The Vanadiferous Asphaltites of Central Peru

Occurring as a Series of Veins in Cretaceous Limestones, They Are Found in Four Districts—Vanadium Is Present, but Not in Sufficient Quantity To Make Commercial Extraction Profitable

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THROUGHOUT the period of the war, and during the year following the armistice, attention was turned to the asphaltite deposits of central Peru as a possible source of vanadium, the ores of which were then in considerable demand. Investigations of some of the more promising of these deposits were made by a number of engineers with a view to burning the asphaltite and producing an ash sufficiently high in vanadic oxide to warrant its exportation to the United States or England. After satisfactory tests had been carried on in the laboratory, several practical experiments were made in the field on small lots, but the results obtained were not definite enough to justify the exploitation of any of the deposits on a commercial scale. It is extremely doubtful, in fact, whether the contained vanadium of these asphaltites could ever be profitably extracted, except under abnormal conditions.

Many of the Yauli and Huari deposits have been worked intermittently for the last thirty years, the asphaltite being burned under boilers and in reverberatory furnaces, and used for domestic purposes.

OCCURRENCE OF VANADIUM COMMON IN PERUVIAN ASPHALTITES

The presence of vanadium in the Llacsacocha asphaltite was discovered as early as 1892, at which time the mine was being worked by a French company to furnish fuel for boilers at the near-by silver mines of Andaychagua. Several tons of the ash are reported to have been shipped to France for experimental purposes. Subsequent investigations showed that the occurrence of vanadium was not confined to the Llacsacocha deposit, but that practically all of the asphaltites of the region carried appreciable amounts of the metal.

D. Foster Hewitt has described some of the asphaltites of the Yauli district in connection with his reports on the famous Minasragra mine of the Vanadium Corporation, and has suggested an interesting theory of their origin. Among other authorities who have discussed these deposits are W. F. Hillebrand, W. G. Wagner, Lester Strauss, F. Malaga Santolalla, and C. L. Romero. In 1919 I had occasion to make a detailed study of this field, and I present herewith some of the data obtained at that time.

OCCURRENCE IN FOUR DISTRICTS

The vanadiferous asphaltites of central Peru are found in the departments of Junin and Lima, along both slopes of the western Cordillera of the Andes, at altitudes ranging from 12,000 to 16,000 feet. The known occurrences extend from Marcapomacocha on the north to Sillapata on the south. They may be roughly divided into four districts, the location of which is shown on the accompanying map.

The district of Yantac, near Marcapomacocha, comprising part of the Province of Yauli, Department of Junin, and part of the Province of Canta, Department of Lima, lies about twenty-eight miles over rough trails from Casapalca, on the Central Railway of Peru, at an altitude of over 15,000 ft. More than a dozen veins have been discovered. They occur interstratified in limestone of Cretaceous age and vary in thickness from a few inches to five feet. The asphaltite carries from 10 to 20 per cent ash, which runs from 5 to 16 per cent vanadic oxide, with an average of about 7 per cent. A typical analysis of the asphaltite is as follows: Moisture, 5.2 per cent; volatiles, 10.3 per cent; fixed carbon, 72.2 per cent; ash, 12.3 per cent.

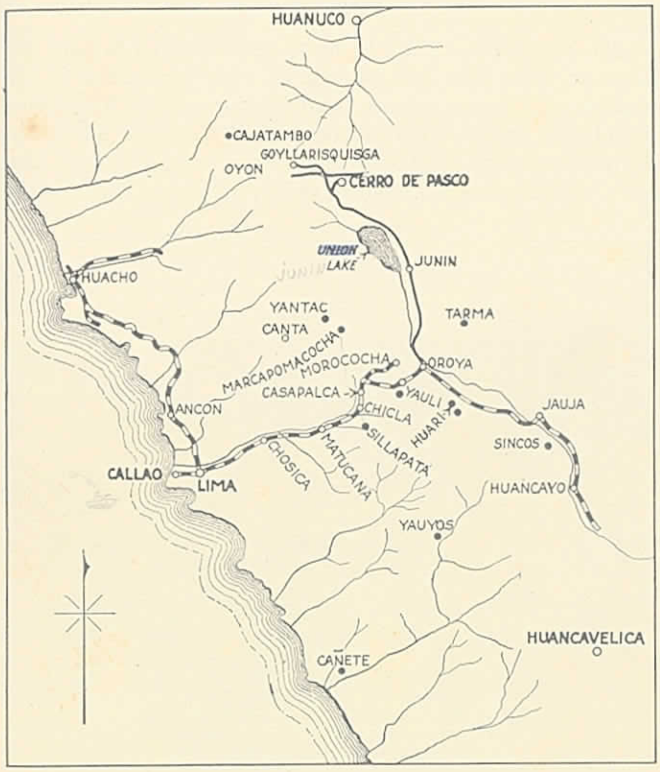
The Yantac district is at present of little or no commercial importance as a source of fuel, because of the difficulties of transportation and the irregular occurrence of the asphaltite in *rosarios*, or small lenses separated by nearly barren stretches. Furthermore, the high percentage of ash and the comparatively low vanadium content render the asphaltite unsuitable as a source of the alloy.

THE DISTRICT OF YANTAC (MARCAPOMACOCHA)

The asphaltite deposits of Sillapata are situated in the Province of Huarochiri, Department of Lima, fifteen miles from the railway station of Matucana, at an altitude of 14,000 ft. The veins occur in a strip of metamorphosed limestone between two large flows of rhyolitic rocks. They are narrow and irregular, the asphaltite having been deposited both along the planes of stratification of the limestone and in fissures cutting across the formation at various angles. The asphaltite is low in volatiles and high in fixed carbon and ash. It breaks fine, and, consequently, is practically worthless for domestic use. The vanadium content of the asphaltite will average slightly less than 1 per cent V_2O_5.

The most important deposits of asphaltite are found near Huari, a small town in the Province of Tarma, Department of Junin, lying a few miles west of the southern extension of the Central Railway, at an elevation of 12,000 ft. The mineral is more nearly a true asphaltite (grahamite) in its appearance and behavior and in analysis. There are two deposits in the Huari district which warrant a brief description.

The Chiucho Mine.—This property is situated fifteen miles from the railway, at an elevation of about 13,800 ft. It has been worked to a depth of 150 ft. and produces about 300 tons of asphaltite per month. The asphaltite occurs in lenticular deposits interstratified in a series of limestones and sandstones. The principal vein, which varies in thickness from 6 in. to 35 ft., strikes northwest and southeast, with a nearly vertical dip. Unlike most of the other asphaltites, the mineral burns with a long, yellow, smoky flame and easily melts down into a sticky, tar-like substance. Owing to its low ash, the asphaltite is regarded highly as fuel. A typical analysis of Chiucho asphaltite is as follows: Moisture, 2.35 per cent; volatiles, 40.45 per cent (sulphur, 4.9 per cent); fixed carbon, 55 per cent; ash, 2.20 per cent.



SKETCH MAP OF CENTRAL PERU SHOWING THE LOCATION OF THE ASPHALTITE DEPOSITS

The percentage of vanadium present in the ash is unusually low, ranging from 1 to 2.5 per cent.

The La Lucha Mine.—This property is situated five miles from the railway, to which it is connected by a small tramway. The vein, which follows the bedding planes of limestone, consists of a series of lenses widely separated by long barren stretches. A notable feature of the deposit is the number of narrow, horizontal stringers of asphaltite which branch off from the vein and penetrate the cracks in the limestone. The asphaltite is similar in character to that of the Chiucho mine, though somewhat higher in ash and even lower in vanadium. A typical analysis is as follows: Moisture, 1.15 per cent; volatiles, 48.65 per cent (sulphur, 5.2 per cent); fixed carbon, 44.48 per cent; ash, 5.72 per cent.

The asphaltites of the Yauli district, which, with the exception of the Rumichana mine, are not at present important as a source of fuel, are of interest because of their generally high vanadium content, and the consequent possibility of their being worked for that element. The asphaltite is distinctly anthracitic in character, is low in ash, and burns with little or no flame, leaving a light, feathery ash, which when exposed to the weather becomes green, owing to the presence of vanadic oxide. It occurs in highly deformed and tilted limestones of Upper Cretaceous age, both along the planes of stratification and in gash veins cutting independently across the formation. To illustrate the varied types of deposits in the district three characteristic veins will be described.

Llacsacocha Mine.—The old Llacsacocha mine lies thirteen miles, by trail, south of the town of Yauli. The asphaltite, though softer, resembles certain types of anthracite in appearance. It is black and lustrous, apparently free from pyrite, and occurs as a series of lenses which may be traced for more than 1,200 ft. along a single bedding plane in limestones dipping at angles of from 55 deg. southwest to nearly vertical. Numerous faults of small displacement and lines of shearing within the lenses are evidences of considerable local movement since the formation of the asphaltite. With the asphaltite are associated bands of dark shale.

At first glance the deposit appears to be an ordinary seam of somewhat crushed semi-anthracite coal, but closer inspection reveals tiny fissures filled with asphaltite radiating from the main vein. The inclusion of "horses" of waste within the asphaltite, and especially the manner in which it has been deposited around these fragments, are additional proof of the origin of the vein.

About one hundred feet east of the Llacsacocha vein in the foot-wall country rock occurs an intrusive sheet of light green, acidic rock, which also follows the bedding planes of the limestone. This intrusion may have had some influence in the alteration of the original asphaltum to its present anthracite state. Several analyses of the clean Llacsacocha asphaltite are available, and of these the following is a typical example: Volatiles, 88.2 per cent; fixed carbon, 9 per cent; ash, 2.8 per cent.

Samples of several piles of clean asphaltite on the dumps averaged 3 per cent ash, carrying 15 per cent V_2O_5, indicating a vanadium content in the material of but 0.45 per cent V_2O_5. Mr. Hewitt, however, gives as the result of thirty-seven samples, secured from the workings, an average of 7.3 per cent ash and 1.06 per cent V_2O_5 in the asphaltite, which probably more nearly represents the average vanadium content of the deposit as a whole, inasmuch as the "bone" appears to run higher in the metal than the clean asphaltite. It is probable that asphaltite could be produced in some quantity from the mine which would average from 4 per cent to 5 per cent ash, with 15 per cent to 20 per cent as the proportion of V_2O_5 in the ash. In actual practice the percentage of ash would be higher, owing to the difficulty of obtaining complete combustion. Although the vanadium content of the asphaltite may average 1 per cent V_2O_5, attempts to burn it on a commercial scale have not proved successful, because of the mechanical difficulty of securing an ash free from unburned asphaltite and the fact that the proportion of ash in it is so low that, even should a clean ash be obtained, the large tonnage that must be mined and burned to produce a ton of ash makes the cost almost prohibitive.

Rumichaca Mine.—This property is probably the largest of the Yauli series. Owing to its favorable location on the railway, the mine has been extensively worked for the last eight years, the asphaltite being shipped to the Casapalca smelter. The asphaltite is similar in character to that of Llacsacocha, but breaks finer in mining, making it of little value, except for certain smelter purposes. It occurs in irregular lenses interstratified in limestone, and varies in thickness from a few inches to forty feet at one point. The strike is north 37 deg. west, and the dip varies from 70 deg. southwest to vertical.

A large number of samples, taken from the run-of-mine, clean-screened asphaltite and "bone," show that although the "bone" is much higher in ash, it is also somewhat richer in vanadium. The average of all samples gave 16 per cent ash, with 5.3 per cent V_2O_5 in the ash. Samples of a 2,000-ton pile of clean asphaltite gave an average of 9 per cent ash, which carried 7 per cent V_2O_5. Experiments were made in burning the Rumichaca asphaltite for its vanadium, resulting in the production of 1.5 tons of ash averaging 8 per cent V_2O_5. Great difficulty was experienced in causing the asphaltite to burn, owing to the predominance of fines. No doubt special furnaces could be devised to handle this material, but the vanadium content appears to be too low to warrant such an undertaking.

Negrita Mine.—The Negrita mine, situated fifteen miles from the railway, near Huallacocha Lake, at an altitude of nearly 16,000 ft., is an excellent example of the true fissure of asphaltite cutting across the limestones and shales of the district. The vein strikes northeast and dips 60 deg. northwest. Three distinct lenses have yielded about 2,000 tons of asphaltite of good quality. Where the vein cuts a stratum of shale it becomes narrow and badly split up, owing, probably, to the greater elasticity of the shale, in which a clean fracture is less likely to be produced than in the limestone. However, at a distance of about a thousand yards, another vein, known as the Cacharata, exhibits a two-foot fissure of asphaltite, which is entirely across a series of shales. Both veins are not far from a large intrusion of monzonite.

A sample from the only available pillar in the Negrita workings showed 2 per cent ash, with 17 per cent vanadic oxide in the ash. A general sample of a pile of 130 tons of asphaltite gave 9.5 per cent ash, carrying 5 per cent vanadic oxide. Although the Negrita asphaltite breaks more coarsely and is generally purer than that of Llacsacocha or Rumichaca, it is similar in appearance and analysis.

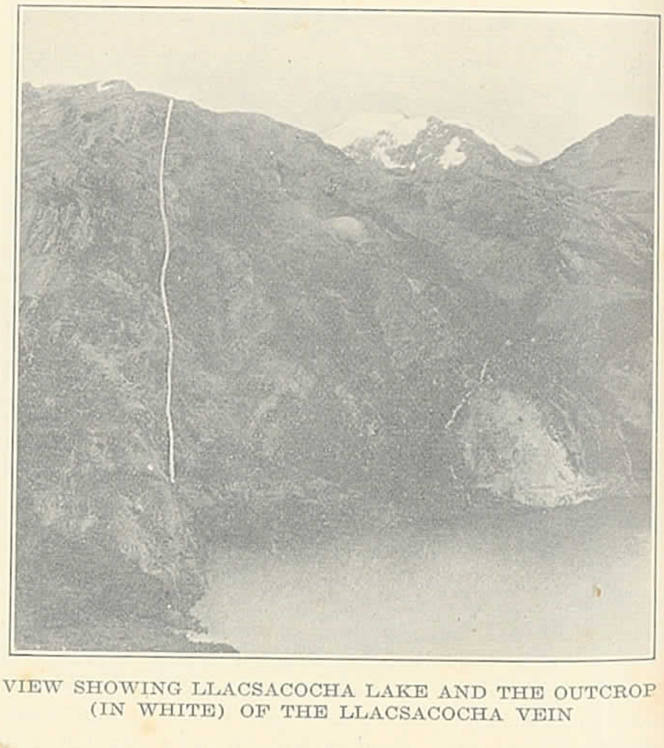
Asphaltites Occur as Lenses in Cretaceous Limestones

It will be noted from the foregoing that, with the exception of the Huari veins, there exists a marked similarity in the occurrence and geological association of the Peruvian asphaltites. They are all found as series of lenses in extremely deformed and tilted limestones of Cretaceous age, in which are narrow interbedded bands of shale. They appear to be invariably in the neighborhood of later igneous rocks, a circumstance which may be only accidental, or may have exercised some influence in the formation of the deposits. The asphaltites exhibit little or no pyrite, but carry from 2 to 5 per cent of sulphur. They all contain vanadium, which is probably present as a sulphide.

Judging from their analyses and physical properties, the Huari asphaltites must be classed as grahamite (G. H. Eldridge, 22d Ann. Rep., Geol. Sur. 1901). Practically all of the other asphaltites more nearly resemble impsonite, although in many cases the proportion of fixed carbon to volatile hydrocarbon is higher than that indicated in typical analyses of impsonite. The impsonite varieties undoubtedly represent a later stage in the metamorphosis of the asphalts than the grahamites of Huari. Their relation to the grahamites corresponds to that between anthracite and bituminous coal. The difference between the two types of asphaltite may be due to greater distortion of the sedimentary strata in which the impsonite occurs and to the proximity of recent igneous rocks.

Lenses Show Characteristic Widening and Pinching

The asphaltites seem to have been formed toward the close of the period of movement which resulted in the violent warping, faulting, and tilting of the limestones which are so prevalent in central Peru. The lenticular formation of the deposits may be due to the fact that they are invariably fissure veins, whether they follow or cut across the bedding planes of the limestone. These fissures having originally had a somewhat undulating course, subsequent movement has brought the concave and convex portions of the fissure walls opposite each other, causing the characteristic widening and pinching of the asphaltite.



VIEW SHOWING LLACSACOCHA LAKE AND THE OUTCROP (IN WHITE) OF THE LLACSACOCHA VEIN

Fairly definite theories have been advanced regarding the origin of asphaltites in general. In Peru it would appear that certain fissures had tapped "pools" or reservoirs of heavy asphaltic petroleum existing either in the limestones and shales or in some underlying formation. The oil probably arose in the fissure, owing to hydrostatic pressure, much as it rises in many wells when the oil sands are perforated. True asphalts were then formed by the inspissation of the petroleum. They were the products of natural distillation, the volatile constituents of the original petroleum having been lost. Subsequent pressure, creating a tendency for the fissure to close and thus squeeze the asphaltum filling, caused some of the material to be forced out into the tiny joints and crevices of the wall rock. Continued pressure, aided possibly by heat and by the presence of sulphur in the form of sulphuretted hydrogen, produced a general hardening of the material and a metamorphosis to its present coal-like state.

Explanation of Vanadium Concentration Difficult

The origin of the vanadium in the asphaltite presents an interesting, if difficult, problem. Vanadium is known to occur in minute quantities in many rocks, both igneous and sedimentary, but its possible presence in the country rock of these asphaltites would scarcely explain its concentration and intimate mixture with the asphaltite. Assuming that the asphalt was derived from petroleum which originally occurred in the surrounding sediments and which found its way into open fissures, presumably this oil followed certain definite channels in reaching such fissures. It is hard to conceive of its having percolated through the entire rock mass in such a manner as to dissolve and collect any vanadium present, even if the chemical reactions required in such a process were possible.

There seems to be a relation between the bitumens and the presence of vanadium. Although I was unable to discover any instance of vanadium having been detected in asphaltic petroleum, traces of the metal have been found in many asphaltite veins in the United States, and even in deposits of asphalt. This association is particularly marked at Minasragra, Peru, the most important known deposit of vanadium in the world, which Mr. Hewitt regards as "an extreme phase of differentiation from asphaltite." Again, in the Province of Jauja, many miles from the nearest asphaltite deposit, I examined a stratum of black carbonaceous shale of great length, and more than thirty feet in thickness, which careful sampling showed to have an average vanadium content of over 1 per cent V_2O_5.

The unlikelihood of vanadium having been derived from the rocks in which the asphaltite fissures are found, or from vanadiferous solutions circulating in the veins during their formation, together with the widespread occurrence of vanadium associated with asphalts, asphaltites, and even oil shales, in various parts of the world, leads me to believe that the metal was an original constituent of the asphaltic petroleum or bitumen from which the Peruvian asphaltites were formed.

South African Gold Production

The following table, compiled by the Transvaal Chamber of Mines, shows the comparison between the Transvaal gold output in quantity and value for the years 1919 and 1920:

	1919	1920
Witwatersrand:		
Yield, ounces	8,111,271	7,949,585
Estimated value	£38,261,020	£43,486,224
Outside districts:		
Yield, ounces	218,820	204,587
Estimated value	£1,032,180	£1,118,631
Transvaal:		
Yield, ounces	8,330,091	8,154,172
Estimated value	£39,293,200	£44,604,855

Movements of Metals and Ores

Imports and exports of the more important metals and ores to and from the United States as reported by the Department of Commerce for March, 1921, and the figures for March, 1920, as finally revised, are as follows:

IMPORTS MARCH, 1920 AND 1921
(In Pounds, Unless Otherwise Stated)

	March, 1920	March, 1921
Antimony ore, contents	89,653	....
Antimony matte, regulus, or metal	4,665,778	1,776,484
Brass, fit only for remanufacture	2,819,756	539,068
Copper:		
Ore, contents	4,638,591	4,029,414
Concentrates, contents	2,952,288	4,816,400
Matte, regulus, etc., contents	2,175,457	1,020,103
Imported from (in part):		
Spain	118,720	123,648
Canada	4,900,757	423,480
Mexico	1,939,658	2,432,400
Cuba	....	2,852,773
Chile	1,980,494	2,782,246
Venezuela	....	49,307
Peru	49,227	330,952
Unrefined, black, blister, etc	19,108,437	12,448,823
Refined, in bars, plates, etc	10,139,643	324,060
Old, etc., for remanufacture	120,824	35,062
Composition metal, copper chief value	8,897	450
Lead:		
Ore, contents	1,698,771	341,211
Bullion, contents	2,582,956	1,867
Imported from:		
Canada	1,141,974	163,269
Mexico	3,132,378	9,867
Other countries	7,375	169,942
Pigs, bars and old	563,031	1,993,264
Imported from:		
Germany	....	127
Canada	2,880	7,800
Mexico	560,151	1,985,337
Manganese ore, long tons	18,970	69,710
Imported from (in part):		
Cuba, long tons	29	....
Brazil, long tons	12,200	30,750
British India, long tons	1,000	38,460
Tungsten ore, long tons	217	64
Pyrites, long tons	14,251	18,773
Imported from:		
Spain, long tons	14,251	11,223
Tin ore, long tons	541	1,852
Tin bars, blocks, pigs, etc	11,980,019	3,028,356
Imported from (in part):		
United Kingdom	1,764,609	907,289
Straits Settlements	9,490,145	1,689,489
Hongkong	409,613	319,201
Australia	159,510	56,000
Zinc:		
Ore, contents	5,355,218	981,494
Imported from:		
Canada	786,963	470,927
Mexico	4,568,255	510,567
Blocks or pigs and old	2,748	6,162,061

EXPORTS OF COPPER, LEAD AND ZINC
(In Pounds)

	March, 1920	March, 1921
Copper:		
Concentrates, contents	10,000	60,970
Unrefined, black, blister, etc	....	33,613
Refined, in ingots, bars, etc	82,266,959	36,574,236
Exported to (in part):		
Belgium	2,605,158	2,106,438
France	7,203,950	2,925,938
Germany	10,661,454	19,020,962
United Kingdom	12,439,106	7,406,780
Canada	4,861,385	1,224,040
Netherlands	2,652,061	1,164,846
Composition metal, copper chief value	60,308	3,216
Old and scrap	5,600	....
Pipes and tubes	405,756	293,826
Plates and sheets	2,267,786	830,544
Wire, except insulated	2,965,129	984,878
Lead:		
Pigs, bars, etc.:		
Produced from domestic ore	960,207	77,458
Produced from foreign ore	4,894,156	3,138,794
Exported to (in part):		
Netherlands	896,000	784,000
Sweden	448,000	112,000
United Kingdom	448,000	2,017,347
Argentina	421	112,000
China	112,172	1,200
Canada	730,234	21,649
Zinc:		
Dross	1,481,676	7,340
Spelter:		
Produced from domestic ore	18,542,204	174,106
Produced from foreign ore	9,516,034	....
Exported to (in part):		
France	6,309,990	....
United Kingdom	18,706,833	....
Canada	18,063	3,750
Mexico	1,295	136,833
In sheets, strips, etc	2,481,851	171,865