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UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, SECRETARY

BUREAU OF MINES
JAMES BOYD, DIRECTOR

REPORT OF INVESTIGATIONS

INVESTIGATION OF SUBLETTE RIDGE VANADIUM DEPOSIT, LINCOLN COUNTY, WYO.

BY

PAUL T. ALLSMAN, FOREST H. MAJORS,
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INTRODUCTION AND SUMMARY

The vanadiferous deposits of the Sublette Ridge and Salt River Range, 2 miles east of Raymond, Idaho, in western Lincoln County, Wyo., were examined August 24 to August 30, 1942, by an engineer of the Bureau of Mines, who was shown these properties by W. W. Rubey of the Geological Survey, Washington, D. C.

The Sublette Ridge deposits are owned by the former U. S. Phosphate Co. H. F. Chaney, Portland, Oreg., is the representative for the company.

The following report covers the history of the district, outlines the physical features and communications, mentions the property, and notes the ownership. The deposits and ore are described, and work performed by the Bureau of Mines is explained in detail. Ore-dressing tests and methods are explained.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is made: "Reprinted from Bureau of Mines Report of Investigations 4476."

2/ Mining engineers, Bureau of Mines, Salt Lake City, Utah.

ACKNOWLEDGMENTS

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HISTORY

The presence of vanadium in phosphate rock of the Phosphoria (Permian) formation was reported first by the Geological Survey in a report by George R. Mansfield in 1927.[3]

During the progress of work by the Geological Survey in this area in 1938, shale beds carrying values as high as 1.2 percent V_2O_5 were discovered.

After this preliminary investigation, the Geological Survey began a study of vanadiferous beds in the region, the results of which were disclosed in an announcement by W. W. Rubey and V. E. McKelvey on July 23, 1942.[4]

Following this announcement, the Bureau of Mines was requested to explore the deposit. Operations were begun in October 1942. Soon afterward, the Wyodak Coal & Manufacturing Co. began a parallel program of exploration, which continued until the Bureau of Mines completed its work in January 1943.

The Anaconda Copper Mining Co., at Conda, Idaho, has been recovering vanadium as a byproduct from their phosphate-mining activities. At the Conda mine, the vanadium occurs in the phosphate beds in percentages of approximately 0.18 to 0.32 V_2O_5.

PHYSICAL FEATURES AND COMMUNICATIONS

The vanadiferous beds occur on the western flank of Sublette Ridge. The altitude of the outcrop area of the deposit ranges from 6,400 to 7,300 feet. Sublette Ridge attains an altitude of over 9,000 feet. The floor of Thomas Fork Valley west of Sublette Ridge is at an altitude of 6,300 feet. The climate of the region is typical of Rocky Mountain areas, with considerable precipitation in the mountains and semiarid conditions existing in the valleys. Winters are long and severe, with temperatures reported as low as 52° F. below zero. Summers are mild and pleasant.

The most important streams near the deposit are Raymond Creek and Thomas Fork Creek. Raymond Creek has a flow of about 20 second-feet in August. It crosses the deposit transversely at Raymond Canyon and could be developed for milling purposes. All water resources of the area are used for irrigation, and rights to its use are owned by residents of Thomas Fork Valley. Thomas Fork Creek flows through Thomas Fork Valley from north to south and empties into the Bear River.

The paved Wyoming State Highway 91 parallels the deposit about 1 mile distant. Secondary dirt roads connect the deposit with the highway.

3/ Mansfield, George R., Geography, Geology, and Mineral Resources of Part of Southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 1927, p. 212.

4/ Rubey, W. W., and McKelvey, V. E.: U.S. Geol. Survey Manuscript Rept., July 23, 1942.

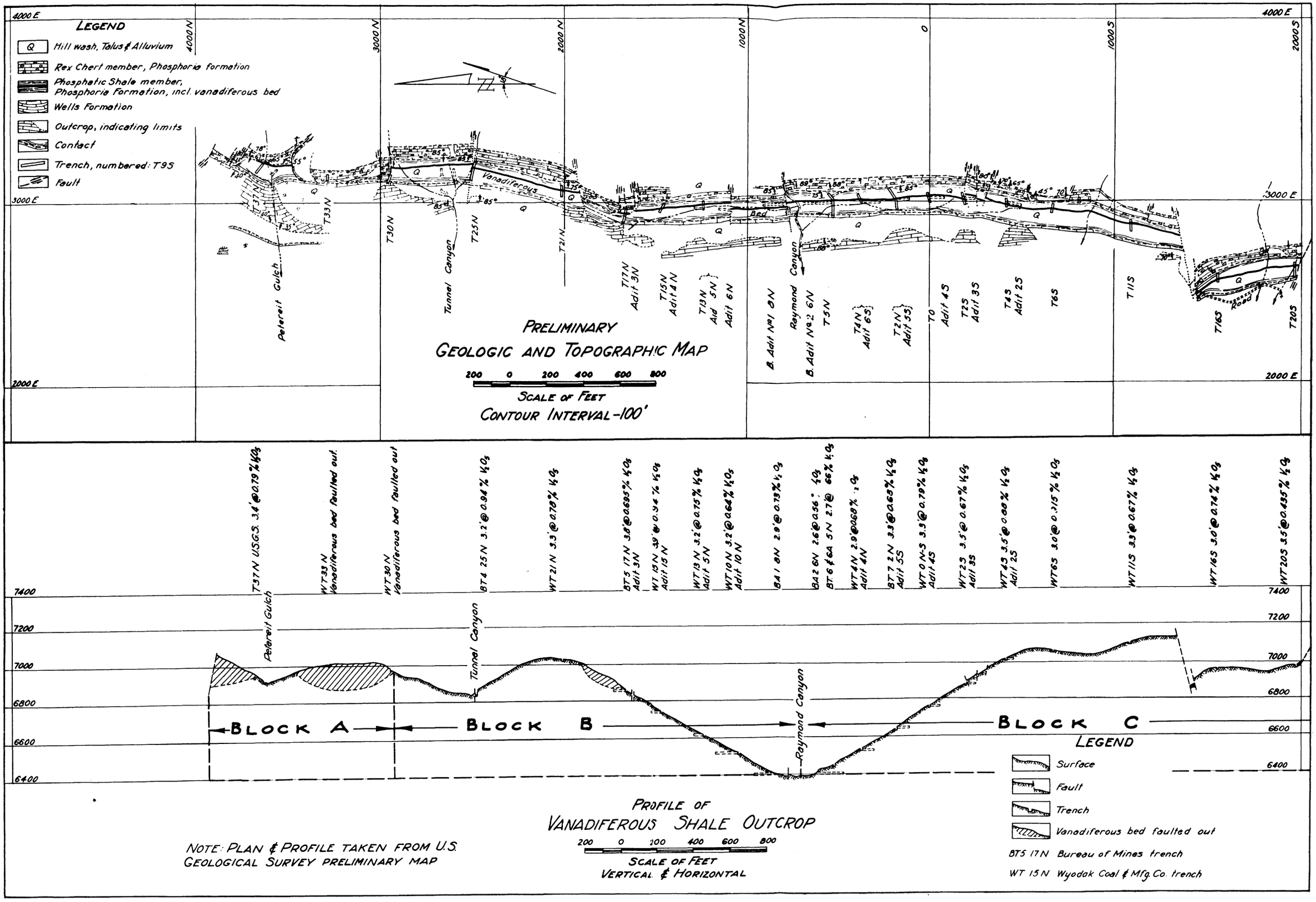

Figure 1. - Sublette Ridge vanadium district, Raymond Canyon-Petereit Gulch area, Lincoln County, Wyo.

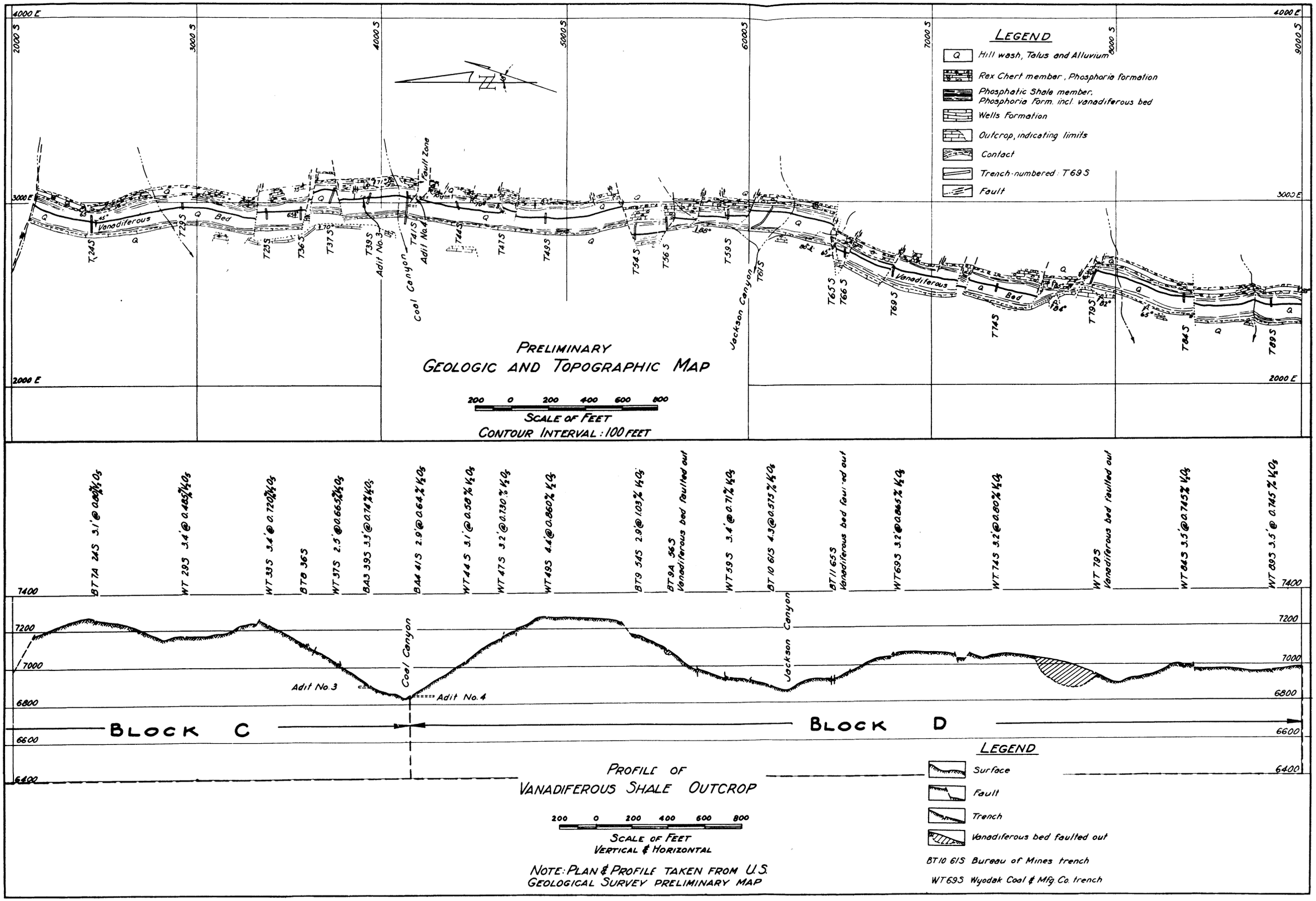

Figure 2. - Sublette Ridge vanadium district, Coal Canyon-Jackson Canyon area, Lincoln County, Wyo.

The nearest shipping point, at Border, Wyo., approximately 4 miles from the deposit, may be reached via Wyoming State Highway 91. Montpelier, Idaho, (population 2,500), 22 miles from the deposit, is the nearest town of sufficient size to serve as a source of small tools and some operating supplies.

PROPERTY

The Sublette Ridge deposits are privately owned. The deposit is controlled by the former U. S. Phosphate Co. H. F. Chaney, of Portland, Oreg., is the owner*s representative (1942), and exploration agreements were made through him by the Bureau of Mines. The deposits are in sec. 19, T. 27 N., R. 119 W.; sec. 31, T. 27 N., R. 119 W.; and secs. 6, 7, and 18, T. 26 N., R. 119 W. The property is operated by the Wyodak Coak & Manufacturing Co. under contract with Metals Reserve Co.

THE DEPOSITS

The prevailing country rocks in the area are carbonaceous, phosphatic shales and argillaceous and cherty limestones, all members of the Phosphoria formation of Permian age and of sedimentary origin (figs. 1 and 2).

The vanadiferous bed is composed of a black, carbonaceous shale 2.5 to 4.3 feet thick. Stratigraphically, this bed occurs in the Phosphoria about 50 feet below the base of the Rex limestone-chert member. The line of outcrop extends through two separate areas for a total of about 6.5 miles. The smaller area is that of the northern Sublette Ridge deposit, and the larger area is that of the southern Sublette Ridge deposit. The bed appears to have been omitted by faulting between the two areas from a point north of Petereit Canyon for a distance of about 1.5 miles.

The Phosphoria formation in the northern Sublette Ridge is on a highly compressed and eroded anticline in which a U-shaped line of outcrop is formed by the vanadiferous bed. The southern Sublette Ridge deposit is on the eastern exposed limb of the same anticline in which the northern deposit occurs. Natural exposures and exposures by trenching of the vanadiferous shale bed occur on the west limb of the anticline, on the north slope of Evans Canyon. At this point, the black vanadiferous bed is 33 inches thick, weathers brownish-gray, and is overlain by a dense limestone stratum 24 inches thick. The beds at this locality strike N. 50° W. and dip 60° W. Another vanadiferous bed in Coal Canyon, on the southern deposit, is 33 inches thick and is overlain by an 18-inch limestone bed and underlain by 13 inches of slightly vanadiferous shale, under which lies a bed of limestone 1 foot thick. At this point, the strike is northerly and the dip 70° E. In Raymond Canyon, near the north end of the southern deposit, the Phosphoria formation is essentially vertical, the dip gradually flattening southward to about 50° in Francis Canyon. The line of outcrop extends over a vertical range of several hundred feet.

The bed weathers to a soft, friable shale on the line of outcrop, whereas underground it is medium-hard. Sectional sampling and chemical analyses of the

hard, unweathered bed indicate that the principal values are contained in the upper 30 inches of the bed, which assays 1.0 percent V_2O_5. The total width of the bed, 3.3 feet, averages 0.746 percent V_2O_5.

The vanadium mineral of these deposits has not been determined, but the available evidence indicates that values are contained in an organo-vanadium compound. As no evidence of leaching or secondary deposition is present in the deposits, it is assumed that the vanadiferous compound is relatively insoluble.

The continuity of the deposits has been interrupted by numerous faults. These are classified in two systems. One type displaced the bed transversely, and the other produced thickening, thinning, and in places omission of the bed along the strike. The importance of the latter system may be great, as it is assumed that the strike faults are complements of a parallel regional fault in the area.

From the vicinity of Raymond Canyon, the transverse faulting becomes more pronounced toward the north and south extremities of the area. The numerous faults have divided the deposits into isolated and partly disconnected segments. Because of this condition, the costs of development and mining will be excessive. However, the dip of the deposits and their relation to the surface features are favorable for drift-and-raise development from adit levels.

THE ORE

Not considering the altered ore, which has only a surface occurrence, two types of ore were represented by the samples studied - (1) laminated, shalelike material and (2) lenticular fragments up to 6 inches in diameter.

1. Thin sections of the laminated ore show the presence of very small particles of quartz, feldspar, and calcite, with sporadic occurrences of chlorite. The distribution of these minerals in the groundmass is uniform, but their grain size varies from a maximum of approximately 280-mesh to 1,600-mesh. The areas between the quartz, calcite, and feldspar grains are opaque and comparable in size to that of the transparent minerals. Many of the nonmetallics are stained cinnamon brown by inclusions of micron-size particles.

2. Sections of the lenticular phase of the ore show that it is harder and more compact than the laminated ore and, also, that it is relatively high in lime, almost to the exclusion of silica. Occasional veins of secondary calcite occur as a filling in fracture, and rhombohedral crystals of calcite are common. This phase of the ore appears to be a replacement of limestone, and the fragments of calcite are uniformaly scattered through the carbonaceous material.

Analyses of a typical section of the vanadiferous bed follows:

	Assay, percent		Assay, percent
Insoluble	57.8	V_2O_5	0.61
SiO_2	43.6	SO_4	.05
Fe	3.10	Loss on ignition	15.4
CaO	9.30	Pb	.05
S	3.85	MgO	1.85
CO_2	6.80	Cu	.025
Al_2O_3	12.55	Au	.00
C	9.90	Ag	.26
P	.83		

With the exception of the vein calcite, the lime is notably discolored by what appears to be diffused carbonaceous material. The average grain size of the calcite particles is about 280-mesh, although some of the well-developed crystals are 65- to 299-mesh.

Examination of finely crushed ore indicated that the carbonaceous slime adheres tenaciously to the surfaces of the calcite and siliceous grains, which indicates that it would be difficult to remove them from a finely ground pulp by flotation.

Minus 200-mesh grinding will be necessary to liberate the calcite and siliceous grains from the carbonaceous matrix, which obviously will produce a very fine slime. Examination of polished surfaces of both types of ore resulted in the identification of sulfide particles of minus 1,600-mesh dimensions. Study of these particles with an oil-immersion objective at 1,050 diameters magnification indicated that they represented two species of minerals - (1) definitely pyrite and (2) a darker-colored, softer sulfide somewhat like chalcopyrite or pentlandite.

These sulfides occur uniformly distributed through the ore but differ in their mode of association. The pyrite appears to occur independent of any other mineral in the ore, but the softer sulfide mineral is almost invariably associated with a gray mineral having a slightly bluish tint.

WORK BY BUREAU OF MINES

Several short adits and one adit approximately 400 feet in length were driven during prospecting work conducted by the former U. S. Phosphate Co. Most of these were inaccessible when the Bureau of Mines began to explore the deposit. These adits and several trenches were worked a few years ago to prospect for phosphate beds that occur in the Phosphoria formation.

York Canyon

The Bureau of Mines reopened the longer adit in York Canyon for a distance of 380 feet. Retimbering through several caved sections was necessary. This adit was driven across the strike of the Phosphoria formation through strongly faulted ground. Careful geologic mapping and sampling failed to locate the vanadiferous bed. Work was continued beyond the normal position of the bed.

Therefore, it was concluded that the horizon had been removed by faulting. The bed was exposed and sampled in a trench on the surface above the adit.

Evans Canyon

In Evans Canyon, a shaft was sunk 71 feet on the west limb of the anticline. Fault zones were encountered; and an 18-foot crosscut was driven into the hanging wall. The fault evidently has considerable throw and probably represents a complementary fault in the footwall of the major regional fault. The Dinwoody formation, which lies stratigraphically above the Rex formation, was tentatively identified as the bed encountered in the crosscut. No ore-reserve estimates were made for this area.

Raymond and Coal Canyons

The Bureau of Mines drove 321 feet of adits on the vanadiferous bed in Raymond and Coal Canyons. The Wyodak Coal & Manufacturing Co. advanced seven adits in Raymond Canyon, spaced at 125-foot vertical intervals, for a total distance of approximately 730 feet. The Bureau of Mines began work in Raymond Canyon on adits 1 and 2, on the north and south sides of the canyon, respectively. Shortly after adit 1 was begun, the Wyodak Coal & Manufacturing Co. assumed the work in this adit at 37 feet from the portal. Adit 2 was driven by the Bureau of Mines for 121 feet. The vanadiferous bed was intersected at about 70 feet from the portal, and drifting continued along the bed until work was discontinued on the project by the Bureau of Mines. Adit 3 was driven on the vanadiferous bed for 38.5 feet on the north side of Coal Canyon. Adit 4 was driven south along the vanadiferous bed for a total distance of 106 feet. At 25 feet from the portal, the drift encountered a fault zone. The drift was turned to the east at 70 feet from the portal and again encountered the vanadiferous bed at 85 feet, which continued to the face of the drift.

The Bureau of Mines excavated 26 trenches (32,000 cubic feet) along the line of outcrop of the vanadiferous bed. The Wyodak Coal & Manufacturing Co. excavated 27 additional trenches.

Under an agreement between the Bureau of Mines and the Wyodak Coal & Manufacturing Co., all workings of the company were accessible to the Bureau of Mines for sampling. Results and estimates are based upon sampling completed on all workings by the Bureau of Mines and the Wyodak Coal & Manufacturing Co.

ORE DRESSING

Method

The several samples of vanadiferous shale submitted to the Bureau of Mines ore-dressing laboratory at Salt Lake City for metallurgical investigation differ very little in mineralogical composition. The actual proportions of V_2O_5, carbon, sulfur, phosphorus, and lime, plus magnesia, associated with the siliceous shale appear to have a zonal distribution across the vanadiferous beds. In general, the vanadium content is higher when the organic carbon and sulfur content are high. The mechanical concentration or separation of the

mineral constituents was investigated in two phases, the first consisting of an attempt to liberate the minerals by fine grinding and concentrate by flotation and/or slime elutriation, and the second being an attempt to take advantage of the zonal distribution of vanadium and make a gravity separation of mineral strata by heavy media or "sink-and-float" processes. Both types of treatment showed some degree of separation; however, only the latter treatment gave promise of having economic significance.

The samples of Sublette Ridge ore submitted for metallurgical testing gave the following chemical analyses:

	Assay, percent								
	V_2O_5	S	C	P	CaO	MgO	SiO_2	Al_2O_3	Fe
Wy-1.1 altered.....	0.81	0.78	4.62	0.92	5.5	0.55	52.0	12.3	3.55
Wy-1.2 altered, composite.....	.645	.65	3.90	1.26	7.1	.5	53.2	9.5	2.75
Wy-1.3 Met. A.....	.52	4.1	10.69	1.15	9.9	2.0	43.8	12.7	2.8
Wy-1.4 Met. B.....	.77	4.05	10.9	.410	6.5	2.5	46.5	12.15	2.95
Wy-1.9 Met. D.....	.525	3.40	9.21	.927	10.4	2.3	42.2	11.6	2.4
Wy-1.10 Met. F.....	.920	4.00	8.5	.33	5.2	2.3	49.0	12.63	1.10
Wy-6.1 Wyodak composite.....	.605	3.85	9.9	.83	9.3	1.85	43.6	12.55	3.1

The Wyodak composite sample of Sublette Ridge ore is fairly representative of a cross-bed sample, and the following testing data will be reported for that sample alone.

Flotation

True liberation of mineral constituents being impossible within practical grinding limits, the type of separation obtained seems to be independent of the size of flotation feed. Both xanthate and fatty-acid collectors have been used with fair success; however, a kerosene-pine oil circuit appears to give comparable results at lower cost. The following table gives a representative test with metallurgical data:

TABLE 1. - Flotation of minus 400-mesh ore

Reagents:
2.2 pounds per ton kerosene pH,.7.5
6.0 pounds per ton Na_2SiO_3
1.3 pounds per ton pine oil

Product	Weight, percent	Assay, percent		Distribution, percent V_2O_5
		V_2O_5	L.O.I.[1]	
Concentrate No. 1.....	8.4	1.1	38.3	14.3
Concentrate No. 2.....	12.4	.96	32.4	20.0
Concentrate No. 3.....	16.8	.81	24.7	22.9
Concentrate No. 4.....	13.7	.59	17.1	13.6
Cleaner tailing No. 1.....	7.9	.475	-	6.3
Cleaner tailing No. 2.....	20.5	.300	-	10.4
Rougher tailing.....	20.3	.365	-	12.5
Calculated heads.....	100.0	.594	15.4	100.0

1/ L.O.I. = Loss on ignition.

A composite of concentrates Nos. 1, 2, 3, and 4 contained 70.8 percent of the vanadium of the ore and represented 51.3 percent of the original weight. It analyzed as follows:

	Percent		Percent
V_2O_5.....	0.815	Fe.....	3.7
C.....	15.52	Pb.....	.1
CO_2.....	3.7	Zn.....	.05
CaO.....	6.3	SiO_2.....	34.4
MgO.....	1.4	Al_2O_3.....	12.8
S.....	5.6	L.O.I.....	27.0

Remarks. - A duplicate test on 65-mesh ore gave a recovery of 78.8 percent at a grade of 0.742 percent V_2O_5, rejecting 35.6 percent of the original weight and consuming only half the quantity of reagents noted above.

Heavy-media Separation, Sink and Float

The following test was carried out on minus 2-inch ore. Only the plus 10-mesh fractions were treated by "sink and float," and the high vanadium-bearing material concentrated in the low density fractions. Table concentration of minus 10-mesh ore indicated only a slight concentration of vanadium in the slime. The metallurgical data are given in table 2.

Remarks. - By reducing the media density to 2.45, a recovery in float and minus 10-mesh fines of 81.9 percent was obtained as a product assaying 0.84 percent V_2O_5.

TABLE 2. - Heavy-media separation minus 2-inch ore

Size	Product	Media density	Percent weight	Assay, percent				Distribution, percent			
				V_2O_5	CaO	P	S	V_2O_5	CaO	P	S
-2+10 mesh	Float	2.41	24.5	1.16	3.9	0.15	4.4	46.9	12.0	5.1	29.6
Do.	do.	2.49	35.9	.51	5.4	.58	3.8	30.1	24.4	28.1	37.1
Do.	do.	2.59	25.1	.24	11.7	1.33	3.1	10.0	36.6	45.6	21.3
Do.	do.	2.59	4.6	.08	30.6	1.42	1.7	.6	17.6	8.9	2.1
-10 mesh..		-	9.9	.76	7.6	.91	3.7	12.4	9.4	12.3	9.9
Calculated heads....		-	100.0	.61	8.0	.73	3.7	100.0	100.0	100.0	100.0
Composite float....		2.49	60.4	.77	4.8	.40	4.1	77.0	36.4	33.2	66.7
Composite float, incl. -10 mesh..		-	70.3	.77	7.2	.48	4.0	89.4	45.8	45.5	76.6

From these tests it was concluded that (1) the liberation and separation of the vanadium-bearing minerals were no greater with minus 400-mesh grinding than they were on coarse ore, and (2) by "sink and float" treatment of minus 2-inch ore, up to 40 percent of the original weight, which contained 65 percent of the lime and phosphorous, could be rejected with a loss of less than 20 percent of the vanadium, and (3) treatment of mine-run ore by heavy-media methods would compare favorably with selective mining for the purpose of rejecting high-lime and phosphorous wall rock.