}P\bar{\infty}$, found by Trechmann on turnerite from the Binnenthal, Switzerland; $-7P\bar{\infty}$ and $-\frac{1}{2}P$, found by Miers in Cornwall; and $\frac{1}{2}P\grave{\infty}$, on crystals from Nil St. Vincent, Belgium, and western Siberia.

The usual crystal habit is tabular, parallel to $\infty P\bar{\infty}$; also short columnar, and sometimes elongated parallel to ∞P. Cryptolite occurs always in very small crystals, elongated parallel to ∞P. The crystals are usually well developed and free from distortion. They vary in size from the microscopic needles of cryptolite, which have a thickness of .004 to .016 mm. (0.00015 to 0.00062 inch), to the abnormally large monazite crystals that have been found in Amelia County, Va., 5 inches in length. The more general variation lies between one twentieth and 1 inch. Irregular masses of monazite, devoid of crystal planes, as large as 15 to 20 pounds, have been found in Amelia County, Va., and in rounded masses up to 12¼ pounds at the Villeneuve mica mine in Ottawa County, Quebec.

Twins are not common. The twinning plane is parallel to $\infty P\bar{\infty}$; also to oP (Zirkel, Vol. I, p. 432.) Twins are sometimes cruciform.

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[1] N. von Kokscharow, Materialien zur Mineralogie Russlands, vol. 4, 1862, pp. 7-34.
[2] G. von Rath, Zeitschr. für Kryst., vol. 13, 1888, p. 596.

The axial ratio has been determined on specimens from different localities, as follows:

Axial ratios of monazite from various localities.

$\breve{a}$	$\bar{b}$	$\overset{\mid}{c}$	β(oP∧∞P$\bar{\infty}$)		Localities.	Determined by—
			°	′		
0.9742	1	0.9227	103	46	Watertown, Conn. (eremite).......	J. D. Dana.
0.9705	1	0.9221	103	46	Ural Mountains. Sanarka............	Koksharow.
0.9658	1	0.9217	103	28	Laacher See (turnerite)................	Vom Rath.
0.9609	1	0.9081	103	26½	Hiddenite mine, N. C..................	Do.
0.9693	1	0.9255	103	40	Milhollands Mill, N. C	E. S. Dana.
0.9735	1	0.9254	103	37	Schüttenhofen, Bohemia.............	Scharizer.
0.9718	1	0.9238	103	·42	Nil St. Vincent	Franck.

Some of the principal angular measurements are:

Angular measurements of monazite.

∞P$\bar{\infty}$∧∞P			oP∧P$\bar{\infty}$			∞P$\bar{\infty}$∧oP			∞P$\grave{\infty}$∧P			∞P$\bar{\infty}$∧P$\bar{\infty}$			Localities.	Measured by—
°	′	″	°	′	″	°	′	″	°	′	″	°	′	″		
43	25	0				76	14	0				39	20	0	Watertown, Conn., (eremite).	J. D. Dana.
43	18	30	37	11	0	76	14	0	59	37	0	39	03	0	Ural Mountains, Sanarka.	Koksharow.
43	12	30	37	12	30	76	32	0	59	42	30	39	20	30	Laacher See (turnerite).	Vom Rath.
43	17	10	37	07	40	76	20	0	59	40	0	39	12	30	Milhollands Mill, N. C.	E. S. Dana.
43	25	0	37	03	0	76	23	0	59	36	0	39	20	0	Schüttenhofen, Bohemia.	Scharizer.

PHYSICAL CRYSTALLOGRAPHY.

The cleavage is most perfectly developed parallel to the basal pinacoid (oP.); it is also distinct as a rule parallel to ∞ P$\bar{\infty}$; sometimes parallel to ∞P$\grave{\infty}$, imperfect; parallel to —P$\bar{\infty}$ (noticed by Vom Rath on turnerite from Laacher See[1]). Parting is sometimes developed parallel to oP and ∞ P. It is brittle with a conchoidal to uneven fracture. The hardness is 5 to 5.5. The specific gravity varies from 4.64 to 5.3. The luster is resinous to waxy. The crystal faces are splendent in fresh, pure specimens; dull in weathered, impure specimens. The color is honey yellow, yellowish brown, amber brown, reddish brown, brown or greenish yellow. Derby[2] describes specimens of *lusterless*, *whitish* grains in muscovite granite of São Paulo, Brazil, which he proved to be cerium phosphate.

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[1] Poggendorff, Annalen, 1871, Erg.-Bd. 5, p. 418; Sitzungsber. Bayer. Akad. Wiss. 1870, vol. 2, p. 271.

[2] Am. Jour. Sci. (3), vol. 37, 1889, pp. 109-114.

The monazitoid of Hermann is of a dark-brown color, due to impurities. In weathered specimens of impure monazite the surface is rough, dull, and sometimes covered with a light-brown earthy substance.

The purest specimens of monazite are transparent, becoming translucent and even totally opaque in the impure varieties.

It is frequently difficult to distinguish monazite, in fine grains, from certain other minerals by the uninitiated eye. Some varieties of yellowish-brown quartz are quite easily confounded with monazite; so also, at times, sphene, zircon, epidote, corundum, etc. For the benefit of the unscientific prospector it may be stated that the chief macroscopic distinctions are those of color, hardness, and specific gravity. The color is usually yellowish, inclined to reddish, brownish, or more rarely greenish tints. The fresh unaltered grains are transparent or translucent. The larger crystals are frequently dull in luster and opaque.

The hardness is from 5 to 5.5, between that of apatite and orthoclase (feldspar). Thus it can be scratched by a fragment of ordinary feldspar, (hardness 6) or quartz (hardness 7). The hardness of sphene is 5 to 5.5, of zircon 7.5, of epidote 6 to 7, of corundum 9. The specific gravity of monazite is 4.64 to 5.3; that of quartz is only 2.6, of sphene 3.5, of zircon 4.7, of epidote 3.25 to 3.5, of corundum 3.95 to 4.10.

OPTICAL CRYSTALLOGRAPHY.

Thin sections, by transmitted light, are colorless to yellowish. Pleochroism is generally scarcely noticeable. Absorption $\mathfrak{b} > \mathfrak{c} = \mathfrak{a}$. The plane of the optic axes is perpendicular to the plane of symmetry $\infty P \grave{\infty}$. The positive acute bisectrix lies in the obtuse angle β; hence sections parallel to oP show the full interference figure.

Optical measurements of monazite.

$b=\mathfrak{b}$	°	′	Localities.	Measured by—
$\overset{\mid}{c} \wedge \mathfrak{c}$	=1	04	(Turnerite) Tavetsch, Switzerland	Trechmann.
	=3	00	Arendai, Norway	Wülfing.
	=3	46	Norwich, Connecticut	Des Cloizeaux.
	=5	54	Schüttenhofen, Bohemia	Scharizer.

The opitcal angle is small; various measurements give:

Optical measurements of monazite.

2 E(red)	2 E(yellow).	2 E(violet).	2V (red).	2 V (yellow).	Dispersion.	Localities, etc.
° '	° '	° '	° '	° '		
29 04	....	28 48	....	....	$\rho > v$	Norwich, Conn., Des Cloizeaux.
31 08½	....	31 43½	....	....	$\rho < v$	Sibera, Des Cloizeaux.
25 22	24 56	....	....	12 44	$\rho > v$	Schüttenhofen, Bohemia, Scharizer.
29 07	28 25	....	14 50	14 29	....	Pisek, Bohemia, Vrba.
34 12	....	....	....	....	$\rho < v$	Turnerite, Tavetsch, Trechmann.

The dispersion is weak and horizontal. The single refraction is high; double refraction considerable.

Optical measurements.

a	β	γ	$\gamma—a$	$\gamma—\beta$	$\beta—a$	Localities, etc.
1.9285	1.9465	....	....	....	....	Schüttenhofen, Bohemia, Scharizer.
1.7957	1.7965	1.8411	0.0454	0.0446	0.0008	Arendal, Norway, E. Wülfing.

CHEMICAL COMPOSITION.

COMPOSITION AND ANALYSES.

The earlier discoverers had very little knowledge of the true chemical composition of monazite. Breithaupt,[1] in 1829, concluded from the high specific gravity of the Siberian monazite that it was a metallic oxide or acid in combination with some of the earths. Shepard[2] stated in 1835 that monazite was inferred to consist of the oxide of uranium with some one or more of the earths (according to blowpipe tests of Breithaupt). At the same time turnerite, according to blowpipe experiments of Mr. Children, was supposed to contain chiefly Al_2O_3, CaO, MgO, and a little iron, with traces of SiO_2. In 1837 Shepard published an analysis of his edwardsite (see table, anal. No. 29, p. 19), in which he first pointed out the existence of cerium. He deduced the relationship P_2O_5: CeO=1: 1½, making

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[1] Schweigger—Seidel, vol. 55, 1829.
[2] Treatise on Mineralogy, 1st edition; vol. 2, 1835.

the mineral a basic sesqui-phosphate of cerium protoxide. He also found 7.77 per cent ZrO_2, but it is doubtful whether this is an original constituent; more probably it may be referred to the presence of the mineral zircon as an impurity in the sample, which is an almost constant accompaniment of monazite. He found further, Al_2O_3, SiO_2, FeO, MgO, and a trace of glucina.

Kersten,[1] in 1839, analyzed the specimens from the Ural Mountains, previously determined by Breithaupt to be a combination of uranium oxide with some of the earths, but found no trace of uranium. He did find it to be essentially a phosphate of cerium and lanthanum oxides, and was the first to show the presence of La_2O_3, ThO_2, SnO_2, MnO, CaO, and traces of TiO_2, and K_2O. (See table, anal. No. 20, p. 18.)

In 1846 Woehler[2] published an analysis of cryptolite from Arendal, Norway, determining it to be a phosphate of cerium oxide. (See table, anal. No. 21, p. 18.) He could find neither ZrO_2 nor ThO_2, from which he concluded that the absence of ThO_2 distinguished cryptolite from monazite and edwardsite.

In 1847 Hermann[3] came to the conclusion that monazite was the neutral phosphate of cerium, in which a large part of the cerium was replaced by lanthanum and a small part by CaO, MgO, and MnO in the varieties of lighter specific gravity, while the heavier varieties (sp. gr. 5.281) contained less P_2O_5, and a large part of the stannic acid was replaced by tantalic acid (Ta_2O_5). (See table, anal. No. 17, p. 18.) This variety he called monazitoid, which occurs at Lake Ilmen, near Miask, Siberia. It is of a dark-brown color as distinguished from the lighter color of monazite. At first Hermann denied the presence of thoria in monazite and monazitoid, but later he found as high as 32.44 per cent ThO_2 in a specimen[5]. (See table, anal. No. 19, p. 18.) Monazite and monazitoid, he says, have the same form, and are therefore heteromeric, having different composition. Like all heteromeric minerals they show a tendency to mix, and thus give a series with slight difference in specific gravity. Koksharow[4] believed that monazitoid was simply an impure variety of monazite,

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[1] Poggendorff, Annalen, vol. 47, 1839, p. 385.
[2] Poggendorff, Annalen, vol. 67, 1846, p. 424.
[3] Jour. prakt. Chemie, vol. 40, 1847, p. 21.
[4] Materialien zur Mineralogie Russlands, vol. 4, 1892, pp. 7-34.
[5] It is highly probable that the greater part of this was lanthanum.

where the tantalic acid was derived from columbite and samarskite, in which the crystals of monazitoid were intergrown, and this appears most probable. Blomstrand[1], in his analysis of specimens from the Ilmen Mountains (same locality as Hermann's monazitoid), found 16.64 per cent ThO_2, but no tantalic acid. (See table, anal. No. 15, p. 18.)

In 1850 Watts[2] published an analysis of his phosphocerite, which he determined to be a phosphate of cerium protoxide, including lanthanum and didymium.

Websky,[3] in 1865, in making blowpipe tests on monazite from the Riesengebirge, found cerium, phosphoric acid, and titanic iron; the latter, however, must have been an impurity in the powder, probably from the ilmenite, which is mentioned as occurring as an associated mineral in this locality.

Radominsky's variety of monazite, kårarfveite, from Sweden, was found by him to contain 4.33 per cent fluorine[4]. (See table, anal. No. 16, p. 18.) Blomstrand's analysis of a specimen from the same locality showed only 0.33 per cent fluorine. (See table, anal. No. 11, p. 17,) and he concluded that the so-called kårarfveite was simply an impure variety of monazite.

Scharizer[5] first pointed out, in 1887, the presence of an element of the erbium group in the monazite from Schüttenhofen, Bohemia. His determination was made on a thin section by means of a spectroscopic attachment to the microscope.

Genth,[6] in 1889, published an analysis of monazite from the Villeneuve mica mine in Canada, in which he determined 4.76 per cent of $(Y, Er)_2 O_3$. (See table, analysis No. 37, p 20.)

Blomstrand,[7] in 1889, also showed the presence of yttrium in the monazite from southern Norway; and he first pointed out here the presence of lead oxide.

Below is given a table containing a number of analyses of monazite from various localities, with references:

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[1] Zeltschr. für Kryst., vol. 20, 1892, p. 367.

[2] Quart. Jour. Chem. Soc. London, vol. 2, 1850, p. 131.

[3] Zeltschr. Deutsch geol. Gesell., Berlin, vol. 17, 1865, p. 567.

[4] Compte Rendu, vol. 78, 1874, p. 764.

[5] Zeitschr. für Kryst, vol. 12, 1887, p. 255.

[6] Am. Jour. Sci., vol. 38, 1889, p. 203; Zeitschr, für Kryst., vol. 19. 1891, p. 88.

[7] Zeitschr. für Kryst., vol. 15, 1889, p. 99; Geol. Föreningens, Förhandl., Stockholm. vol. 9, 1887, p. 160.

Analyses of monazite from various localities.

[Per cent.]

	1	2	3	4	5	6	7	8	9	10	11	12
P_2O_5	28.62	29.41	27.07	26.37	28.27	27.99	27.55	28.94	23.85	27.28	25.56	26.59
Ce_2O_3	32.52	36.63	25.82	31.23	28.06	30.98	29.20	30.58	27.73	30.46	37.92	29.62
La_2O_3	29.41	26.78	30.62	24.51	29.60	25.88	26.26	29.21	21.96	24.37	20.76	26.43
Di_2O_3												
Y_2O_3	2.04	1.81	2.03	1.83	1.82	2.76	3.82	.78	2.86	1.58	.83	2.54
ThO_2	4.54	3.81	9.60	9.20	9.34	9.03	9.57	7.14	9.05	11.57	8.31	10.39
SiO_2	1.51	.93	1.85	2.10	1.65	1.58	1.86	1.32	5.95	2.02	2.48	2.16
Al_2O_3	.22	.12	.15		.16			.18			.41	
Fe_2O_3	.36	.33	1.01	1.97	.66	1.25	1.13	.42	4.63			
FeO										1.10	.36	.75
MnO			.08	.28						.24		
CaO	.84	.34	.91	.93	.53	.55	.69	1.19	4.83	1.05	1.17	.88
MgO			.03	.16								
ZrO_2									.66			
SnO_2	.22	.09		.21						.08	.13	
PbO			.58					.33		.26	.84	.31
F											.33	
Ta_2O_5												
TiO_2												
H_2O	.27	.18	.35	1.53	.21	.20	.52	.09	1.61	.38	1.65	.52

1 to 10 inclusive. From pegmatite veins of southern Norway, by C. W. Blomstrand, Geol. Föreningens Förhandl., Stockholm, 1887, vol. 9, p 160. Zeitschr. für Kryst., vol. 15, 1889, p. 99.

11. From Kårarfvet, Sweden, by C. W. Blomstrand.

12. From Hölma, Sweden, by C. W. Blomstrand, Geol. Föreningens Förhandl., Stockholm, 1889, vol. 11, p. 171; Zeitschr. für Kryst., 1891, vol. 19, p. 109.

Analyses of monazite from various localities.

[Per cent.]

	13	14	15	16	17	18	19	20	21
P_2O_5	27.32	25.09	19.13	27.38	17.94	28.05	28.15	28.50	27.37
Ce_2O_3	31.81	34.90	22.88	67.40	*a*49.35	*a*37.36	35.85	26.00	73.70
La_2O_3	31.86	17.60	14.69		21.30	27.41		23.40	
Di_2O_3									
Y_2O_3	.52	.43	1.71						
ThO_2	5.55	17.82	16.64				32.45	17.95	
SiO_2	1.37	2.90	9.67						
Al_2O_3	.13		2.90						
Fe_2O_3	.26	.43		.32	Tr.				
FeO			3.56						1.51
MnO			4.89					1.86	
CaO	.55	.36	1.25	1.24	1.50	1.46	1.55	1.68	
MgO			.40	Tr.	Tr.	.80			
ZrO_2									
SnO_2	.95	.43	.40			1.75	Tr.	2.10	
PbO									
F				4.35					
Ta_2O_5					6.27				
TiO_2								*c*Tr.	
H_2O	.41	.56	.71	Some.	1.36		1.50		

a=CeO. c=TiO_2+K_2O.

13 to 15, inclusive. From Ilmen Mountains, by C. W. Blomstrand, Lunds Universitets Årskrift, 1888, vol. 24. Zeitschr. für Kryst., 1862, vol. 20, p. 367.

16. From Kårarfvet, Sweden, by F Radominski, Compte. Rendu, 1874, vol. 78, p. 764.

17. Monazitoid from Lake Ilmen, Miask, by R. Hermann, Jour. prakt. Chemie. 1847, vol. 40, p. 21.

18. From Ilmen Mountains, Siberia, by R. Hermann, Kok., Materialien zur Mineralog. Russ., vol. 4, 1862. Rammelsberg's Handbuch d. min. Chemie, 2d ed., 1875, p. 305.

19. Rammelsberg's Handbuch d. min. Chemie, 2d ed., 1875, p. 305.

20. From Ilmen Mountains, near Miask, by C. Kersten, Poggendorff, Annalen, vol. 47, 1839, p. 385.

21. Crypolite from Arendal, Norway, by F. Woehler, Poggendorff, Annalen, 1846, vol. 67, p. 424.

Analyses of monazite from various localities.

[Per cent.]

	22	23	24	25	26	27	28	29
P_2O_5	28.78	29.66	28.40	25.09	24.61	29.10	28.70	26.66
Ce_2O_3	27.73	67.38	59.1	36.64	68.08	*a* 46.14	31.30	*a* 56.53
La_2O_3	39.24		8.9	30.21		24.5	39.9	
Di_2O_3								
Y_2O_3								
ThO_2				1.23				
SiO_2	1.60			3.21				3.33
Al_2O_3				3.11				4.44
Fe_2O_3	1.30	*b* 2.95						Tr.
FeO								
MnO				Tr.				
CaO	.90							
MgO				Tr.				Tr.
ZrO_2								7.77
SnO_2								
PbO								
F								
Ta_2O_5								
TiO_2								
H_2O								

a=CeO. b=Fe_3O_4.

22. Monazite from Arendal, by C. F. Rammelsberg, Zeitschr. Deutsch. geol. Gesell., Berlin, 1877, vol. 29, p. 79; Zeitschr. für Kryst., 1879, vol. 3, p. 101.
23. From Johannisberg, Sweden, by H. Watts, Quart. Jour. Chem. Soc. London, 1850, vol. 2, p. 131.
24. Turnerite from Luzerne. by F. Pisani, Zeitschr. für Kryst., 1877, vol. 1, p. 405.
25 to 26, inclusive. From county of Gough, New South Wales, by A. Liversidge, Zeitschr. für Kryst., 1884, vol. 8, p. 87.
27. From Antioquia, New Grandada, by Damour, Ann. Chem. Phys. (3), vol. 51, p. 445.
28. From Caravellas, Brizil, by H. Gorceix. Zeitschr. für Kryst., 1887, vol. 12, p. 643.
29. Edwardsite from Norwich, Conn., by C. U. Shepard, Am. Jour. Sci., 1837, vol. 32, p. 162; Poggendorff, Annalen, 1838, vol. 43, p. 148.

Analyses of monazite from various localities.

[Per cent.]

	30	31	32	33	34	35	36	37
P_2O_5	28.18	29.28	26.12	29.32	26.05		26.95	26.86
Ce_2O_3	33.54	31.38	29.89	37.26	73.82		64.45	24.80
La_2O_3	28.33	30.88	26.66	31.60				26.41
Di_2O_3								
Y_2O_3								*d* 4.76
ThO_2	8.25	6.49	14.23	1.48		18.6		12.60
SiO_2	1.67	1.40	2.85	.32		2.7	5.85	.91
Al_2O_3								
Fe_2O_3								1.07
FeO								
MnO								
CaO								1.54
MgO								.04
ZrO_2								
SnO_2								
PbO								
F								
Ta_2O_5								
TiO_2								
H_2O	.87	.20	.67	.17	.45		.91	.78

$d=Y_2O_3+Er_2O_3$.

30. From Portland, Conn., by S. L. Penfield, Am. Jour. Sci., vol. 24, 1882, p. 250; Zeitschr. für Kryst., vol. 7, 1883, p. 366.
31. From Burke County, N. C., by S. L. Penfield, Am. Jour. Sci., vol. 24, 1882, p. 250; Zeitschr. für Kryst., vol. 7, 1883, p. 366.
32. From Amelia County, Va., by S. L. Penfield, Am. Jour. Sci., vol. 24, 1882, p. 250; Zeitschr. für Kryst., vol. 7, 1883, p. 366.
33. From Alexander County, N. C., by Penfield & Sperry, Am. Jour. Sci., vol. 36, 1888, p. 322; Zeitschr. für Kryst., vol. 17, 1890, p. 407.
34. From Amelia County, Va., by G. A. König, Proc Acad. Nat. Sci. Phila., 1882, p. 15; Zeitschr. für Kryst., vol. 7, 1883, p. 423.
35. From Amelia County, Va., by F. P. Dunnington, Am. Jour. Sci., vol. 24, 1882, p. 153; Zeitschr. für Kryst., vol. 7, 1883, p. 423.
36. From Ottawa County, Quebec, by G. C. Hoffman, Am. Jour. Sci., vol. 34, 1887, p. 73; Zeitschr. für Kryst., vol. 15, 1889, p. 127.
37. From Ottawa County, Quebec, by F. A. Genth, Am. Jour. Sci., vol. 38, 1889, p. 203; Zeitschr. für Kryst., vol. 19, 1891, p. 88.

Below are given the thoria contents of a number of samples from North Carolina, which were analyzed for the writer by Dr. Charles Baskerville, assistant chemist of the North Carolina geological survey. These analyses are not made on the pure mineral, but on the commercial monazite sand, which contains up to about 67 per cent. monazite, the remainder being quartz, garnet, zircon, and other accessory minerals.

Thoria contents of North Carolina monazite sand.

[Per cent.]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ThO_2	0.175	0.225	2.15	2.25	0.40	6.54	0.125	0.29	2.48	0.26	1.27	6.30	5.19	5.87	6.26	1.75	1.93	3.40

1. Bennett's Mill, Silver Creek, Burke County.
2. Northeast side Brindle Ridge, Burke County.
3. White Bank gold mine, Burke County.
4. Hall's Creek, at Morganton road crossing, Burke County.
5. Bailey's Creek, 3 miles southwest of Glen Alpine Station, Burke County.
6. Linebacher place, Silver Creek, Burke County.
7. Mac'Lewrath place, Silver Creek, Burke County.
8. East fork of Satterfield Creek, Burke County.
9. Mac Lewrath Branch, McDowell County.
10. Bracket town, South Muddy Creek, McDowell County.
11. Long Branch, McDowell County.
12. Alexander Branch, McDowell County.
13. Daniel Peeler's farm near Bellwood, Cleveland County.
14. Proctor's farm, near Bellwood, Cleveland County.
15. Wade McCurd's farm, Carpenter's Knob, Cleveland County.
16. Tailings from No. 15.
17. Henrietta, Rutherford County.
18. Fallston, Cleveland County.

METHOD OF ANALYSIS OF MONAZITE SAND.

The method of analysis employed by Dr. Baskerville is given below in his own words[1]. He claims only "approximate results, and absolute accuracy cannot be vouched for." It is substantially the same as Prof. S. L. Penfield's method[2] with a few modifications.

The pulverized sand, 2 grams, is weighed into a small flask holding about 100 c. c.; 10 c. c. H_2SO_4 (1 :1) are added, and the whole cooked on a sand bath with frequent agitation, until the

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[1] From a letter to the writer, March, 1895.

[2] Am. Jour. Sci. (3), vol. 24, 1882, p. 258.

acid becomes concentrated and fumes arise. A small funnel is used in the neck of the flask to prevent loss by spitting and bubbling. It is allowed to cool, and if not completely decomposed, a fresh amount of H_2SO_4 is added, and the previous operation repeated. Add a little water, keeping the temperature down as well as possible. The insoluble silicates are removed by filtering and washing with cold water. The clear filtrate is diluted to 400 or 500 c. c., and an excess of oxalic acid added, whereby the oxalates of the cerium metals and thorium are precipitated. This is done in the hot solution, allowing the same to boil a few moments after adding the oxalic acid. It is then allowed to remain in the cold for twelve hours, when it is filtered and washed with cold water.

The precipitated oxalates are ignited by heating slightly above faint redness. After all the carbon is burned off, the contents of the crucible are turned into a platinum or porcelain dish, washing the crucible with H_2SO_4 (1 :1). On heating, the oxides are usually dissolved completely; the excess of H_2SO_4 is gotten rid of by gentle heat. To accomplish this, the disk is placed on a triangle inside of an iron dish to which the lamp flame is applied. The sulphates, which are almost invariably colored red, yellow or orange, are dissolved in water. The whole mass is usually completely soluble in about 15 c. c. H_2O, but on further dilution a precipitate is formed. The solution is made up to 200 or 300 c. c., i. e., sufficient water is added to hold all the thorium sulphate in solution; it is then boiled and filtered. If the filtrate is acid, it is neutralized with NH_4OH, and the thorium is precipitated out by means of $Na_2S_2O_3$. The filtered precipitate is burned to ThO_2 and weighed as such in a platinum crucible.

CHEMICAL AND BLOWPIPE REACTIONS.

Monazite is with difficulty and incompletely soluble in hydrochloric acid. It is attacked completely by sulphuric acid, and by potassium acid sulphate. It is infusible before the blowpipe flame, turning gray. When moistend with H_2SO_4 it colors the flame bluish green (phosphorus reaction). The borax and salt of phosphorus beads are yellowish when hot, and colorless on cooling;

the saturated borax bead becomes enamel white on flaming. Fused with soda, the mass treated with water and filtered, the residue dissolved in a little HCl, the solution gives with oxalic acid a precipitate, which on ignition becomes brick red (cerium oxide). With soda on charcoal a little tin is sometimes obtained.

MICHRO-CHEMICAL REACTIONS.[1]

For cerium.—The dilute solutions of cerium sulphate or chloride give, with oxalic acid or ammonium oxalate, a precipitate, which is at first flocculent but soon becomes crystalline, being composed of fine, doubly terminated, often forked and serrated prisms; in more concentrated solutions these form themselves into radial groups. The little crystals have an oblique extinction and a high double refraction. In hot, very dilute solutions thin rhomboidal plates are precipitated, whose acute angle is about 86°; they have a tendency to form rectangular intergrowths, and appear to be monoclinic.

For phosphorus.—Phosphoric acid is precipitated in a solution of the sulphate by the addition of ammonium molybdate, which on drying gives little crystals resembling rhombic dodecahedrons, yellow in reflected and greenish in transmitted light.

Derby[2] has found that these micro-chemical tests are the best means of identifying monazite.

SPECTROSCOPIC TESTS.

Scharizer[3] tested the absorption spectrum of a basal cleavage plate of the Shüttenhofen monazite by replacing the ocular of the microscope with a spectroscope *à vision directe.* The illumination was obtained by the reflection of direct sunlight from a concave mirror. The spectrum showed a broad absorption band in the yellow between the Fraunhofer lines C and D, corresponding to didymium, and a less broad one at the end of the green near the line F, corresponding to erbium.

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[1] H. Rosenbusch, Mikroscopische Physiograhie, Vol. I., 3d ed., 1892, p. 266.
[2] Am. Jour. Sci. 3, vol. 37, 1889, pp. 109 114. Zeitschr. für Kryst., vol. 19, 1891, p. 78.
[3] Zeitschr. für Kryst., vol. 12, 1887, p. 264.

CHEMICAL MOLECULAR CONSTITUTION OF MONAZITE.

Penfield,[1] in his analyses of Connecticut, North Carolina, and Virginia monazite (see anal. Nos. 30, 31, 32, 33; p. 20), deduces the relation

$$(Ce, La, Di)_2O_3 : P_2O_5 = 1:1$$
$$ThO_2 : SiO_2 = 1:1$$

The former corresponds to the normal phosphate of the cerium metals ($R_2P_2O_3$); the latter corresponds to that of normal thorium silicate, which, in combination with a small percentage of water, makes the mineral thorite or orangite ($ThSio_4H_2O$). He concludes, then, that monazite is essentially a normal phosphate of the cerium metals, in which thorium silicate is present in varying proportions as an impurity in the form of the mineral thorite or orangite.

Dunnington[2] had somewhat previously come to the same conclusion.

Rammelsberg's[3] formula of thorium-free monazite from Arendal, Norway, was $R_2P_2O_8 = (Ce, La, Di)_2P_2O_8$, thus agreeing with Penfield.

Blomstrand,[4] from his analyses of Norwegian and Siberian monazite (see anal. No. 1-10, 13–15, pp. 17, 18), concludes that the mineral is a normal tribasic phosphate, an excess of bases being combined with SiO_2. Thus: $m(3RO,P_2O_5)+2RO, SiO_2+pH_2O$, where $m=5$ to 20, and p=less than 1 usually.

He does not believe, as Penfield does, that the thoria is originally combined with silicia as thorite, but that it is a primary constituent, present as the phosphate, either in combination with the cerium or as an isomorphous mixture, thus:

$$\overset{IV}{Ce}.\overset{III}{Ce}(O_3PO)_2 \text{ and } \overset{II}{R}\overset{IV}{Th}(O_3PO)_2;$$

and that it is altered to the silicate by siliceous waters.

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[1] Am. Jour. Sci. (3), vol. 24, 1882, p. 250: vol. 36, 1888, p. 322. Zeitschr. für Kryst., vol. 7, 1883, p. 366; vol. 17, 1890, p. 407.

[2] Am. Chem. Jour., vol. 4, 1882, p. 138.

[3] Zeitschr. Deutsch. geol., Gesell. Berlin. vol. 29, 1877, p. 79. Zeitschr. für Kryst., vol. 3, 1879, p. 101.

[4] Zeitschr. für Kryst., vol. 9, 1887, p. 160; vol. 20, 1892, p. 367.

Rammelsberg[1] has explained the analyses of Kersten and Hermann (see anal. Nos. 19, 20, p. 18), respectively, by the formulæ:

$$\left\{\begin{matrix} 5\ R^3P^2O^8 \\ Th^2P^2O^9 \end{matrix}\right\} \text{ and } \left\{\begin{matrix} 3\ R^3P^2O^8 \\ Th^3P^4O^{10} \end{matrix}\right\}$$

which does not, however, appear to express a constant molecular constitution.

ARTIFICIAL PRODUCTION OF MONAZITE.

In 1875 Radominsky[2] produced monazite artificially by treating a solution of impure cerium salt with sodium phosphate, adding an excess of chloride of cerium, and heating to redness. After cooling and crystallization, long yellow prisms with striated surfaces were formed. The specific gravity was 5.09, and the compound, by analysis, was found to agree in composition with that of the mineral monazite.

GEOLOGICAL AND GEOGRAPHICAL OCCURRENCE.

The following table presents the salient features of the geographical, geological, and mineralogical occurrences of monazite. All known localities at which the mineral monazite and its equivalents, turnerite, cryptolite, etc., have been found up to the present time are tabulated here. It is placed at the beginning of this chapter as a general introduction, and for the purpose of convenient reference, to what is to follow.

Conditions of occurrence of monazite.

Localities.	Country Rocks.	Associated Minerals.
UNITED STATES.		
East Blue Hill, Me	Gneiss	
Wakefield, N H	do	Rutile, cassiterite. (?)
Westerly, R. I	Granite	
Narragansett Pier, R. I	do	
Westford, Mass	Gneiss	Xenotime.
Ayer, Mass	do	Zircon, rutile.
Norwich, Conn	do	Sillimanite.
Chester, Conn	do	do
Watertown, Conn	Granite	(In albite) Apatite, zircon, tourmaline.
Portland, Conn		
Yorktown, N. Y		Sillimanite.
New Speedway, along Harlem river, New York City		Xenotime.
Amelia Court House, Va	Albitic granite	Microlite, amazonite, beryl, apatite, orthite, columbite, manganese tantalate.

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[1] Handbuch der mineral. Chemie. 1875, p. 305.

[2] Comptes Rendus, vol. 80, 1875, p. 305.

Localities.	Country Rocks.	Associated Minerals.
UNITED STATES.—Continued.		
Deake mica mine, Mitchell county, N. C.	Mica schist.	Autunite, uraninite, gummite, garnet.
Ray mica mine, Yancey county, N. C.		(In orthoclase.) Beryl. garnet.
Mars Hill, Madison county, N. C.		
Boomer, Wilkes county, N. C.		Quartz, garnet, zircon, rutile, magnetite, ilmenite.
Milholland's Mill, Alexander county, N. C.	Garnetiferous mica schist.	Rutile.
Emerald and hiddenite mine, Alexander county, N. C		In quartz.
Burke, Rutherford, Cleveland, Polk, Catawba, and Lincoln counties, N. C.	In gneiss, and stream placers	Quartz, garnet, zircon, rutile, brookite, xenotime, fergusonite, corundum, epidote, beryl, cyanite, magnetite, pyrite, menaccanite.
Crowders Mountain, Gaston county, N. C		
Todd's Branch, Mecklenburg county, N. C	Gold placers.	Garnet, zircon, diamond...
Spartanburg and Greenville counties, S. C	Gneiss, and stream placers	(Same as Burke, etc. counties, N. C.)
"The Glades," Hall county, Ga	Gold placers.	Quartz, rutile, garnet, etc.
CANADA.		
Villeneuve mica mine, Ottawa county, Quebec	Pegmatite.	Garnet, tourmaline, uraninite.
SOUTH AMERICA.		
Rio Chico, Antioquia, United States of Columbia.	Gold placers.	
Alcobaca, Province of Bahia, Brazil	Beach sands.	
Caravellas, Province of Bahia, Brazil	do	
Salabró, Province of Bahia, Brazil	Diamond sands.	Quartz, zircon, garnet, disthene, staurolite, corundum.
Province of Minas Geraes	do	Magnetite, ilmenite, pyrite.
Province of Minas Graes, Rio de Janeiro, and São Palo, Brazil.	Gold placers.	
Provinces of Bahia, Minas Geraes, Rio de Janeiro, and São Palo, Brazil	Porphyritic granulitic, and schistose gneisses, red syenite, granite dikes...	Apatite, magnetite, ilmenite, rutile, garnet, zircon, Sillimanite.
Buenos Ayres, Argentine Republic	River sands.	Zircon.
Cordoba, Argentine Republic.	Gneiss and granite...	
ENGLAND.		
Cornwall.	Clay slates	Quartz, albite.
SWEDEN.		
Hölma		
Kårarfvet	Albitic granite.	Gadolinite, hjelmite, emerald.
Johannisberg	Cobalt ore	
NORWAY.		
Dillingsö, Moss, Lönnesby, Arendal, Narestoe, Hitteroe, Hvalö	Pegmatite	
Arendal and Midbö		Cryptolite in apatite.
Noterö	Granite	In feldspar, enveloped by orthite.
Helle		
FINNISH LAPMARK.		
Ivalo	Gold sands.	Zircon.

Localities.	Country Rocks.	Associated Minerals.
RUSSIA.		
Ilmen Mountains	Albitic granite	Zircon, columbite, samarskite.
Sanarka River	Placers	
BELGIUM.		
Nil St. Vincent		
FRANCE.		
Le Puys, near St. Christophe, Dauphine		Adularia, crichtonite, sphene, anatase.
SWITZERLAND.		
Binnenthal		
Olivone, near Mte. Camperio	Quartz vein, traversing mica schist.	Rutile.
Tessin		
Perdatsch		
Santa Brigritta, near Ruaras, Tavetsch Valley.		
GERMANY.		
Laacher See, near Coblentz	Druse in sanadine bomb.	
AUSTRIA.		
Josephinenhuette, Riesengebirge, Silesia	Pegmatite	(In black mica.) Ilmenite, fergusonite, yttrium spar, zircon.
Schreiberhau, Silesia		Gadolinite, yttrium-spar, xenotime, fergusonite.
Schüttenhofen, Bohemia	Pegmatite	Apatite.
Pisek, Bohemia		In beryl and feldspar.
AUSTRALIA.		
Vegetable Creek, County Gough, New South Wales.		

Monazite is an accessory constituent of the granite eruptives and their derived gneisses. It has been found in these rocks over widely separated areas of the earth's surface, and further search and study is liable to reveal its probable universal presence, in varying proportions, in most granites and granite gneisses. Thus Derby[1] has found monazite as a constant accessory constituent in the porphyritic, granulitic, and schistose gneisses of the provinces of Bahia, Minas Geraes, Rio de Janeiro, and São Palo, in Brazil, representing 300 miles along the axis of the great gneiss region of the Maritime Mountains. The granite dikes, intersecting the gneiss, also carry monazite.

The gneisses of the South Mountain region in North Carolina, covering an area of some 2,000 square miles, in Burke, McDowell,

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[1] Am. Jour. Sci., Vol. 37, 1889, pp. 109-114.

Rutherford, Cleveland, Polk, Catawba, Lincoln, and Gaston counties, and extending into Spartanburg and Greenville counties, S. C., have been shown to contain monazite.[1] I have since identified the mineral in the thin sections of several specimens of mica gneiss collected in that locality. The rocks are granitic mica gneisses, hornblende gneisses, which approach more nearly to diorite gneisses, and pegmatites. (See map. Plate II.)

Monazite has recently been found in Hall county, Georgia, near "The Glades," a post-office about 10 miles northeast of Gainesville, on the north side of the Chattahoochee river. It occurs in the gold placers of Flat creek and its tributaries, the Glade, Stockeneter, Hamilton and Huram branches.

Derby,[2] by examining the heavy residues of a number of hand specimens, selected at random from the collection in the National Museum, of Washington, D. C., described the occurrence of monazite in certain granites and gneisses of Maine, New Hampshire, Rhode Island, and Massachusetts.

The monazite of Chester, Portland, and Watertown, Conn., is an accessory constituent of the granite and gneisses. In Amelia county, Va., it is found in albitic granite; also in the Ilmen Mountains of Russia.

The pegmatites of southern Norway, Silesia, and Bohemia, and of some of the mica mines in Canada and North Carolina, also contain monazite.

Derby (in paper above cited) has found monazite in a red syenite at Serra do Stauba, in the province of Bahia, Brazil. The basic eruptives (diabase, quartz-diorite, mica-diorite, and minette) thus far examined by him in Brazil showed no traces of monazite.

The turnerite of the Laacher See (which is an extinct volcanic crater), near Coblentz, in Prussia, was found in a druse of a sanadine bomb, the only known occurrence of monazite in an undoubted volcanic rock.[3] It was grown into and upon a crystal of orthite.

The turnerite of Olivone, Switzerland, occurs in a quartz vein, 20 to 30 cm. thick, traversing crystalline schists.[4] The percentage

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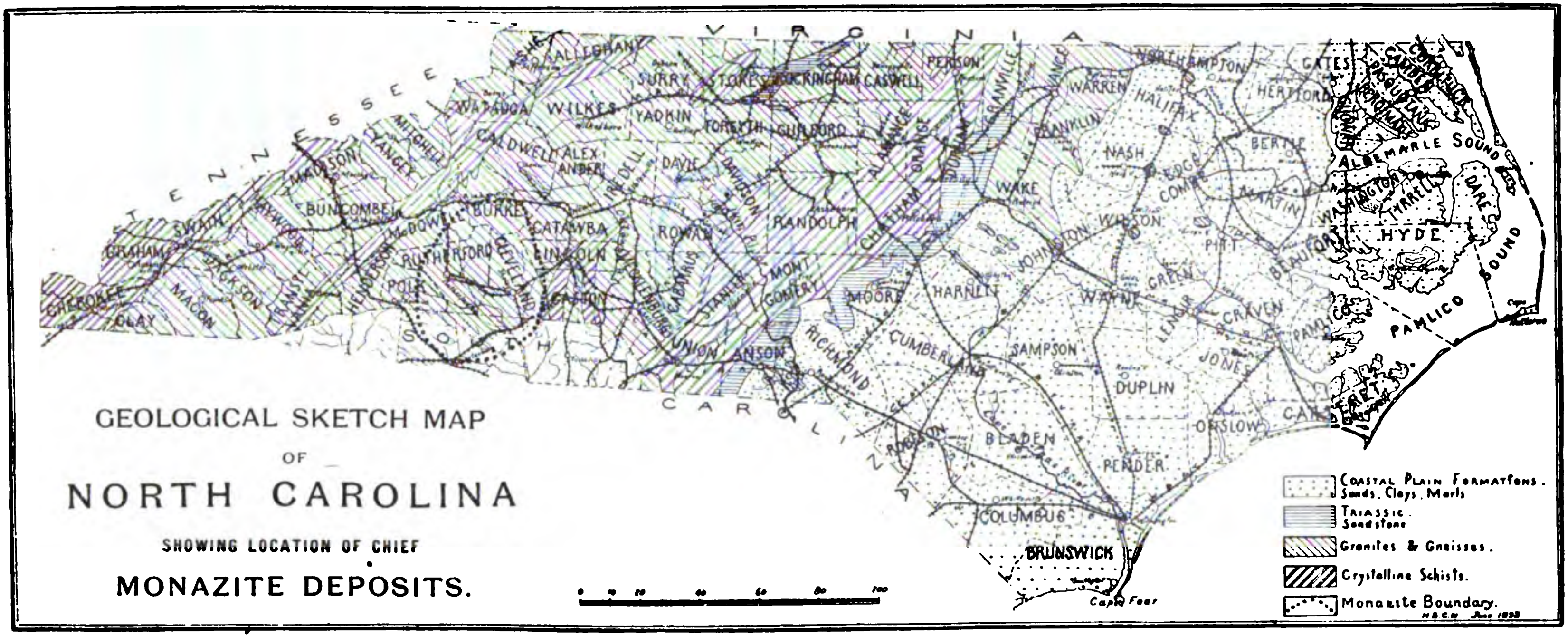
[1] Trans. Am. Inst. Min. Engr., Mar., 1895.

[2] Proc. Rochester, Acad. Sci., vol. 1, 1891, pp. 294–206.

[3] G. von Rath., Poggendorff, Annalen, 1871, Erg.-Bd., 5, p. 413.

[4] G. Seligman, Zeitschr. für Kryst., vol. 9, 1884, p. 420.



WORKABLE MONAZITE AREA IN NORTH CAROLINA.

of monazite in these rocks is exceedingly small, often infinitesimal; thus Derby (in paper above cited) states that the granite dikes in the gneiss of Serra de Tingua, near Rio, are rich in the yellow mineral, carrying 0.02 to 0.03 per cent, and a fine-grained granite dike on the outskirts of Rio de Janeiro showed 0.07 per cent monazite.

The cryptolite of Norway occurs as inclusions of very fine, needle-shaped crystals in apatite.

While making a reconnaisance trip through the North Carolina region, the writer, in company with Messrs. H. A. J. Wilkens, E. M., and Jno. R. Kirksey, discovered on June 19th, 1895, the interesting, and so far as known new, occurrence of monazite in cyanite. The locality where first observed was at the Peeler and Ivester placers on a branch of Knob creek, about 16 miles north of Shelby in Cleveland county, N. C. Numerous fragments of a light blue grey cyanite, usually less than one inch, but occasionally as large as three inches in longest dimension, were found in the tailing dumps from the bottom gravels that had been washed in the sluice boxes. The fragments of pure cyanite contained intimately intergrown crystals of monazite, the latter constituting as much as 50 per cent of the mass at times, though some pieces of the cyanite were practically barren. The bed rock and out cropping ledges near here were carefully examined, in the hope of finding the original source of this monazite-bearing cyanite, but without success. It probably occurs in irregular nests and veinlets through the pegmatitic mica gneiss, which forms the country rock.

Derby thinks (in paper above cited) that there is "a reasonable probability that zircon, and to a less degree monazite, may prove to be guide minerals by which eruptives and their derivatives can be certainly identified, no matter what degree of alteration they may have suffered."

Monazite has not been found in the sedimentary rocks, although it may be present in some of these as a secondary mineral of transportation.

The economically valuable deposits of monazite are found in the placer sands of streams and rivers, and in the irregular sedimentary sand deposits of old stream beds and bottoms. Plates I. and III. illustrate the occurrence of monazite sands along the upper reaches of a small branch. The decomposition and disintegration of the crystalline rocks, the original source of the mineral, has proceeded to considerable depths, particularly in the southern, unglaciated countries. By erosion and secular movement the material is deposited in the stream beds and there undergoes a natural process of sorting and concentration, the heavy minerals being deposited first and together. The richer portions of these stream deposits are thus found near the head waters. Such deposits have been described from North and South Carolina in the United States, from Brazil, and from the Sanarka river in Russia.

The beach sand deposits along the coast of Brazil, in the province of Bahia, have a similar explanation, the concentration there being brought about by the action of the waves.

ACCESSORY MINERALS.

The main constituent of the granitic rocks (quartz, feldspar, and mica) all contain the monazite as intergrowths, though it appears to be more generally confined to the feldspar.

Zircon may be regarded as a constant associate; in fact, it is even a more important and general accessory constituent of the rocks than monazite. Among the other usual associated minerals, of coeval origin with the monazite, are xenotime, fergusonite, sphene, rutile, brookite, ilmenite, cassiterite, magnetite, and apatite; sometimes beryl, tourmaline, cyanite, corundum, columbite, samarskite, uraninite, gummite, autunite, gadolinite, hjelmite, and orthite.

The association of monazite with orthite, gadolinite, samarskite; uraninite, and hjelmite is interesting as suggesting the possibility of some genetic relationship.

Among the principal secondary and metamorphic minerals found in association with monazite are rutile, brookite, anatase, epidote, orthite, garnet, sillimanite, and staurolite.

ECONOMIC USE.

The economic value of monazite lies in the incandescent proper-

WASHING GRAVEL AND SAND IN STREAM BEDS FOR MONAZITE, LATTIMORE MINE.

THIS VALLEY, 9 MILES N. E. OF SHELBY, IS 100 TO 200 YARDS WIDE, AND ITS UNDERLYING GRAVEL EVERYWHERE YIELDS MONAZITE.

ties of the oxides of the rare earths—cerium, lanthanum, didymium and thorium—which it contains. These are utilized, principally the thoria, together with limited quantities of the lanthanum and didymium, in the manufacture of the Welsbach and other incandescent gaslights. The cerium goes to the drug trade as the oxalate.

The Welsbach light consists of a cylindrical hood or mantle composed of a fibrous network of the rare earths, the top of which is drawn together and held by a loop of platinum wire. It is permanently suspended over the flame of a specially-devised burner, constructed on the principles of the Bunsen burner, in which the gas is burned with the access of air, thus utilizing the heating and not the illuminating power of the hydrocarbons. The mantle becomes incandescent, glowing with a brilliant and uniform light.

The method of manufacturing this mantle is in brief as follows: A cylindrical network, about 1½ inches in diameter, is woven out of the best and strongest cotton thread. This is first washed in ammonia and then in warm water, being wrung out in a mechanical clothes wringer each time. It is then soaked in a solution of the rare earths and dried in a revolving hot-air bath. After being cut to the proper lengths, each cylinder is shaped over a wooden form, and the upper end is drawn together by a loop of platinum wire. The cotton fiber is then burned off under the flame of a Bunsen lamp, which leaves a network of the rare oxides exactly resembling the original woven cylinder, each fiber being identically preserved, excepting that the size is somewhat reduced by shrinkage. After a series of tempering and testing heats of various intensities the mantle is ready for use. The exact composition of the solution of the rare earths is not known, being one of the trade secrets; but it is a well known fact that monazite rich in thoria is sought after, and the natural inference is that this element constitutes one of the most important ingredients.

METHODS OF EXTRACTION AND CONCENTRATION.

The commercially economical deposits of monazite are those occurring in the placer sands of the streams and adjoining bottoms and in the beach sands along the seashore. The geographical areas over which such workable deposits have been found up to the present time are quite limited in number and extent. In the United States the placer deposits of North and South Carolina stand alone. This area includes between 1600 and 2000 square miles, situated in Burke, McDowell, Rutherford, Cleveland, and Polk counties, N. C., and the northern part of Spartanburg county, S. C. The principal deposits of this region are found along the waters of Silver, South Muddy, and North Muddy creeks, and Henrys and Jacobs Forks of the Catawba river in McDowell and Burke counties; the Second Broad river in McDowell and Rutherford counties; and the First Broad river in Rutherford and Cleveland counties, N. C., and Spartanburg county, S. C. These streams have their sources in the South Mountains, an eastern outlier of the Blue Ridge. The country rock is granitic biotite gneiss and dioritic hornblende gneiss, intersected nearly at right angles to the schistosity by a parallel system of small auriferous quartz veins, striking about N. 70° E., and dipping steeply to the N.W. Most of the stream deposits of this region have been worked for placer gold. The existence of monazite in commercial quantities here was first established by Mr. W. E. Hidden, in 1879. The thickness of these stream gravel deposits is from 1 to 2 feet, and the width of the mountain streams in which they occur is seldom over 12 feet. The percentage of monazite in the original sand is very variable, from an infinitesimal quantity up to 1 or 2 per cent. The deposits are naturally richer near the head waters of the streams.

The monazite is won by washing the sand and gravel in sluice boxes exactly after the manner that placer gold is worked. The sluice boxes are about 8 feet long by 20 inches wide by 20 inches deep. Two men work at a box, the one charging the gravel on a perforated plate fixed in the upper end of the box, the other one working the contents up and down with a gravel fork or perforated shovel in order to float off the lighter sands. These boxes are cleaned out at the end of the day's work, the washed and concentrated monazite being collected and dried. Magnetite, if present, is eliminated from the dried sand by treatment with a large hand magnet. Many of the heavy minerals, such as zir-

MINING AND WASHING GRAVEL BEDS FOR MONAZITE, LATTIMORE MINE.

THE GRAVEL, 2-4 FEET THICK, LIES ON GRAY GNEISS, AND IS IN TURN OVERLAIN BY 2-4 FEET OF SAND AND LOAM.

con, menaccanite, rutile, brookite, corundum, garnet, etc., can not be completely eliminated. The commercially prepared sand, therefore, after washing thoroughly and treating with a hand magnet, is not *pure* monazite. A cleaned sand containing from 65 to 70 per cent. monazite is considered of good quality. From 20 to 35 pounds of cleaned monazite sand per hand, that is, from 40 to 70 pounds to the box, is considered a good day's work.

But very few regular mining operations are carried on in the region. As a rule each farmer mines his own monazite deposit and sells the product to local buyers, often at some country store in exchange for merchandise.

At the present time the monazite in the stream beds has been practically exhausted, with few exceptions, and the majority of the workings are in the gravel deposits of the adjoining bottoms. These deposits are mined by sinking pits about 8 feet square to the bed rock and raising the gravel by hand labor to a sluice box at the mouth of the pit. The overlay is thrown away excepting in cases where it contains any sandy or gritty material. The pits are carried forward in parrallel lines, separated by narrow belts of tailing dumps, similar to the methods pursued in placer gold mining. At the Blanton and Lattimore mines on Hickory creek, 2 miles northeast of Shelby, Cleveland county, N. C., the bottom is 300 to 400 feet wide, and has been partially worked for a distance of one-fourth of a mile along the creek. The overlay is from 3 to 4 feet, and the gravel bed from 1 to 3 feet thick. (See Plate IV.)

The methods of mining and cleaning are much more systematic in Spartanburg county, S. C., than in the North Carolina regions. Although the raw material contains on an average fully as much garnet, rutile, titanic iron ore, etc., as that in the North Carolina mines, a much better finished product is obtained, and more economically, by making several grades. Two boxs are used in washing the gravel, one below the other. The gravel is charged on a perforated plate at the head of the upper box, and the clean-up from this box is so thoroughly washed as to give a high grade sand, often up to 85 per cent. pure. The tailings discharge directly into the lower box, where they are rewashed, giving a second grade sand. At times the material passes through as many as five washing treatments in the sluice boxes. Even after these grades are obtained as clean as possible by washing, the material, after being thoroughly dried, is further cleaned by pouring from a cup, or a small spout in a bin, in a fine, steady stream from a height of about 4 feet, on a level platform; the lighter quartz and black sand with the fine-grained monazite (tailings) falls on the periphery of the conical pile and is constantly brushed aside with hand brushes; these tailings are aftewards rewashed. Instead of pouring and brushing, the material is sometimes treated in a winnowing machine similar to that used in separating chaff from wheat.

Although the best grade of sand is as high as 85 per cent. pure, its quantitative proportion is small as compared with the second and other inferior grades, and there is always considerable loss of monazite in the various tailings. It is impossible to conduct this washing process without loss of monazite, and equally impossible to make a perfect separation of the garnet, rutile, titanic iron ore, etc., even in the best grades. The additional cost of such rewashing and rehandling must also be taken into consideration.

If the material washed contains gold, the same will be collected with the monazite in concentrating. It may frequently pay to separate it, which can easily be accomplished by treating the whole mass over again in a riffle box with quicksilver.

It has been shown that the monazite occurs as an accessory constituent of the country rock, and that the latter is decomposed to considerable depths, sometimes as much as 100 feet. On account of the minute percentage of monazite in the mother rock, it is usually impracticable to economically work the same in place, by such a process as hydraulicking and sluicing, for instance. However, even hillside mining has been resorted to. Such is the case at the Pheifer mine, in Cleveland county, N. C., 2 miles northeast of Shelby. (See Plate V.) The country rock is a coarse mica (muscovite and biotite) gneiss, and the small

LEVYTYPE CO. PHILA.

DIGGING AND WASHING HILL-SIDE SOIL FOR MONAZITE.

PHEIFER MINE, 3 MILES N. E. OF SHELBY. THE SOIL, 1-4 FEET THICK, HAS BEEN FORMED FROM MONAZITE BEARING GNEISS, IN PLACE.

monazite crystals may at times be distinctly seen, unaided by a magnifying glass, in this rock. It is very little decomposed and still quite hard, and the material that is mined for monazite is the overlying soil and subsoil, which is from 4 to 6 feet thick. This is loaded on wheelbarrows and transported to the sluice boxes below the water race. The yield is fairly good, and the product very clean, though the cost of working, of which, unfortunately, figures could not be obtained, must be considerably in excess of that of bottom mining. Where the rock contains sufficient gold, as it somtimes does, to be operated as a gold mine, there is no reason why the monazite can not be saved as a valuable by-product.

OUTPUT AND VALUE OF MONAZITE IN THE UNITED STATES.

As the percentage of thoria is variable in different sands, the value of the sand consequently varies in a measure also. It is stated that the transparent greenish and yellowish brown varieties are often rich in thoria, but this can not be depended on.

Hidden[1] has suggested that the difference in cleavage may be an indication of the presence or absence of thoria, that crystals with the cleavage best developed parallel to $\infty P \breve{\infty}$ are the pure phosphate of the cerium earths, free from thoria, while those in which the cleavage is best developed parallel to 0P, contain thoria. But the cleavage is rarely observable in the rolled grains, and if it were the above statement is by no means a proven fact. He also makes the suggestion (in paper above cited) that the density may afford a test of the approximate comparative amount of thoria present, and in support of this he mentions the following examples:

Relation of thoria contents to density in monazite.

Specific gravity.	ThO_2	Localities.	References.
	Per cent.		
5.30	14.23	Amelia Court-House, Va	Table, p. 20, anal. No. 32.
5.20-5.25	8.25	Portland, Conn	Table, p. 20, anal. No. 30.
5.10	6.49	Burke County, N. C	Table, p. 20, anal. No. 31.

However, this will scarcely hold, for in other instances monazite of the specific gravity 4.64 has been shown to contain

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[1] Am. Jour. Sci., vol. 32, 1886, p. 207. Zeitschr. für Kryst., vol. 12, 1887, p. 507.

as much as 9.20 per cent. thoria (from Moss, Norway; see p. 17, anal. No. 4); and again, monazite of the specific gravity 5.19 contained but 3.18 per cent. thoria (from Dillingsö, Norway; see p. 17, anal. No. 2). On the whole, there is no method of determining even the probable percentage of thoria, excepting by chemical analysis. Some monazite contains practically no thoria. The best North Carolina sands (highest in thoria) came from Burke and Cleveland counties. Some of the highest grade sand from Brindletown, Burke county, runs from 4 to 6.60 per cent. thoria; sand from Gum Branch, McDowell county, is reported to run 3.30 per cent; sand from the vicinity of Bellwood and Carpenter's Knob, in Cleveland county, runs from 5 to 6.30 per cent. The fluctuation of the thoria percentage is, however, considerable even in the same locality. It also depends, of course, in a measure on the degree of concentration of the sand.

The price of North Carolina monazite has varied from 25 cents per pound in 1887 to as low as 3 cents for inferior grades and 6 to 10 cents for the best grades in 1894 and 1895. It is only during the past two years that the mining and concentration of monazite sand in the South Mountain region has grown to a regular industry, and it is at present progressing with increased vigor. In 1887 Mr. Hidden shipped from the Brindletown district, in Burke county, N. C., 12 tons of monazite sand. And during 1888 and 1889 a number of tons (exact quantity unknown) were shipped from North Carolina to the Welsbach Light Company in Philadelphia. The product and value of the sand during 1893 and 1894 is given below. It was shipped in part to the Welsbach Light Company and in part to Europe (Germany and Austria).

Product and value of monazite in 1893 *and* 1894.

1893.		Value at mines.	1894.		Value at mines.
Quantity.	Price.		Quantity.	Price.	
Pounds.	*Cents.*		*Pounds.*	*Cents.*	
110,000	6	$6,600	460,000	....	$31,050
20,000	5	1,600	80.000	....	4,800
			6,855	....	343
130,000	....	7,600	546,855	....	36,193

In Brazil considerable deposits of monazite occur in the beach sands along the seashore. The largest of these is found in the extreme southern part of the Province of Bahia, near the island of Alcobaca. The surf as it breaks against the cliffs washes away the lighter earths and minerals, leaving naturally concentrated deposits of monazite along the beach. Sacks filled with this sand were shipped to New York in 1885, the deposit having been taken for tin ore. Its true character was, however, soon recognized, and since then a number of tons have been shipped in the natural state, without any further concentration or treatment, as ballast, mainly to the European markets. It is reported to contain 3 to 4 per cent thoria. Very little exact information concerning these Brazilian deposits is at present available. Monazite has also been found in the gold and diamond placers of the Provinces of Bahia (Salabro and Caravellas), Minas Geraes (Diamantia), Rio de Janeiro and São Paulo. It has been found in the river sands of Buenos Ayres, Argentine Republic, and also in the gold placers of Rio Chico, at Antioquia, in the United States of of Colombia.

In the Ural Mountains of Russia monazite is found in the Bakakui placers of the Sanarka River. The placer gold mines of Siberia are reported to contain monazite.

Economic deposits of monazite are also reported to exist in the pegmatite dikes of Southern Norway. It is picked by the miners while sorting feldspar at the mines. It is not known to exist in placer deposits. The annual output is stated to be not more than one ton, which is shipped mainly to Germany.[1]

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[1] U. S. Consular Report; vol. 48, No. 179, Aug. 1895, p. 550.

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