ART. XLVII.—*A New Occurrence of Carnotite*;* by
EDGAR T. WHERRY.*Introduction.*

THE more or less definite bright yellow uranium-vanadium mineral known as carnotite has been heretofore observed at a number of points in western Colorado and eastern Utah,† and as an alteration product of “davidite,” a rare-earth-bearing rutile, at “Radium Hill,” South Australia.‡ The purpose of the present paper is to call attention to its occurrence near Mauch Chunk, Carbon County, Pennsylvania.

In Genth’s *Mineralogy of Pennsylvania*§ autunite was stated to “have lately been found in a conglomerate from the neighborhood of Mauch Chunk,” the exact locality being, however, unknown. Specimens labeled similarly are included in several of the old collections of Pennsylvania minerals, but a study of these and of a considerable quantity of material collected at what is probably the original locality, the eastern end of Mt. Pisgah, immediately north of the town of Mauch Chunk, has shown that the mineral in question is really to be classed as carnotite.

Although the locality was re-discovered, by accident, by the writer in 1908, and the nature of the mineral proved by qualitative tests, detailed study was deferred in the hope of obtaining more satisfactory material when opportunity should present itself for thorough examination of the deposit. As this hope has not been realized, in spite of exhaustive search, it was decided to proceed with analysis of the specimens on hand, and to publish an account of the occurrence.

General Description.

The mineral presents the form of an amorphous to minutely crystalline bright yellow coating or impregnation in a conglomerate, often penetrating cracks in the quartz pebbles. Microscopic examination shows it to be quite impure, containing much limonite and clayey matter, and even the most crystalline-looking specimens show only an occasional translucent rectangular flake, with straight extinction, suggesting the tetragonal or orthorhombic system.

* Presented at the Baltimore meeting of the A. A. A. S., 1908; abstract in *Science*, vol. xxix, p. 751, 1909.

† Hillebrand and Ransome, *Bull. U. S. Geol. Survey*, No. 262, pp. 9-31, 1905; Fleck and Haldane, *Rept. State Bur. Mines, Colorado*, 1905-06, pp. 47-115, 1907; Gale, *Bull. U. S. Geol. Survey*, No. 315, pp. 110-117, 1907; *Bull. No. 340*, pp. 256-262, 1908.

‡ Crook and Blake, *Mineralogical Magazine*, vol. xv, pp. 271-284, 1910.

§ Report B, 2nd Penna. *Geol. Survey*, p. 144, 1874.

Chemical Composition.

Material for analysis was obtained by scraping off the coating from a specimen of rather friable conglomerate, and contained accordingly considerable amounts of quartz, as well as some limonite and kaolin. As the yellow substance proved to be entirely soluble in dilute nitric acid, while the greater part of these impurities are insoluble, this seemed adequate for the purpose in hand. Uranium and vanadium were determined by the method of Campbell and Griffin,* which was first tested on known solutions of the metals and found to give very accurate results. Iron and calcium were obtained in the usual ways, water by loss on ignition, and potassium, by difference. Barium, lead, and phosphoric acid could not be detected with certainty; the strong radio-activity of the mineral indicates the presence of radium, although its amount is of course too small to be estimated, while lack of material also prevented establishment of the presence of helium.

The analytical results are given in the first column of the accompanying table, and the figures obtained by deducting the insoluble matter, iron oxide and water, and recalculating the remainder to 100 per cent, in the second. The iron is certainly present as limonite, and while a part of the water may belong to the carnotite, the amount in this form is indeterminate, so it is best disregarded in calculating the formula. The results are given in the first decimal place only because of the unsatisfactory character of the sample. Most of this work was carried out, under the direction of the writer, by Mr. J. S. Long of Lehigh University, to whom much credit is due for skilful handling of the problems presented.

Analysis and Ratios.

	1	2	Ratios	
V ₂ O ₅	7.2	21.1	.116	1.00
UO ₃	23.8	69.8	.243	2.09
Fe ₂ O ₃	6.1	---		
CaO	1.5	4.4	.079	} .129 1.11
K ₂ O (diff.)	[1.6]	4.7	.050	
H ₂ O	10.5	---		
Insoluble	49.3	---		
	<hr/> 100.0	<hr/> 100.0		

Without attempting to place undue confidence in these results, it cannot be denied that they show a tendency to approach a definite ratio, (Ca, K₂)O.2UO₃.V₂O₅, or (Ca, K₂)

* Jour. Ind. Eng. Chem., vol. i, pp. 661-665, 1909.

$(\text{UO}_2)_2(\text{VO}_4)_2$, which is identical with that indicated by the previous work on carnotite.* Hillebrand† has shown, to be sure, that different samples of the mineral from Colorado vary rather widely in composition, yet throughout his and the other published analyses the ratio 1:2:1 for the three oxides is continually indicated. This is shown by the following table, in which the analyses have been recalculated to 100 per cent after deducting, as probably foreign to the mineral, the iron and phosphoric acid and also the water, whose amount is so variable that its rôle is uncertain.

Analyses of Carnotite (Recalculated).

	1	2	3	4	5	6
V_2O_5 -----	21.16	21.28	22.03	22.72	21.50	21.89
UO_3 -----	67.41	66.85	65.44	64.72	64.70	65.48
$\text{R}'\text{O}$ -----	----	----	4.59	4.12	4.73	5.86
$\text{R}'_2\text{O}$ -----	11.43	11.87	7.94	8.44	9.07	6.77
	100.00	100.00	100.00	100.00	100.00	100.00
	7	8	9	10	Calculated 1:2:1	
V_2O_5 -----	21.85	23.05	23.2	21.1	22.44	21.34
UO_3 -----	65.27	65.68	66.2	69.8	70.65	67.64
$\text{R}'\text{O}$ -----	6.48	6.40	3.2	4.4	6.91	----
$\text{R}'_2\text{O}$ -----	6.40	4.87	7.4	4.7	----	11.02
	100.00	100.00	100.0	100.0	100.00	100.00

1, 2, Colorado: Friedel and Cumenge, Bull. Soc. Franc. Min., vol. xxii, p. 26, 1899 and elsewhere; considerable $\text{R}'\text{O}$ probably present but overlooked and weighed with the $\text{R}'_2\text{O}$ (Hillebrand).

3-8, Colorado: Hillebrand, Bull. U. S. Geol. Survey, No. 262, p. 25, 1905.

9, South Australia: Crook and Blake, Min. Mag., vol. xv, p. 271, 1910.

10, Pennsylvania. The results of the present study.

Calculated, a, for $\text{R}' = \text{Ca}$; b, for $\text{R}' = \text{K}$.

The cause of the variations in these analyses is not altogether clear; but, after all, they are perhaps no greater than is to be expected in view of the non-homogenous character of the samples examined, and the difficulties of the analytical procedure. In any case the evident similarity of the material from the three widely separated localities justifies no other conclusion than that we are dealing with a definite mineral species, of the formula $(\text{Ca}, \text{K}_2)(\text{UO}_2)_2(\text{VO}_4)_2$.

This formula at once suggests relationship with the uranite or autunite group, the members of which contain, however, from 8 to 10 molecules of water of crystallization. The amount of water found in the various samples of carnotite

* Cf. Crook and Blake, loc. cit.

† Loc. cit.

varies from none in the Australian to perhaps 6 molecules in the Pennsylvania mineral, but then it must be remembered that most of this material is amorphous, leaving the question open as to its possible water content when well crystallized. The mineral may therefore be provisionally admitted to that group, which, named according to Washington's suggestion* (with one modification, the retaining of -ite as a termination, which, in the writer's opinion, may be desirable, to avoid confusion with chemical terms), becomes :

Uranite Group.

$R''(UO_2)_2(R''O_4)_2 \cdot 8H_2O$; chiefly orthorhombic.

Autunite	Ca	$(UO_2)_2(PO_4)_2 \cdot 8H_2O$.	Calcium phosphuranite
Uranospinite .	Ca	$(UO_2)_2(AsO_4)_2 \cdot 8H_2O$.	“ arsenuranite
Torbernite . .	Cu	$(UO_2)_2(PO_4)_2 \cdot 8H_2O$.	Copper phosphuranite
Zeunerite . . .	Cu	$(UO_2)_2(AsO_4)_2 \cdot 8H_2O$.	“ arsenuranite
Uranocircite .	Ba	$(UO_2)_2(PO_4)_2 \cdot 8H_2O$.	Barium phosphuranite
Carnotite (Ca,K ₂)		$(UO_2)_2(VO_4)_2 \cdot xH_2O$.	Calcium-potassium vanaduranite

Geological Relations.

Mt. Pisgah, the ridge extending westward from the Lehigh River just north of the town of Mauch Chunk, represents a synclinal mass of the Pottsville formation, the great series of interbedded sandstones and conglomerates regarded as the lowest member of the Pennsylvanian, overlying the Mauch Chunk red shale, the top of the Mississippian.† The contact between these formations, as exposed in the cuts of the highway and electric railroad across the eastern end of the ridge, is not a sharp one, but shows interbedding of the two types of sediment through a thickness of at least 100 feet. In addition to the red shale, there are also small lenses of black shale in the midst of the conglomerates.

The carnotite occurs in scattered streaks and patches throughout the lower portion of the conglomerate, not extending far above the last red shale layer, although ledges of conglomerate continue to be exposed 600 feet farther to the summit of the ridge. As the road turns westward, gradually rising across the beds, the layer containing it can be followed to a distance of 2000 feet, but then disappears beneath the roadway, and no trace of the mineral could be found at the corresponding horizon where again exposed near Tamaqua, 10 miles further west. Although its distribution is quite irregular, it is certainly most

* This Journal, vol. xxxiii, pp. 137-151, 1912.

† For a full description of these formations see Stevenson, Bull. Geol. Soc. Amer., vol. xiv, pp. 15-96, 1903 ; vol. xv, pp. 37-210, 1904.

frequently met with in the vicinity of the masses of black shale, and in fact small nodules of it are occasionally found in the shale itself.

That it has been deposited in its present form by circulating surface waters is clear. It is often locally concentrated along the more porous beds, and streaks may be observed beneath cracks in the rock from which water trickles out during wet weather. But its source is apparently to be sought in these lenses of black shale.

These dark shales do not owe their color to carbon, as might be supposed at first sight, but, as shown by microscopic examination, chiefly to the presence of hornblende, biotite, and other silicates in a fine state of subdivision, yet, in part, in fairly fresh condition. They can best be accounted for as a result of the peculiar climatic conditions which, as pointed out by Barrell,* prevailed here during late Mississippian times.

Under ordinary conditions of weathering silicates are decomposed, and only silica, kaolin, and ferric oxide remain to enter into the formation of sedimentary deposits. But in arid climates disintegration in general exceeds decomposition, so that heaps of greatly broken up, but comparatively unaltered, minerals will accumulate, and, when a more or less sudden change to conditions of heavier rainfall sets in, considerable quantities of these undecomposed minerals may be carried down into places of accumulation of sediments. These dark shales are believed, then, to represent "black sand" streaks, which, by reason of their distinctive specific gravity, have accumulated at points where the flow of the streams was favorable.

The materials of this portion of the Pottsville conglomerate were evidently derived from the crystalline Highlands of Pennsylvania, New Jersey, and New York; for while white quartz makes up the majority of the pebbles, occasional pieces of banded gneiss, crystalline limestone, and serpentine, of types familiar in that region can be seen in the carnotite-bearing beds. It has been found by Hillebrand† that vanadium is an almost universal constituent of igneous rocks, including the metamorphics of this Highland region, and is largely contained in their dark silicates. Under ordinary conditions of weathering much of this vanadium is carried away in solution, so that the average sediments contain only one-fifth to one-tenth as much as the rocks from which they were derived. In the present instance, however, it would seem reasonable to expect the concentration of practically all of the vanadium in the black shales as a purely mechanical process. Analysis of several samples of these rocks showed amounts varying from 0.08

* Bull. Geol. Soc. Amer., vol. xviii, pp. 449-476, 1907.

† Bull. U. S. Geol. Survey No. 167, pp. 49-55, 1900.

to 0.21 per cent V_2O_5 . These specimens were free from any visible admixture of carnotite, and that no microscopic inclusions of such a mineral were present was proved by the insolubility of the vanadium in nitric acid, as well as the absence of proportionate amounts of uranium, noted in the succeeding paragraph. This vanadium probably replaces other sesquioxides in the silicates;* and as the fine state of division of the latter renders them easily attacked by surface waters, oxidation of the vanadous compound and development of some secondary vanadate is the natural thing to expect.

Uranium is also present in the metamorphic rocks of the New York-Pennsylvania Highlands, as shown by the radioactivity† of several widespread minerals, such as allanite and zircon, as well as the occasional appearance of columbite, uraninite, etc. Because of analytical difficulties no attempts have been made to determine its proportion in these rocks as a whole, but it may perhaps mount into the hundredths per cent. On the disintegration of the rocks, as described above, the uranium-bearing minerals would, of course, be expected to accumulate in the black sand lenses, along with those carrying the vanadium. Chemical examination showed, however, only about 0.002 per cent of UO_2 to be present, an amount whose concentration by circulating waters seems rather unlikely. It is not impossible that some of the pebbles of the conglomerate may contain uranium minerals, but no definite evidence of this has been, or, in the nature of the case, is likely to be, obtained, so that the immediate source of the uranium entering into the carnotite remains obscure, although in the total absence of deep-seated vein phenomena there can be little question as to its ultimate derivation in some manner from the sediments.

The conclusion to be drawn from these studies is, then, that the development of the carnotite at this locality has been made possible by mechanical concentration of uranium and vanadium minerals originally distributed through large bodies of crystalline rocks, brought about by a sudden change from a dry to a moist climate. To claim an identical origin for the deposits in Colorado and Utah would be hazardous, yet the published descriptions show that they also occur in arenaceous formations overlying "Red Beds," and if similar climatic changes were responsible for the change in character of the sedimentation there, it is quite possible that the concentration of the constituents of the mineral has been brought about in the same manner.

Indeed, it may be permissible to suggest that the frequent

* Cf. Hillebrand, loc. cit.

† Wherry, Jour. Frank. Inst., vol. clxv, pp. 59-78, 1908.

association of these elements uranium and vanadium with coal, pointed out more particularly by Clarke,* has a similar significance. The upper portion of the Pottsville formation in the Mauch Chunk region contains interbedded coal seams, the development of which was certainly connected with the favorable stimulus to plant growth resulting from the same change of climate which made possible the formation of the carnotite. In general, even though the association is not a genetic one, it seems reasonable to expect that, whenever the period preceding that of coal formation has been so dry that dark silicates have been broken up and transported to the points where the coal flora is to develop without extensive decomposition, the elements uranium and vanadium may be looked for as constituents of the ash. Or, in other words, in their presence or absence, we may have a new method of throwing light on certain details of the climatic conditions of past geologic times.

Summary.

1. Carnotite has been discovered in a new locality, Mauch Chunk, Carbon County, Pennsylvania.

2. As it agrees in composition with material from Colorado and South Australia, and these agree among themselves better than has usually been supposed, carnotite is entitled to be classed as a distinct mineral species, with the formula $(\text{Ca}, \text{K})_2(\text{UO}_2)_2(\text{VO}_4)_2$, belonging to the uranite group.

3. The vanadium and probably the uranium also have been extracted by circulating surface waters from black shales, which have been formed in the midst of conglomerates by mechanical concentration of dark minerals from the crystalline rocks to the south and east, following the change from arid to moist climatic conditions at the beginning of Pennsylvanian time.

4. As the Colorado deposits occur in a similar position, their origin may have been the same, and it is suggested that the frequent association of these elements with coal may also be connected with such a climatic change.

Lehigh University, South Bethlehem, Pa.,
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* Bull. U. S. Geol. Survey No. 491, pp. 672-678, 1911.