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PRELIMINARY INVESTIGATION OF CONCENTRATING CERTAIN MINERALS IN IDAHO PLACER SAND

By

W.W. Staley, and

and

James S. Browning

University of Idaho
Moscow, Idaho

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INTRODUCTION

Because of the considerable interest developing in certain heavy minerals occuring in placer deposits this investigation was undertaken. The minerals of possible commercial value in Idaho black sands, which concentrate with the gold, consist principally of monazite, magnetite, ilmenite, zircon, and garnet. Quartz, various types of country rock, and very minor amounts of numerous other minerals are present.

This research will deal only with an investigation of the monazite, zircon, ilmenite, and magnetite.

The sands roughly divides itself into two groups depending on specific gravity and grain size. In one group are the minerals of commercial value plus the garnet. This group has the higher specific gravity and, with the exception of some of the garnet, magnetite, and ilmentite, generally the smaller grain size. This division suggests the possible use of classification, tabling, and screening.

It was found that, with the exception of quartz, all of the minerals would float with oleic or other fatty acids without conditioning, thus giving a bulk concentrate. To further separate the heavy minerals by flotation would require a complex differential method.

A combination of screening, gravity methods, and magnetic separation proved successful. The present work is confined almost entirely to an investigation of those methods.

No particular difficulty was experienced in regulating a magnetic field which would separate and extract magnetite, ilmenite, garnet, and monazite. The zircon remained with the quartz and other non-magnetic material.

At the time of this investigation only one company was stockpiling heavy mineral jig concentrates. The experimental material was obtained from dredging operations in the Boise Basin, Boise County, Idaho. Some work of a check nature was done on sluice box sands from several other localities.

The various samples investigated were collected by W.W. Staley, during the summer of 1947.

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* Professor of Mining, School of Mines, University of Idaho, Moscow, Idaho.
** Research Fellow, Idaho Bureau of Mines and Geology, Moscow, Idaho.

PREVIOUS WORK

The first monazite of commercial quantity produced from the black sands in the United States, came from the stream beds and bottom lands of North Carolina.(1) Commercial production first began about 1890. Most of the recovery was made by the use of sluice boxes in the stream beds, which process made a 20 to 60 per cent monazite concentrate. This concentrate was then dried and treated with a Wetherill magnetic separator. With these machines it was possible to produce a 92 per cent monazite concentrate. Of the other minerals present, only gold was recovered. Because of a drop in the price of monazite, and also because these deposits could not compete with the newly developed Brazilian sources, production in North Carolina ceased in 1906.

In 1909, the Centerville Mining and Milling Company, Centerville, Idaho, built a plant for the concentration of monazite sands,(2,3). This plant made a very favorable showing in the preliminary work. However, before the plant could go into production, it was destroyed by fire, and has never been rebuilt.

A plant for the treatment of heavy sands is being constructed at McCall, Idaho, by Rare Earth's Incorporated. It is their intention to produce monazite, zircon, and garnet concentrates.

ACKNOWLEDGEMENTS

Appreciation is due Mr. Fred Baumhoff, of Baumhoff and Marshall, for furnishing the jig concentrates from the Boise Basin; also, gratitude to the many individuals who sent in small samples and have evidenced a keen interest in the development of the monazite bearing sands of Idaho. Mr. C. R. Kurtak Chemist, Idaho Bureau of Mines and Geology, make the chemical analyses.

The project as a whole was sponsored by the Idaho Bureau of Mines and Geology, A. W. Fahrenwald, Director.

GEOLOGY AND MINERALOGY

The minerals commonly occuring in black sand are shown in Table I. (4) Many of these are only of passing interest.

By the usual processes of disintegration and erosion the minerals have been liberated from the granite, pegmatite dikes, gneiss, or schist parent rock. Because of their rather high specific gravity and insolubility they are readily concentrated, along with gold, on bed rock. (For further information on the Geology of Idaho Monazite see references 5, 6, 7, 8, 9, 10, 11.) Camera lucida drawings of three of the minerals are shown in Figure I (12).

COMMERCIAL USE OF MINERALS IN BLACK SANDS

GARNET (13)

The principal use of garnet is as an abrasive.

ILMENITE (13)

The titanium content of ilmenite is used in making welding rod coatings, ceramics, alloys, and carbide, with the bulk used in paint pigments.

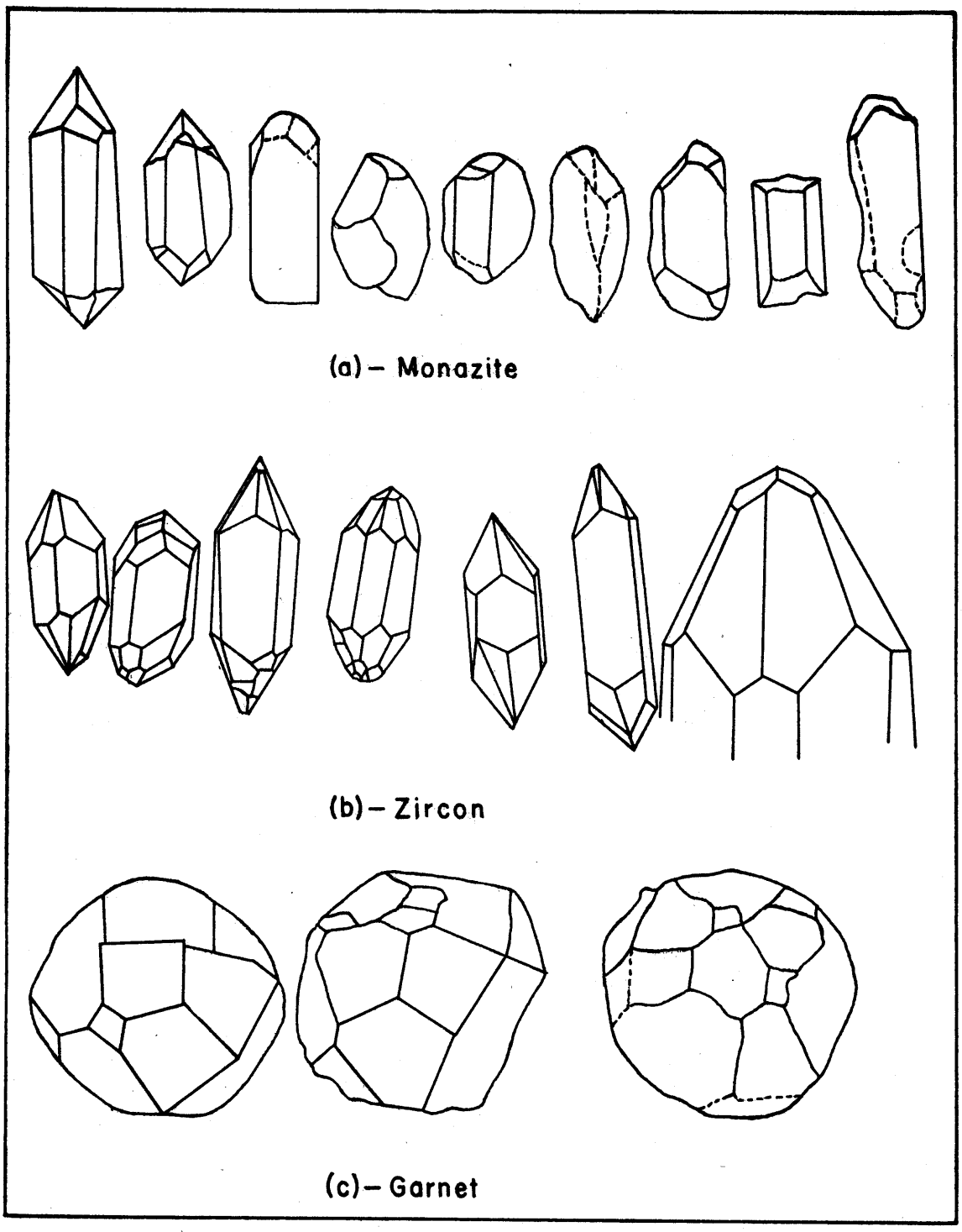

Figure 1– Typical Particle Shape

MONAZITE (14)

Monazite was originally desired because of the thorium content which was used in the manufacture of lamp mantles. The oxide of thorium is used in making radio tubes, as a constituent in special optical lenses, and as a high temperature refractory(melting point 5000 degrees Fahrenheit.)

The mixed rare-earth oxides and fluorides are used as core material in searchlight and projector arc carbons. A cerium-iron alloy is used to make cigarette lighter flints. Chlorides and acetates of the rare-earths are used for waterproofing and as fungicides in the textile industry. The oxalate is used medicinally to prevent nausea and seasickness.

Cerium is used in alloys, and the oxide is used as a coloring agent in ceramic glasses. An important use is as a polishing agent for lenses and prisms. The main advantage of cerium oxide is the great speed with which it polishes.

Lanthanum is the base of a new type photographic lens that contains a considerable quantity of the oxides of the rare earth elements. This glass has a very high density, a high index of refraction, and a low dispersion, making possible improved color correction and curved surfaces with a larger radius.

Neodymium is used chiefly in the glass industry to produce certain colors and to neutralize others.

ZIRCON (13)

Zircon is used in the manufacture of electrical and chemical porcelains, metals and alloys, high temperature refractories, glass, pottery glazes, and vitreous enamels.

VALUE OF MINERALS (12,13,15)

GARNET (13)

Approximately sixty dollars per ton.

ILMENITE (15)

Eighteen to twenty dollars per ton for a concentrate containing 45 per cent titanium oxide.

MONAZITE (12)

One hundred and thirty to one hundred and seventy dollars per metric ton (2205 lbs.) The concentrate must contain a minimum of 95 per cent monazite. The rare earth oxide plus thorium oxide content must be at least 65 per cent, with a maximum of 3 per cent titanium oxide.

If the 65 per cent requirement can be met, there is some indication that the purchasers of monazite will accept less than a 95 per cent grade. Idaho monazite material could thus drop to about a 92 per cent concentrate.

Sixty-five to seventy-five dollars per ton for a concentrate containing 60 per cent zirconium oxide.

PRODUCTION OF MINERALS (13)

ILMENITE

In 1945 the ilmenite production in the United States was 308,516 tons, while that produced elsewhere was 210,066 tons. Approximately 90 per cent of the foreign production was from India.

MONAZITE

There has been no commercial production of monazite in the United States since that of 1906 in North Carolina. In 1945 India produced 112 tons, and Brazil, 437 tons.

ZIRCON

In the United States the production reached 16,000 tons in 1945. Practically all of the domestic production was from Florida. During the same year Australia produced about 16,000 tons; Brazil, 2,372; and India, about 1,500 tons.

EXPERIMENTAL WORK

The black sands studied came from the various gold dredging operations in the placer districts of Idaho.

After the examination of these various sands, it was decided to devote most of the experimental work to the jig concentrate from the Baumhoff and Marshall operation in the Boise Basin. This sample was selected for study because it is more or less representative of Idaho black sand deposits, and it came from the only district in which sufficient quantities of the sands were available for the test work.

A sample from Ruby Placers in the Warren area contained a larger percentage of monazite than the general run of samples. It also contained a small per cent of cinnabar. A sample from the Tyee Mining Company, near Elk City, differed in that it appeared to contain low monazite and high ilmenite.

The Boise Basin gravel is said to contain approximately 60 pounds of heavy minerals per yard of gravel. Table 2 shows a microscopic analysis of the sample. An opaque mineral remained in the fraction with the zircon, apatite, and olivine and was not attracted by a powerful electromagnet. Because this non-magnetic fraction assayed titanium oxide, the opaque mineral was considered to be rutile.

In order to determine the percent of magnetite and ilmenite in the sample, the minerals were separated by the use of an electromagnet and the products assayed to determine the iron and titanium content.

The following is an analysis of a sample of pure monazite, from the Boise Basin as compared with a sample of Indian monazite:

	Boise Basin	India
Thorium Oxide	2.2	8.1
Cerium Oxide	31.7	30.6
Lanthanum, Neodymium, Praseodymium, Samarium, Europium, Gadolinium, Terbium, Yttrium, and other rare earth Oxides	35.1	31.2
Silicon Oxide	0.6	2.4
Calcium, Aluminum, and Iron Oxides	1.6	1.0
Phosphorous pentoxide	26.7	26.2
Titanium Oxide	0.6	
Zirconium Oxide	0.7	

A question which arose early in the investigation was that of deciding upon a rapid and suitable method of control analysis. Previous investigation had indicated that only a very small amount of apatite occurred in the black sands of widely scattered deposits.(12) Staley found that the determination of P_2O_5 (phosphorous pentoxide)would be sufficient for general experimental control. His examination of a number of samples of monazite further indicated, that for practical purposes, the per cent of monazite in a sample could be obtained by multiplying the P_2O_5 percentage by the factor 3.60.

To reduce the number of rather tedious chemical analyses a comparison between chemical analysis and microscopic grain counts was made. The results were sufficiently close that the data given in tables 2, 4, 6, 7, 8, and 9 were found by grain counts.

SCREEN ANALYSIS AND ASSAY OF THE VARIOUS SCREEN SIZES

The results of a screen analysis of the sample from the Boise Basin is given in Table 3. By treating a sample with tetrabromethane(sp. gr. 2.9) a separation of the quartz from the heavier minerals is obtained. The results are shown in Tables 4, 4a, and 5. From this treatment 15 per cent of the material (quartz)was removed in the float product. The minus 35 mesh contains 86.3 per cent of the monazite averaging 5.4 per cent P_2O_5. This is equivalent to 19.4 per cent monazite. The original sample from the dredge ran 2.4 per cent P_2O_5 or 8.6 per cent monazite.

HINDERED SETTLING PRECEDED BY SCREENING

The plus 14, 14/20, 20/28, 28/35, 35/48, 48/65, 65/100, and minus 100 mesh

products were classified in the hindered settling tube. In each case the quartz and some of the garnet were removed. Below the 28-mesh sample, the zircon and monazite began to concentrate. With the 35/48 and 48/65 sizes, the bottom cut of the samples shows a concentration of monazite and zircon of about 60 per cent. It is estimated that a 75 to 85 per cent recovery with a 75 per cent grade of monazite may be made by classifying various screen sizes.

JIG TESTS

The jig used in the following test was a laboratory model of the movable-sieve, diaphragm type. The machine was one designed by A. W. Fahrenwald.

A 5000-gram sample was used. The jig was set to remove as much quartz as possible with a minimum of other minerals. After the first operation the concentrate was recleaned. Table 9 gives the final data from using jig.

ELECTROMAGNETIC SEPARATION

The equipment used in the electromagnetic study was built in the University machine shop. A preliminary attempt at magnetic separation was made with a small U-shaped magnet having about 800 turns of 18-gauge insulated copper wire. Because this set-up lacked sufficient strength, a new magnet was constructed.

The apparatus finally developed is shown in Figure 3. It consists of a U-shaped magnet with a 1 5/8 by 1 5/8 inch soft steel core. The pole pieces are attached by means of screws. The coil of the magnet contained 2000 turns of 16-gauge insulated copper wire. Current was supplied by six 2-volt storage batteries connected in series with a resistance coil so that the desired current could be passed. When passing 15 amperes through the coil it was possible to develop 30,000 ampere turns. Ordinarily the coil would safely carry 8 amperes without overheating, but by using the magnet at short intervals, it was possible to pass 15 amperes.

The material to be separated was placed in a 4-by-12 inch aluminum pan. The current was then turned on by means of a foot switch, and the material passed between the poles of the magnet. The fraction picked up by the various current ratings was then dropped at the other end of the pan by releasing a foot switch and cutting off the current. This process was repeated until the desired separation was made. In all separations the concentrate was recleaned to be sure that there was no entrapment of non-magnetic particles.

With the assistance of the Department of Physics, a series of tests were made to determine the strength of the magnetic field between the poles for various currents. These tests showed that the field strength increased directly with the magnetizing current up to 15 amperes. This indicated that the core had not become saturated at the maximum amperage used, and that the capacity of the core was greater than the capacity of the coil. The magnet produced a uniform field across the width of the pole and gave very satisfactory results.

All the data reported in the following discussion were obtained with the above described arrangement. Some of the data obtained by the small magnet used in the earlier experiments have not been recorded because these data were duplicated with the larger magnet.

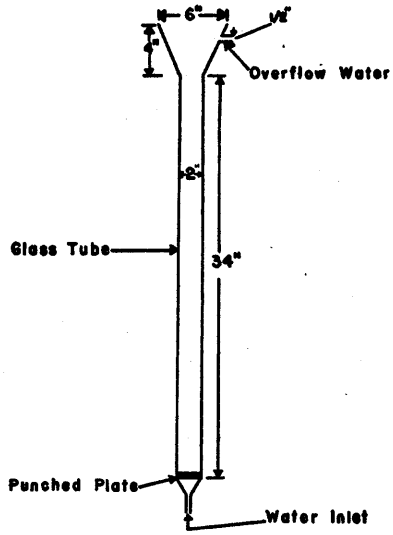

Fig. 2.—Hindered Settling Tube.

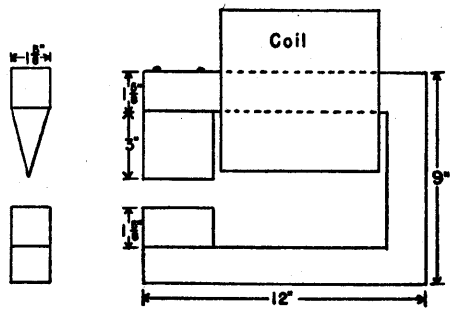

Fig. 3.—Electromagnet

Crushing of the sands was not necessary because the largest particles were only 14-mesh in size. After a number of trials at magnetic separation on various sieve sizes, it was found that the most effective separation could be made by screening the sands into the following sizes: plus 20-mesh, 20/35, and minus 35-mesh. The assay of the various screen sizes is shown in Table 10.

As is shown in Table 10, the plus 20-mesh fraction contains no monazite, 15.4 per cent of the total zircon, and 11.2 per cent of the total titanium oxide. The 20/35 mesh sand contains only 3.6 per cent of the monazite. It does, however, contain 60.1 per cent of the titanium oxide and 42.2 per cent of the zircon. From a commercial viewpoint, the minus 35-mesh has the greatest value; it contains 96.4 per cent of the monazite and 42.4 per cent of the zircon.

The black sand sample was electromagnetically separated according to the above sieve sizes. The current used and the assays of each product are shown in Table 11.

The strongly magnetic fraction was crushed to minus 65-mesh and minus 100-mesh and magnetically separated in an effort to liberate the titanium oxide. However these attempts were unsuccessful. From the results obtained it appeared that the titanium oxide was combined with the magnetite and that the mineral existed as titaniferous magnetite.

The fraction magnetic at 4 amperes contains over 82 per cent of the total titanium oxide content of the sample. This fraction is almost pure ilmenite with a very small amount of garnet. The greatest concentration of the titanium oxide is in the 20/35-mesh size, where over 62 per cent of the titanium oxide occurs. All the screen sizes in the fraction that is magnetic at 4 amperes have an average of 41 per cent titanium oxide. It was expected that the grade of the ilmenite could be raised by crushing the material. One sample was reduced to minus 65-mesh and another sample to minus 100-mesh, and subjected to the magnet. By this process the grade was raised from 41 to 42 per cent. But this was due only to liberation of a small amount of silica that was in the ilmenite.

Approximately 99 per cent of the garnet occurs in the fraction that is magnetic at 7 amperes. This sample also contains 8 per cent of the total titanium oxide. The ilmenite in this fraction is impure and has approximately the same magnetic susceptibility as the garnet which contains an average of 17.8 per cent iron.

The plus 20-mesh nonmagnetic fraction at 7 amperes contains 11.7 per cent of the total zircon.

After a number of trial separations it was found possible to remove the monazite by applying 15 amperes. The 20/35-mesh sample that is magnetic at 15 amperes contains 3.6 per cent of the monazite, and in addition contains other impurities such as garnet and very impure weakly magnetic ilmenite.

The minus 35-mesh sample treated at 15 amperes contained 96.4 per cent of the monazite. The resulting concentrate ran 95.6 per cent monazite, 2.3 per cent garnet, and 2.2 per cent opaque mineral. This sample assays 26.3 per cent

phosphorous pentoxide, 69.0 per cent rare earth oxides and 0.64 per cent titanium oxide. Included with the rare earth is 2.24 per cent thorium oxide.

FLOTATION

The nonmagnetic fraction from the plus 20, the 20/35, and the minus 35-mesh when combined contained 59.2 per cent zircon, 9.2 per cent quartz, 2.1 per cent opaque minerals, and 29.6 per cent of silicate minerals. This sample was ground in closed circuit in the ball mill to minus 65-mesh and thoroughly deslimed. In the desliming there was a loss of 5 per cent of the material. The slimes contained less than 1 per cent of the total zircon.

The deslimed sands were conditioned at 50 per cent solids with 0.3 pounds per ton of oleic acid for 15 minutes. Sulphuric acid for pH regulation and depression of quartz and apatite was added to give a pH of 5.4. The pulp consistency for flotation was 25 per cent solids. Frothing was effected by the use of 0.09 pounds per ton of pine oil. Cleaning of the rougher concentrates was at 15 per cent solids. After recleaning the rougher concentrate five times, a final concentrate was obtained containing 87.1 per cent zircon with a recovery of 85.4 per cent of the total zircon. Table 12 shows the results of this test.

TABLING

A 2000-gram sample was passed over a 12-by-30 inch Wilfley table. The concentrate produced was free of quartz. The middling contained 58 per cent quartz, and 42 per cent heavy minerals. This middling was retabled and the products combined with the first operation. Table 6 gives the result.

HINDERED SETTLING AND TABLING

A 3000-gram sample was treated in a hindered settling tube. The general dimensions are shown in Figure 2. The amount of water in the tube was regulated to give a hindered settling condition. The quartz rose to the top and was siphoned off. The remainder of the column was a rather homogeneous mixture of the remaining heavy minerals. In order to remove as much of the quartz as possible, an excess of the heavy minerals was taken off with the quartz. The classifier products are shown in Table 7. The tailings from the hindered settling separation were tabled. Table 8 gives the final result after combining the concentrate and tailings for the two operations.

SUMMARY AND CONCLUSIONS

SCREENING

On examination of the sands it was determined that no grinding would be necessary since practically all of the minerals had been unlocked by natural processes. By sizing analysis from plus 14 to minus 100-mesh and by chemical analysis of each sieve fraction, it was found that 41.1 per cent of the sample containing about 90 per cent of the monazite was in the minus 35-mesh fraction. Thus, some concentration of monazite can be effected by the simple process of screening.

The sizing analyses also indicated that about 62 per cent of the ilmenite occurs in the 20/35-mesh size fraction.

CLASSIFICATION

Tabling

The Wilfley table tests showed that, by tabling the sands and recleaning the middlings, a 98.8 per cent recovery of the heavy minerals containing 3 per cent quartz was possible.

Hindered Settling Classification Followed by Tabling.

In the hindered settling classification all of the quartz was removed from the heavy minerals. However, the quartz products still contained a high percentage of heavy minerals. This quartz tailing was then tabled to remove the quartz, with the result that a final concentrate was made containing 95.4 per cent of the total heavy minerals with only 0.2 per cent quartz.

Jig Tests

The first operation in the jig was to remove as much quartz as possible without removing any of the heavy minerals. The heavy mineral concentrate was then recleaned; the final concentrate contained 94.7 per cent of the total heavy minerals with 0.2 per cent quartz.

The jig tests produced the greatest recovery of heavy minerals with the least quartz content of any of the gravity methods.

ELECTROMAGNETIC SEPARATION

After a number of trials it was determined that the best magnetic separation could be made by sizing the sands into plus 20, 20/35, and minus 35-mesh products. With electromagnetic separation it was possible to make an 82 per cent recovery of the ilmenite with a grade of about 41 per cent titanium oxide. The principal difficulty encountered in making a better recovery of the ilmenite was that part of the ilmenite was impure and had approximately the same magnetic susceptibility as the garnet in the sample. At 15 amperes 94.0 per cent of the monazite was recovered with a grade of 95.6 per cent.

The nonmagnetic fraction in this separation consisted of zircon, rutile, apatite, olivine, and quartz.

FLOTATION

The nonmagnetic fraction from the electromagnetic separation was ground in a ball mill and thoroughly deslimed. This product was conditioned with oleic acid, and sulphuric acid, and then floated. The rougher concentrate was recleaned five times with the following results: 85 per cent recovery of the zircon, with a grade of 87 per cent.

VALUE OF RECOVERED MINERALS

The black sands as received from the dredge jigs contain about 15 per cent quartz and 85 per cent heavy minerals. By means of the foregoing experimental work, commercially valuable concentrates of ilmenite, monazite, and zircon were produced. On the basis of a 100 per cent recovery the value per ton of

the dredge jig concentrate is ilmenite, $16.68; monazite, $12.41; and zircon, $0.76; or a total of $29.85. The actual values recovered were as follows: ilmenite, $13.68; monazite, $12.00; and zircon, $0.67; or a total of $26.35 per ton of concentrate. This is shown in Table 13.

With the rise in price and the greater demand for monazite in various fields, the incentive for its commercial production should be greatly increased. Up to the present time, the sale of monazite has depended to a large extent on thorium available. Domestic monazite could not meet the commercial requirements because of low thorium content. However, at present the sale of monazite is based on the total rare earth content plus thorium, and the monazite deposits of the United States generally are higher in rare earth content than the foreign deposits.

The Idaho placer deposits that have in the past been dredged for their gold values, possibly may be reworked for the gold that was then lost and for the monazite, zircon, ilmenite, and garnet content.

The most logical system for separating the black sand commercially into its constituent minerals seems to be the establishment of a centrally located concentrating plant. In this way the dredge operators will be able to ship their jig concentrates to this plant for processing. The dredge operators using jigs should attempt to produce a maximum amount of black sands. By doing this, the quartz content will probably be increased in the jig concentrates. However, this may be discarded by the jigs at central concentrating plants. The laboratory flowsheet for black sand concentration is shown in Figure 4.

From the preliminary work reported in this paper, the indicated treatment for the commercial separation of the black sands is as follows:

1. Jigs to remove the quartz.

2. Wet magnetic separation to remove the magnetic material.

3. Drying.

4. Screening the sands into three fractions: plus 20, 20/35, and minus 35-mesh so that the sands may be more efficiently handled by the electromagnets.

5. Electromagnetic separation into an ilmenite concentrate, a residue of impure ilmenite concentrate, a residue of impure ilmenite and garnet, a monazite concentrate, and a residue of zircon, rutile, apatite, olivine, and quartz.

6. Grinding of the nonmagnetic fraction to minus 65-mesh.

7. Flotation of zircon from the other minerals by use of oleic acid and sulphuric acid.

Time did not permit more than a preliminary investigation of the magnetic properties of the garnet minerals. If a market for garnet can be established, no great difficulties should arise in producing a garnet concentrate.

Another valuable mineral which occurs in many Idaho placers is cinnabar. It is nonmagnetic and would occur with the nonmagnetic fraction.

LABORATORY FLOWSHEET FOR CONCENTRATION OF BLACK SANDS

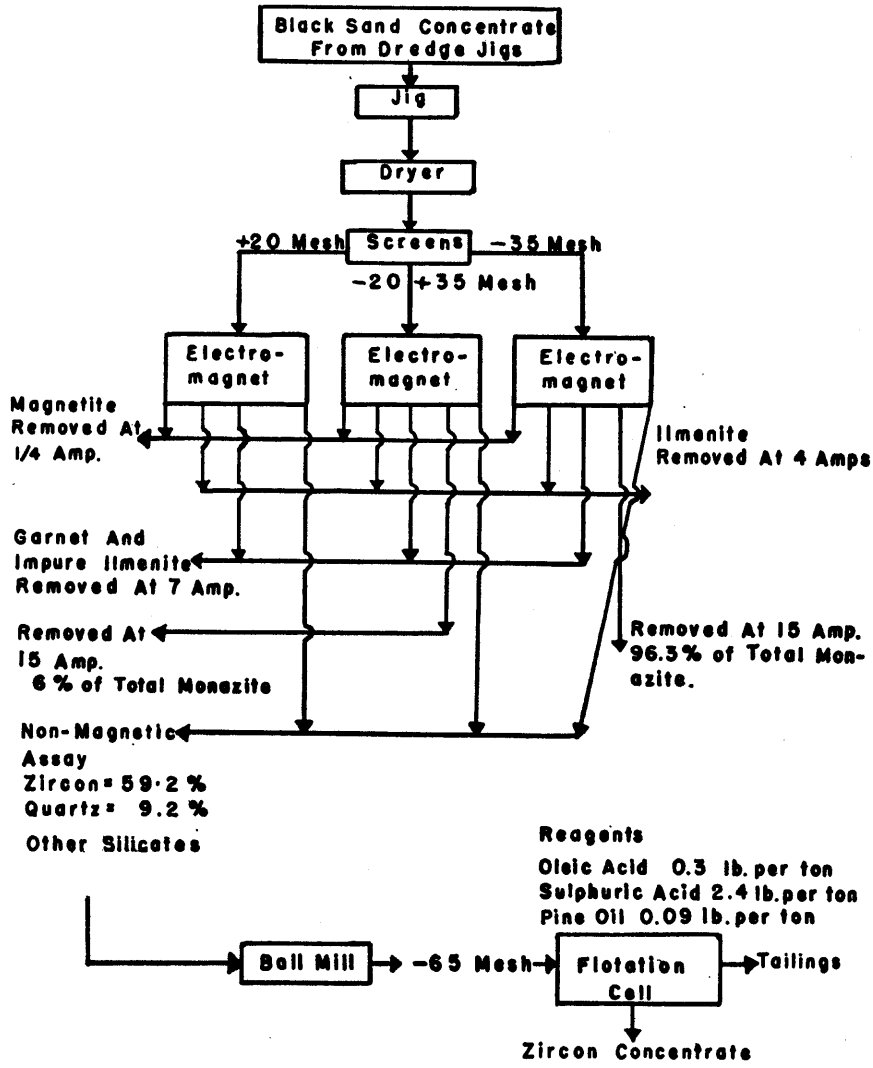

Fig. 4.

REFERENCES

(1) Kithil, K.L., Monazite, Thorium, and Mesothorium. U.S. Bureau of Mines Technical Paper 110 (1915).

(2) Sterrett, D. B., "Monazite in Idaho." Mineral Resources of the United States, Non-Metals, part 2, U.S. Geological Survey, 1909. pp. 898-903.

(3) Sterrett, D. B., "Monazite". Mineral Resources of the United States Non-Metals, part 2, U. S. Geological Survey, 1910, pp. 959-962.

(4) Staley, W. W., "Distribution of Heavy Alluvial Minerals in Idaho". Mineral Resources Report No. 5, Idaho Bureau of Mines and Geology (1948).

(5) Lindgren, Waldemar, The Mining Districts of the Idaho Basin and Boise Ridge, Idaho. p. 677, U.S.G.S. 18th Annual Report, Part II, 1896-97.

(6) Anderson, A. L., The Geology and Mineral Resources of the Region about Orofino, Idaho. p. 60, Idaho Bureau of Mines and Geology, Pamphlet 34. (1930).

(7) Schrader, F. C., An Occurrence of Monazite in Northern Idaho. p. 189, U.S.G.S. Bulletin, 430 (1910).

(8) Shenon, P. J. and Reed, J. C., Geology and Ore Deposits of the Elk City, Orogrande, Buffalo Hump, and Teuvallo Districts, Idaho County, Idaho, U.S.G.S., Circular 9, (1934).

(9) Reed, V. C., Geology and Ore Deposits of the Warren Mining District, Idaho County, Idaho. Idaho Bureau of Mines and Geology, Pamphlet 45 (1938)

(10) Day, D. T., and Richards, R. H., Useful Minerals and Black Sands of the Pacific Slope, p. 1175. U.S.G.S., Mineral Resources (1905).

(11) Staley, W. W., Distribution of Heavy Alluvial Minerals in Idaho, Idaho Bureau of Mines and Geology, Mineral Resources Report No. 5. (1948).

(12) Staley, W.W., Distribution of Heavy Alluvial Minerals in Idaho. Idaho Bureau of Mines and Geology, Mineral Resources Report No. 5 (1948).

(13) Minerals Yearbook, 1945. U.S. Bureau of Mines, pp. 803-810, 831-832, 1573-1574.

(14) Hammond, R. P., "Technology and Uses of Monazite Sand." A.I.M.E., Mining Technology, T.P. 2037, 10, July, 1946.

(15) Engineering and Mining Journal, February, 1948, pp. 89.

ADDITIONAL REFERENCES

Dean, R. S., and Davis, C. W., Magnetic Separation of Ores. U. S. Bureau of Mines Bulletin 425 (1941).

Ford, W. E., Dana's Textbook of Mineralogy, Fourth Edition, John Wiley and Sons, New York, 1922, pp. 822.

Levy, S. I., The Rare Earths, Their Occurrence, Chemistry, and Technology, Edward Arnold, London, 1915, pp. 345.

Lindgren, Waldemar, "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho." Eighteenth Annual Report, part 3, U. S. Geological Survey, 1898, pp. 617-744.

Santmyers, R. M., Monazite, Thorium, and Cerium. U. S. Bureau of Mines Information Circular 6321, August, 1930.

Schlundt, H., Mesothorium. U. S. Bureau of Mines Technical Paper 265 (1922).

Taggart, A. F., Handbook of Mineral Dressing. John Wiley and Sons, New York (1945) pp. 1926.

Youngman, E. P., Titanium. U. S. Bureau of Mines Information Circular 6365, October, 1930.

TABLE I - MINERALS COMMONLY OCCURRING IN THE BLACK SAND

Mineral	Composition	Important Constituent	Sp. Gr.	Hardness
Magnetite	Fe_3O_4	Iron	5.2	5.5-6.5
Gold	Gold usually with silver	Gold, Silver	15-19	2.5-3
Ilmenite	$FeTiO_3$	Titanium, Iron	4.7-4.8	5-6
Garnet	Various	Abrasive	3.2-4.3	6.5-7.5
Zircon	$ZrSiO_4$	Zirconium and ZrO_2	4.2-4.9	7.5
Chromite	$FeO.Cr_2O_3$	Chromium, Iron	4.5-4.8	5.5
Specular Hematite	Fe_2O_3	Iron	4.8-5.3	5-6
Amalgam	(Au,Ag) Hg	Gold, Silver, Mercury	13-14	3-3.5
Pyrite	FeS_2	Iron, Sulphur	4.8-5	6-6.5
Monazite	$(Ce,La,Di)PO_4$ Th and other Rare Earths	Thorium, Cerium, Rare Earths	4.9-5.3	5-5.5
Rutile	TiO_2	Titanium	4.2-4.3	6-6.5
Titanite	$CaTiSiO_5$	Titanium	3.4-3.6	5-5.5
Cinnabar	HgS	Mercury	8	2-2.5
Cassiterite	SnO_2	Tin	7	6-7
Corundum	Al_2O_3	Abrasive	4-4.1	9
Columbite Tantalite	$(FeMn)(Cb,Ta)_2O_6$	-------	5.2-8	6-6.5
Various Uranium Minerals	Various	Uranium, Radium	Heavy	Hard

TABLE II - MINERALOGICAL ANALYSIS OF BLACK SAND SAMPLE FROM BOISE BASIN

Mineral	Head Sample (a)	Heavy Fraction (b)	% Mineral Per Ton of Gravel	Value of Minerals Per Ton of Original Gravel
Monazite	8.27	9.73	0.13	$0.292
Zircon	1.09	1.24	0.024	$0.071
Ilmenite	55.59	65.61	1.31	$0.394
Magnetite	11.23	13.22	0.26	$0.394
Rutile	0.04	0.05	0.001	
Garnet	8.12	9.55	0.19	
Apatite Olivine	0.54	0.60	0.012	
Quartz	15.12			
Total	100.00	100.00	1.977	$0.757

(a) Head sample indicates a jig concentrate of black sands from the dredge.

(b) All silica removed by sink-float separation using tetrabromethane.

TABLE III - SCREEN ANALYSIS OF BLACK SANDS FROM BOISE BASIN

Mesh	Weight Grams	Weight %	Cumulative Percent
+ 14	1.1	1.1	1.1
14/20	7.2	7.2	8.3
20/28	20.3	20.3	28.6
28/35	30.3	30.3	58.9
35/48	23.8	23.8	82.7
48/65	14.3	14.3	97.0
65/100	2.4	2.4	99.4
- 100	0.6	0.6	100.0

TABLE IV - SINK-FLOAT SEPARATION

Product	Weight Grams	Weight %
Float	75.8	15.1
Sink	424.2	84.9

TABLE IV-a - SCREEN ANALYSIS OF SINK PRODUCT

Screen	Weight Grams	Weight %
+ 35	267.7	63.1
- 35	156.5	36.9

TABLE V - SCREEN AND CHEMICAL ANALYSIS OF SINK PRODUCTS

Screen	Weight Grams	P_2O_5 %	Weight P_2O_5
+ 35	59.0	0.6	0.35
35/42	12.9	1.9	0.25
42/48	10.8	3.8	0.41
48/60	9.8	6.7	0.66
60/65	4.5	9.5	0.43
65/80	1.2	13.2	0.16
80/100	1.2	17.2	0.21
- 100	0.6	14.0	0.08
	100.0	2.55	2.55

TABLE VI - RECOVERY OF HEAVY MINERALS BY TABLING

Product	Weight Grams	% Quartz	% Opaque Minerals	% Garnet	% Monazite	% Zircon	% Apatite & Olivine	Recovery of Heavy Minerals
Concentrate	1630	3	73.5	12	10.2	1.3	----	98.8
Tailings	370	95	4	1	----	----	Trace	1.2
Total	2000							

TABLE VII - RECOVERY BY HINDERED SETTLING

Product	Weight Grams	% Opaque Minerals	% Quartz	% Monazite	% Garnet	% Zircon
Concentrate	2180	77.0	0.5	10.0	11.0	1.5
Tailings	820	46.0	48.0	Trace	6.0	Trace
Total	3000					

TABLE VIII - FINAL RECOVERY OF MINERALS BY TABLING AFTER HINDERED SETTLING CLASSIFICATION

Product	Weight Grams	% Opaque Minerals	% Quartz	% Garnet	% Monazite	% Zircon	% Apatite, Olivine	% Recovery of Heavy Minerals
Concentrate	2432	76.4	0.2	10.4	11.4	1.5	0.1	95.4
Tailings	568	18.6	79.1	2.3	----	----	Trace	4.6
Total	3000							

TABLE IX - RECOVERY OF HEAVY MINERALS BY JIGGING

Product	Weight Grams	Weight %	Quartz %	Heavy Min. %	Recovery Heavy Min. %
Rougher conc.	3658	73.1	0.0	100.0	
Mid. conc.	337	6.8	2.4	97.6	
Rougher plus Mid. conc.	3995	79.9	0.2	99.8	94.7
Tails	1005	20.1	77.5	22.5	5.3
Total	5000	100.0			100.0

TABLE X - ASSAY OF PRODUCTS AFTER SCREENING FOR ELECTROMAGNETIC SEPARATION

Product	Weight Grams	Weight %	% Iron	% Total Iron	% TiO_2	% Total TiO_2	% P_2O_5	% Total P_2O_5	% ZrO_2	% Total ZrO_2
Head Sample	------	------	34.58	------	25.8	----	2.82	------	1.09	------
+ 20 Mesh	11.1	11.1	30.70	10.4	25.9	11.2	----	------	1.48	15.4
20/35 Mesh	48.3	48.3	34.6	51.0	32.0	60.1	0.21	3.6	0.93	42.2
- 35 Mesh	40.6	40.6	31.2	38.6	18.2	28.7	6.60	96.4	1.12	42.4
Total	100.0	100.0		100.0		100.0		100.0		100.0

TABLE XI - ASSAY OF THE VARIOUS PRODUCTS OF ELECTROMAGNETIC SEPARATION

+ 20 Mesh	% Total Sample	% Iron	% TiO_2	% P_2O_5	% ZrO_2
Magnetic at 1/4 amp.	0.83	48.3	14.8		
Magnetic at 4 amp.	6.29	35.6	42.0		
Magnetic at 7 amp.	2.57	11.5	16.6		
Nonmagnetic at 7 amp.	1.42				6.0
Total	11.11				
20/35 Mesh					
Magnetic at 1/4 amp.	4.75	64.7	5.4		
Magnetic at 4 amp.	27.19	38.7	42.4		
Magnetic at 7 amp.	13.37	16.3	23.4		
Magnetic at 15 amp.	2.16	12.7	3.8	24.2	
Nonmagnetic at 15 amp.	0.87	4.8	4.2		37.5
Total	48.34				
- 35 Mesh					
Magnetic at 1/4 amp.	7.14	66.3	3.6		
Magnetic at 4 amp.	17.86	38.1	38.6		
Magnetic at 7 amp.	5.54	19.2	20.9		
Magnetic at 15 amp.	9.50	0.4	1.0	26.3	
Nonmagnetic at 15 amp.	0.51	0.10	0.2		62.4
Total	40.55				
Grand Total	100.0				

TABLE XII - RECOVERY OF ZIRCON BY FLOTATION

Product	Weight %	% Zircon	% Zircon Recovery
Feed	100.00	59.2	100.0
Cleaned Concentrate	57.90	87.1	85.4
1st Cleaner Tails	5.34	31.7	2.8
2nd Cleaner Tails	4.67	37.5	2.8
3rd Cleaner Tails	3.29	40.3	2.3
4th Cleaner Tails	3.68	44.7	2.8
5th Cleaner Tails	1.32	34.9	0.8
Final Rougher Tails	23.80	7.6	3.1
Total	100.0		100.0

TABLE XIII - VALUE PER TON OF MINERALS RECOVERED FROM THE SANDS

Product	% of sand as received from dredges	Pounds per ton of sand from dredge	Value per pound	Recovery per cent	Mineral recovery per ton (pounds)	Total value of mineral recovered per ton
Monazite	8.3	166.0	$0.075	96.3	160	$12.00
Ilmenite	55.6	1112	0.015	82.0	912	13.68
Zircon	1.1	22	0.035	85.4	19	0.67
Total						$26.35