

Report of Investigations 8366

Recovering Byproduct Heavy Minerals From Sand and Gravel, Placer Gold, and Industrial Mineral Operations

By J. M. Gomes, G. M. Martinez,
and M. M. Wong



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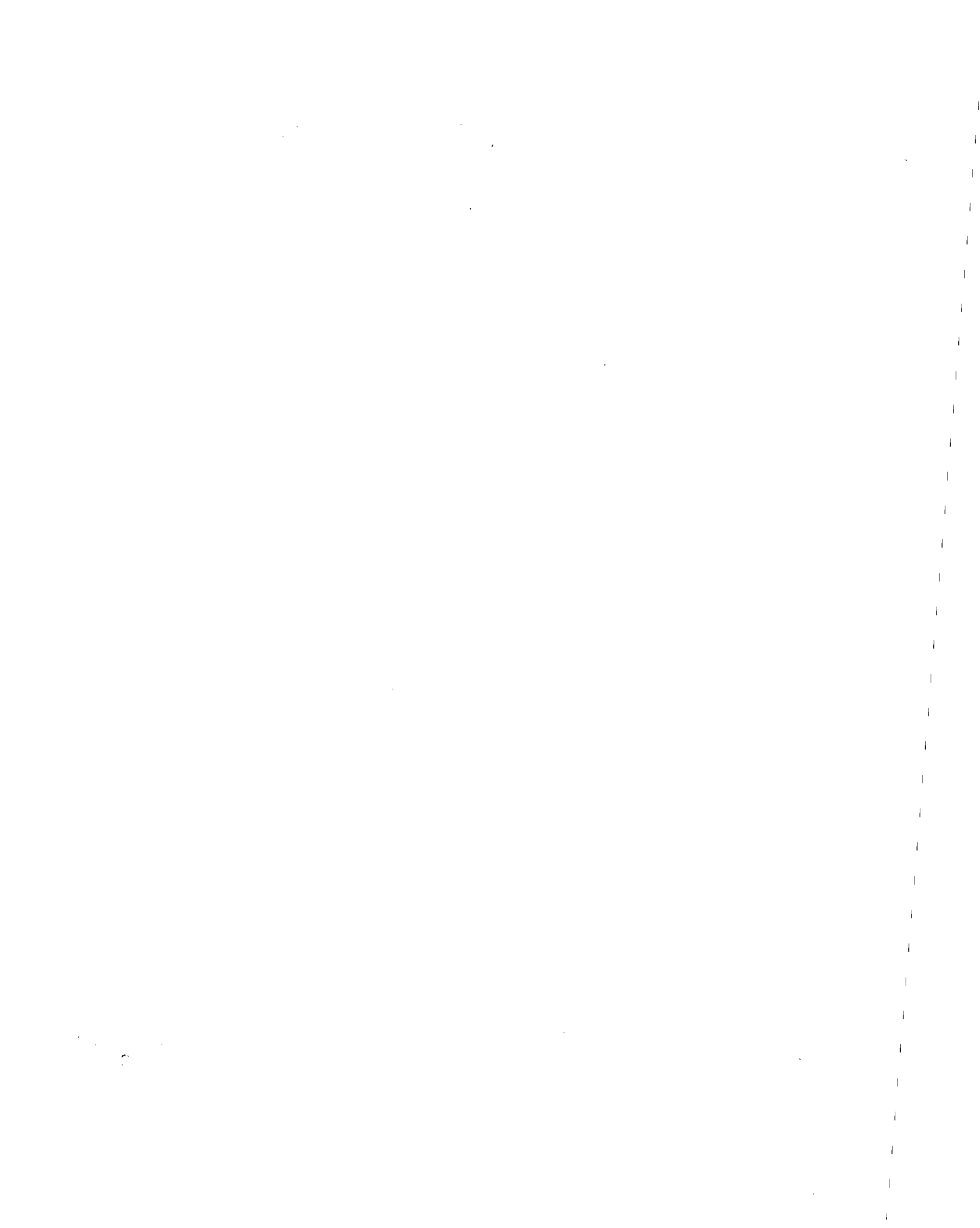
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CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	1
Heavy-mineral sampling.....	3
Beneficiation.....	7
Gravity concentration.....	7
Fractionation of heavy-mineral concentrates.....	8
American River.....	8
Mokelumne River.....	10
Cherokee tailings.....	11
Ione waste material.....	12
Yuba Goldfields black sand.....	13
Discussion and conclusions.....	14
References.....	15

ILLUSTRATIONS

1. Northern California sample locations.....	3
2. Sequence for processing American River sand.....	9
3. Sequence for processing Cherokee tailings.....	11
4. Sequence for processing Ione waste material.....	12
5. Sequence for processing Yuba Goldfields jig concentrate.....	13

TABLES

1. Approximate value increase of heavy minerals.....	2
2. Samples from Pit, Feather, and Yuba Rivers area.....	5
3. Samples from the Klamath Mountains and Coast Range area.....	6
4. Samples from Sacramento-Tahoe area.....	7
5. Recovery of heavy minerals from bulk sand samples.....	8
6. Analyses of heavy-mineral cleaner concentrates.....	8
7. Analysis and distribution of platinum-group metals in heavy-mineral concentrate from American River.....	10
8. Analysis and distribution of radioactive oxides in heavy-mineral concentrates from American River.....	10
9. Fractionation of Cherokee cleaner concentrate.....	11
10. Fractionation of Ione concentrates.....	12

RECOVERING BYPRODUCT HEAVY MINERALS FROM SAND AND GRAVEL, PLACER GOLD, AND INDUSTRIAL MINERAL OPERATIONS

by

J. M. Gomes,¹ G. M. Martinez,² and M. M. Wong³

ABSTRACT

The Bureau of Mines, as part of an effort to maximize minerals and metals recovery from domestic resources, has investigated the feasibility of recovering heavy minerals as byproducts from sand and gravel, placer gold, and industrial mineral operations in northern California. Sand samples from about 50 locations were treated by gravity separation to yield heavy-mineral concentrates (black sands). Mineral compositions of the concentrates were determined by chemical analysis and mineralogical examination. Individual zircon, ilmenite, magnetite, platinum-group metals, thoria, and silica products were prepared from heavy-mineral concentrates by selective separation using low- and high-intensity magnetic, high-tension, and flotation equipment.

INTRODUCTION

As part of its goal to maintain an adequate supply of minerals to meet national economic and strategic needs, the Bureau of Mines investigated the recovery of byproduct heavy minerals (HM) from sand and gravel, placer gold, and industrial mineral operations in northern California. The recovery of gold from sand and gravel operations has been practiced for decades, but the recovery of other minerals has been neglected. The recovery of heavy minerals would have no additional environmental impact because they would be obtained as byproducts.

The heavy-mineral concentrates, referred to as "black sands," have intrigued miners since the first placer gold was recovered. The mineral composition of California black sands was investigated by Day and Richards of the U.S. Geological Survey in 1905 (4),⁴ and a mineral utilization study was made by Day, Wilson, and Clevenger (5). Heavy minerals found in California black sands include magnetite, ilmenite, hematite, chromite, zircon, garnet, scheelite, cinnabar, gold, and platinum-group metals (PGM). All of these minerals

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⁴Underlined numbers in parentheses refer to items in the list of references at the end of this report.

have economic potential. The increase in value based on 1958 dollars for several of these minerals during the period 1958-76 is shown in table 1. The values of rutile and scheelite have increased twofold to threefold during the 18-year period, the values of magnetite and chromite have increased 1.5-fold, and the value of zircon has increased over sevenfold. While the value of ilmenite remained constant, the value of gold and platinum has doubled.

TABLE 1. - Approximate value increase of heavy minerals¹

	1958	1976
Magnetite.....cent per pound..	0.5	0.75
Chromite.....cents per pound..	2	3
Ilmenite.....do.....	1.5	1.5
Rutile.....do.....	5	14
Zircon.....do.....	2	15
Scheelite.....do.....	90	250
Gold.....dollars..	520	1,000
Platinum.....do.....	550	1,150

¹ Based on common 1958 dollars calculated from inflation rate 1958 to 1976, U.S. Bureau of Mines.

Source: Mineral Facts and Problems, BuMines Bull. 585, 1960; Metals week, Vol 47, No. 51, Dec. 20, 1976.

Only a few successful attempts have been reported in the literature on recovering heavy minerals as byproducts from sand and gravel operations. Iron ore was recovered in England (1). The Bureau of Mines reported the recovery of ilmenite, zircon, kyanite, and rutile in the Southeastern United States (2-3). Free gold has been recovered from sand and gravel operations in California for over 40 years. In the late 1930's, over \$200,000 in gold was recovered from the aggregates used in building Friant Dam on the San Joaquin River (6). In recent years, about one-third of California's gold production was derived from sand and gravel operations. Several of the plants that recover gold are located on streams flowing through the Mother Lode or other gold-bearing areas.

The objective of this investigation was to determine the feasibility of recovering heavy-mineral concentrates from sand and gravel, placer gold, and industrial mineral operations and of preparing individual mineral products from these concentrates by various beneficiation techniques. Sand samples were obtained from various northern California locations, and heavy-mineral concentrates were prepared from them. Chemical analyses and mineralogical examinations of the heavy-mineral concentrates were made to identify and determine the quantities of the individual minerals. Recovery of large quantities of heavy-mineral concentrates by gravity concentration was performed on the samples that showed significant quantities of heavy minerals. Separation of the bulk heavy-mineral concentrates into individual mineral concentrates then was investigated using magnetic, high-tension, and flotation equipment.

HEAVY-MINERAL SAMPLING

The locations of northern California operations that provided samples for this investigation are shown in figure 1. The sand and gravel and placer gold operations are principally located in Quaternary alluvial deposits in stream channels or flood plains. These deposits are mainly derived from the weathering of mineralized areas in the Sierra Nevada Range, Coast Range, and Klamath Mountains. Sand and gravel operators in northern California process about 20 million tons of material annually. The placer gold deposits are worked intermittently employing washing plants with ore capacities of 20 to 500 tons/hr.

The sampling procedure used in this study began by obtaining a 40- to 50-lb sample of washed cement or mortar sand from each of the sand and gravel operations. Almost all the recoverable heavy minerals occur in these sand fractions. Data used to calculate the percentage of sand in the deposit were obtained so that the heavy-mineral content of the in-place material could be calculated. Heavy-mineral concentrates were obtained also from placer gold

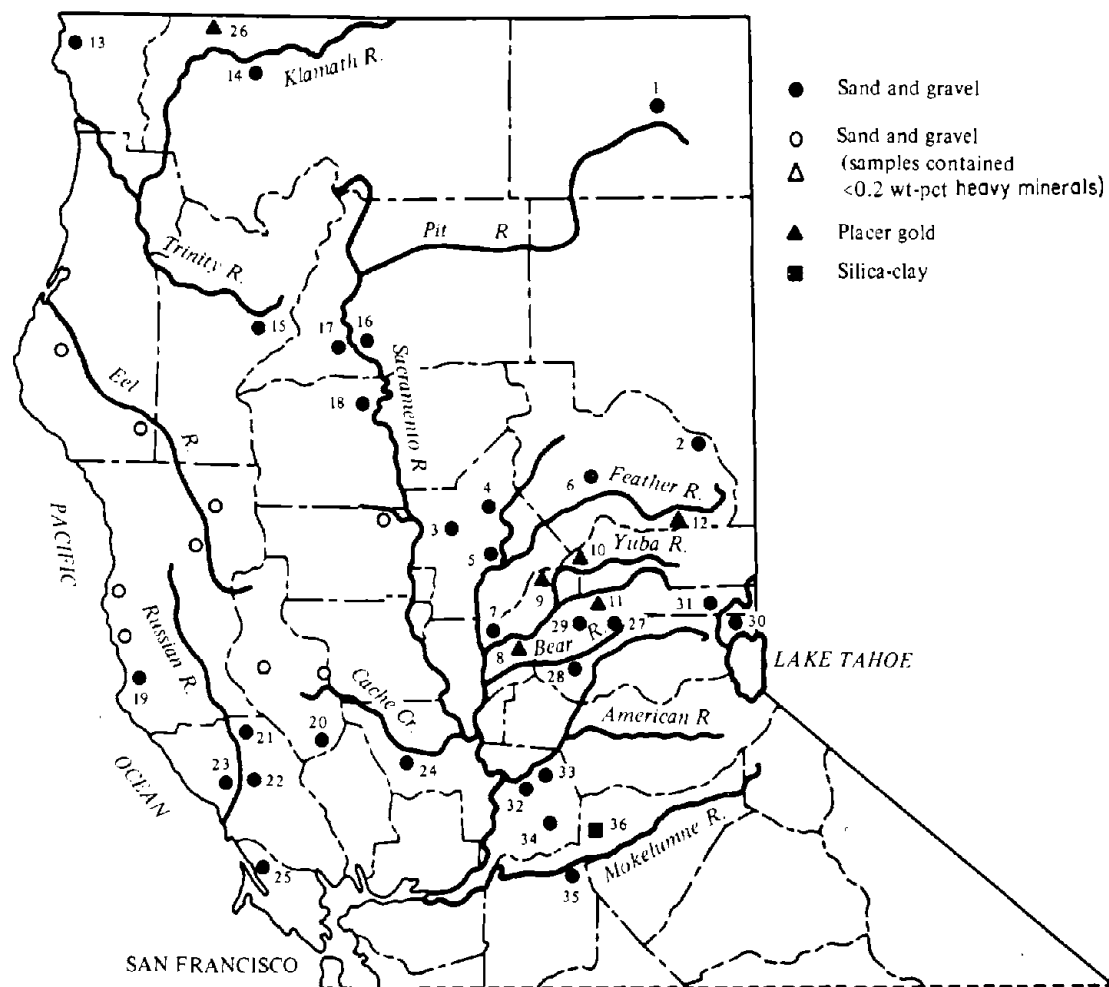


FIGURE 1. - Northern California sample locations.

operations. The operators provided data on ratio of concentration so that calculations could be made to determine the approximate heavy-mineral content of the in-place deposit.

Heavy-mineral concentrates were prepared from sand samples using a Humphreys spiral concentrator. The concentrates were analyzed for Cr_2O_3 , Fe_2O_3 , TiO_2 , ZrO_2 , gold, silver, and platinum-group metals, and a mineralogical examination was made. The concentrations of chromite, ilmenite, and zircon in the deposit were calculated from the analysis. The magnetite concentration was determined by low-intensity magnetic separation and chemical analysis, and an electron microprobe analysis was made on some samples to determine the mineral association and trace elements. The total heavy minerals was determined by a heavy-medium separation procedure using diiodomethane (CH_2I_2) with a specific gravity of 3.3. Samples showing less than 0.2 wt-pct heavy minerals in the deposits were not reported in the tables, but their locations are shown in figure 1.

Results of samples from the Pit, Feather, and Yuba Rivers are shown in table 2. Total heavy-mineral content in the deposits ranged from 0.3 to 2.0 wt-pct. Heavy minerals present were generally magnetite, up to 25 lb/ton, and ilmenite, up to 10 lb/ton. The chromite content was usually about 1 lb/ton, but the French Corral sample contained 3 lb/ton. The Cherokee and Shady Creek samples contained 8 lb/ton zircon, the only samples having a significant zircon content. All samples contained gold, ranging from <0.0001 to about 0.03 oz/ton.

The composition of samples obtained from the Klamath Mountains and Coast Range areas are shown in table 3. The samples showed 0.2 to 2.0 wt-pct heavy minerals in the deposits. Major minerals present were magnetite (up to 22 lb/ton), and ilmenite, (up to 5 lb/ton). The Elliot Creek and Russian River (Windsor) samples contained 5 lb/ton chromite; most other samples contained <1 lb/ton. The zircon content in all samples from this area was 1 lb/ton or less. The Elliot Creek sample also contained 0.03 lb/ton scheelite. This is a significant finding since there are no reported tungsten occurrences in the Siskiyou Mountains. Gold contained in the deposits ranged from <0.0001 to 0.02 oz/ton and platinum-group metals ranged from <0.0001 to 0.0004 oz/ton. Samples from Healdsburg and Cloverdale on the Russian River contained 0.0007 and 0.0005 oz/ton gold, respectively. This is significant since the Russian River area is not considered a gold-bearing area.

TABLE 2. - Samples from Pit, Feather, and Yuba Rivers area¹

Map No. ²	Location	Total HM, wt-pct	Minerals, lb/ton				Oz/ton		
			Magnetite	Ilmenite	Chromite	Zircon	Others ³	Gold	PGM
	Sand and gravel:								
1	Pit River (Alturas).....	0.7	2	5	<1	<1	6	<0.0001	<0.0001
2	Long Valley.....	.3	3	<1	<1	<1	2	.0001	<.0001
3	Butte Creek.....	1.5	7	1	<1	1	21	.0001	<.0001
4	Cherokee tailing dump...	.7	<1	4	1	8	3	.003	<.0001
5	Feather River (near Oroville).	1.0	8	3	<1	1	8	.0002	<.0001
6	Spanish Creek (Quincy)...	1.2	12	1	<1	1	10	.0005	.0010
7	Yuba River (Marysville).	.5	6	1	<1	<1	2	.0001	<.0001
	Placer mines:								
8	Yuba Goldfields.....	1.0	6	1	1	1	11	.002	.0001
9	French Corral.....	1.4	1	8	3	1	15	.010	<.0001
10	Shady Creek.....	2.0	19	10	<1	8	3	.020	.0001
11	Emory Isle.....	1.8	25	1	1	1	8	.028	.001
12	Jameson Creek ⁴	1.6	19	5	<1	<1	7	.03	<.0001

¹Values based on in-place deposit.

²Locations in figure 1.

³Minerals such as garnet, sphene, pyroxenes, olivine, etc.

⁴Also contained 0.03 lb/ton scheelite.

TABLE 3. - Samples from the Klamath Mountains and Coast Range area¹

Map No. ²	Location	Total HM, wt-pct	Minerals, lb/ton					Oz/ton	
			Magnetite	Ilmenite	Chromite	Zircon	Others ³	Gold	PGM
	Sand and gravel:								
13	Smith River.....	0.6	6	<1	1	<1	4	0.0002	<0.0001
14	Scotts River (Ft. Jones).	.8	4	1	<1	<1	10	.0006	<.0001
15	Reading Creek (Douglas City).	1.4	5	5	1	<1	17	.003	.0001
16	Sacramento River (Redding).	1.0	5	1	<1	<1	13	.0003	.0001
17	Clear Creek (Redding)....	.2	3	1	<1	<1	0	.003	.0001
18	Blue Tent Creek (Red Bluff).	.7	9	1	<1	1	3	<.0001	.0001
19	Garces River (Gualala)...	.3	1	<1	<1	<1	5	<.0001	<.0001
20	Putah Creek (Middletown).	.6	2	<1	3	<1	6	<.0001	.0001
21	Russian River (Cloverdale).	.4	2	<1	<1	<1	5	.0005	<.0001
22	Russian River (Healdsburg).	.4	2	1	<1	<1	4	.0007	<.0001
23	Russian River (Windsor)...	.4	1	1	5	<1	1	<.0001	<.0001
24	Cache Creek (Madison)....	.2	1	<1	<1	<1	1	<.0001	<.0001
25	Dillon Beach.....	.2	1	<1	1	<1	2	.0005	.0002
26	Placer mines: Elliot Creek ⁴ (Siskiyou Co.).	2.0	22	1	5	1	12	.02	.0004

¹Values based on in-place deposit.²Locations in figure 1.³Minerals such as garnet, sphene, pyroxenes, and olivine.⁴Also contained 0.03 lb/ton scheelite.

Results of samples from the Sacramento-Tahoe area are shown in table 4. Samples from the sand and gravel operations showed from <1 to 33 lb/ton magnetite in the deposits and up to 7 lb/ton ilmenite. Zircon contents ranged up to 3 lb/ton and chromite, <1 lb/ton. The sample from the waste ponds of a silica-clay operation at Ione contained 400 lb/ton altered ilmenite and 83 lb/ton zircon. This sample was unique in that the relatively low-specific-gravity minerals, such as quartz and clay, had been removed by the operator, resulting in tailings containing 27 wt-pct heavy minerals. This material is a potential source for both titanium minerals and zircon. All samples showed gold in the deposits ranging from 0.0001 to 0.002 oz/ton. The American River and Ione samples also showed about 0.001 oz/ton platinum-group metals; other samples, <0.0001 oz/ton.

TABLE 4. - Samples from Sacramento-Tahoe area¹

Map No. ²	Location	Total HM, wt-pct	Minerals, lb/ton					Oz/ton	
			Magne-tite	Ilmen-ite	Chro-mite	Zircon	Others ³	Gold	PGM
27	Sand and gravel: Bear River (Colfax).	0.8	4	7	<1	3	1	0.002	<0.0001
28	Bear River (Meadow Vista).	.4	1	2	<1	<1	4	.0001	<.0001
29	Greenhorn Creek..	.6	<1	2	<1	<1	9	.0005	<.0001
30	Martis Creek.....	.6	3	1	<1	<1	2	.0001	<.0001
31	Kleinsorge.....	1.4	15	3	<1	<1	7	.001	<.0001
32	American River (Teichert).	.7	10	1	<1	<1	2	.001	.0010
33	American River (Granite).	1.0	10	1	<1	<1	8	.001	.0010
34	Consumnes River (Elk Grove).	.8	1	3	<1	<1	12	.0001	<.0001
35	Mokelumne River..	2.6	33	7	<1	<1	9	.0007	.0001
36	Silica-clay: Ione ⁴	27.0	1	400	<1	83	57	.002	.0015

¹Values based on in-place deposit.

²Locations in figure 1.

³Minerals such as garnet, sphene, pyroxenes, kyanite, tourmaline, and olivine.

⁴Values based on waste material.

BENEFICIATION

Gravity Concentration

Five materials were selected for beneficiation studies: washed sand samples from the American River, Mokelumne River, Cherokee tailings, the heavy-mineral tailings from the silica-clay operation at Ione, and the jig concentrate (black sand) from the Yuba Goldfields dredge. The first three washed sand samples and the Ione heavy-mineral tailings were treated on a Humphreys spiral to recover concentrates containing 58 to 90 wt-pct heavy minerals. The procedure adopted was to recover a primary concentrate weighing 20 to 50 lb from 400 to 500 lb of feed material. The primary heavy-mineral concentrate then was upgraded to recover a cleaner concentrate. The results from preparing the heavy-mineral cleaner concentrates are shown in table 5. The recovery of heavy minerals from each of the three sand samples was approximately 90 pct. The recovery of heavy minerals in the cleaner concentrate from the Ione tailings was 72 pct. An additional 16 pct of the heavy minerals was in a scavenger concentrate prepared from the primary tailings. The scavenger concentrate and the cleaner tailings contained 24 pct of the heavy minerals; these products would have to be recycled.

TABLE 5. - Recovery of heavy minerals from bulk sand samples

Source	HM, wt-pct			Recovery of HM, pct	
	Heads	Primary conc.	Cleaner conc.	Primary conc.	Cleaner conc.
American River (Teichert).....	1.4	22.4	90	93	90
Cherokee.....	.6	10.8	58	99	91
Ione.....	27	55.4	81	80	72
Mokelumne River.....	2.6	38.0	70	90	86

The analyses of the four cleaner concentrates and the jig concentrate from the Yuba Goldfields dredge are shown in table 6. The significant minerals present were magnetite, ilmenite, zircon, gold, and platinum-group metals. Techniques for fractionating the concentrates are discussed individually in the following sections.

TABLE 6. - Analyses of heavy-mineral cleaner concentrates

Source	Pct				Oz/ton	
	Cr ₂ O ₃	Fe ₂ O ₃	TiO ₂	ZrSiO ₄	Au	PGM
American River (Teichert).....	0.3	79.8	3.2	0.8	¹ 0.06	1.0
Cherokee.....	1.2	13.8	8.4	16.0	.17	.001
Ione.....	.2	18.3	41.0	16.4	.005	.001
Mokelumne River.....	.2	67.6	3.2	.3	.02	(²)
Yuba Goldfields ³	2.5	71.0	11.5	.5	.08	.004

¹Most of the gold had been removed by operators beforehand.

²Not detected.

³Jig concentrate.

Fractionation of Heavy-Mineral Concentrates

American River

A concentrate containing 90 wt-pct heavy minerals was prepared from the sand sample obtained from the Teichert operation at Sacramento. The sample had been treated previously for gold recovery by the operator, accounting for the gold content of 0.06 oz/ton, which was lower than the platinum-group-metal content of 0.4 oz/ton. Preliminary study of the American River concentrate indicated that magnetite, platinum-group metals, and thorium values were significant. The processing sequence for preparing and fractionating the concentrate is shown in figure 2.

The heavy-mineral concentrate was fractionated by low-intensity magnetic separation to yield a magnetite product containing 75 pct of the feed material. Analysis of the magnetite product showed, in weight-percent: Fe₂O₃, 96; Cr₂O₃, 0.3; TiO₂, 2.0; ZrSiO₄, <0.1; and platinum-group metals, 0.014 oz/ton. The nonmagnetic fraction contained the following platinum-group metals, in ounces per ton: Pt, 1.5; Pd, 0.23; Ir, 0.84; Os, 0.82; Rh, 0.26; and Ru, 0.11.

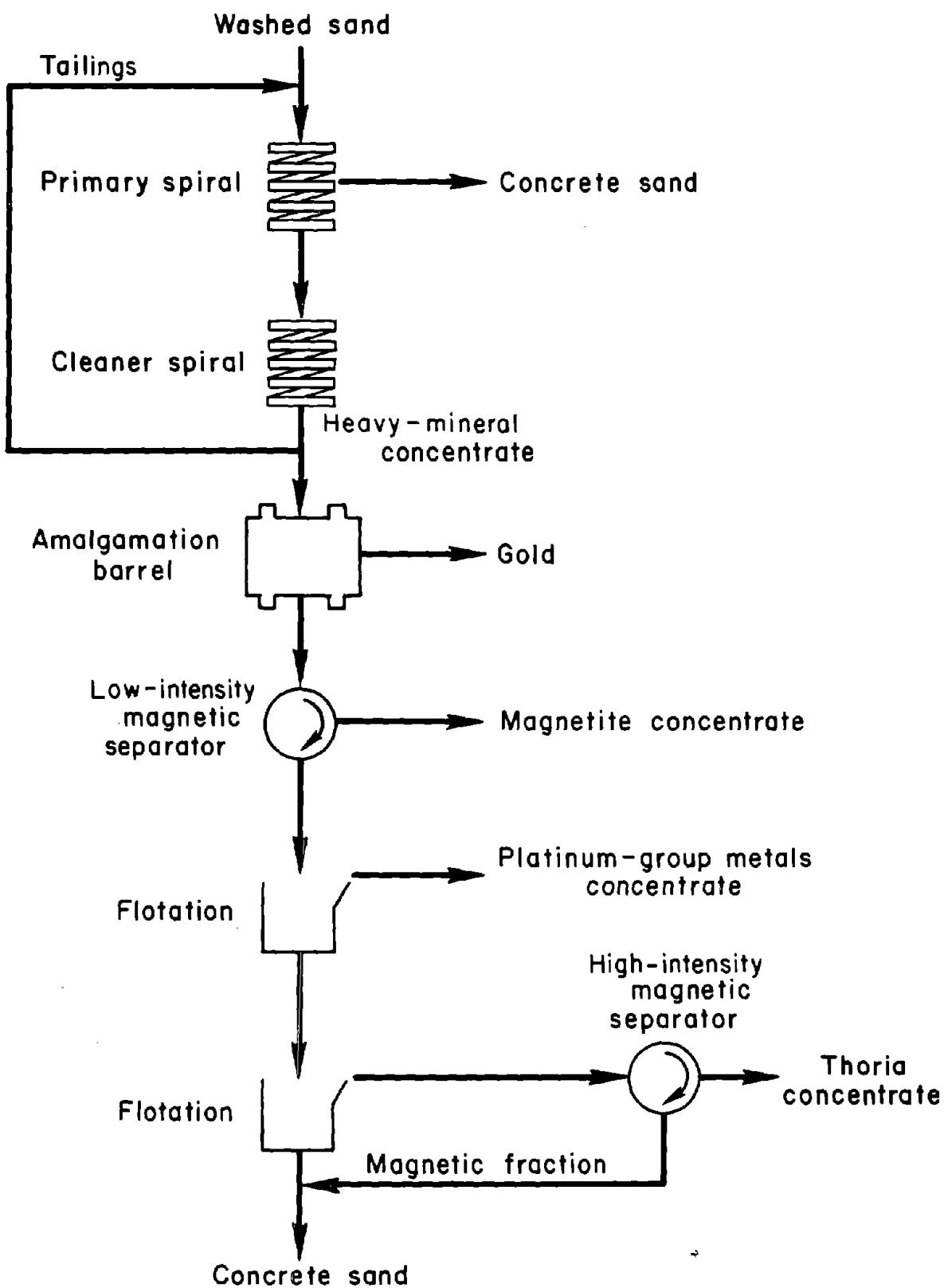


FIGURE 2. - Sequence for processing American River sand.

Microprobe analysis identified ferroplatinum and osmium-iridium alloys. Platinum-group-metal concentrates were prepared from the nonmagnetic fraction by flotation using potassium amyl xanthate and Dowfroth 250.⁵ Over 90 pct of the platinum-group metals was recovered from the low-intensity nonmagnetic fraction. The analyses and distribution of the major platinum-group metals are shown in table 7.

TABLE 7. - Analysis and distribution of platinum-group metals in heavy-mineral concentrate from American River

Sample	Wt-pct	Analysis, oz/ton			Distribution, pct		
		Pt	Ir	Os	Pt	Ir	Os
Low-intensity nonmagnetic..	100	1.50	0.84	0.82	100	100	100
Flotation concentrate.....	.4	348.00	190.00	188.0	93	91	92
Flotation tailings.....	99.6	.11	.08	.07	7	9	8

The flotation tailings, containing 0.68 wt-pct ThO_2 and 0.03 wt-pct U_3O_8 , were treated by fatty-acid flotation to recover a radioactive concentrate containing 3.3 wt-pct ThO_2 and 0.15 wt-pct U_3O_8 . The radioactive minerals in the flotation concentrate were upgraded by high-intensity magnetic separation to remove weakly magnetic minerals such as ilmenite and garnet. The analysis and distribution of the thorium and uranium oxide constituents are shown in table 8. The thorium was present as thorite (ThSiO_4). No specific uranium minerals could be identified by electron microprobe examination.

TABLE 8. - Analysis and distribution of radioactive oxides in heavy-mineral concentrate from American River

Sample	Wt-pct	Analysis, wt-pct		Distribution, pct	
		ThO_2	U_3O_8	ThO_2	U_3O_8
Pt flotation tailings.....	100	0.68	0.03	100	100
Flotation tailings.....	86	.25	.01	32	33
Flotation concentrate.....	14	3.3	.15	68	67
Flotation concentrate:					
High-intensity nonmagnetic...	4.5	8.90	.40	59	60
High-intensity magnetic.....	9.5	.65	.02	9	7

Mokelumne River

The analysis of the heavy-mineral concentrate prepared from the Mokelumne River sample indicated that gold and magnetite were the only significant values that warranted recovery. The processing sequence for recovering gold and magnetite from the Mokelumne River washed sand is similar to the sequence devised for the American River sand sample shown in figure 2. The platinum-group metals and radioactive minerals in the Mokelumne River sand sample were insignificant and, therefore, no attempt was made to recover them.

⁵Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

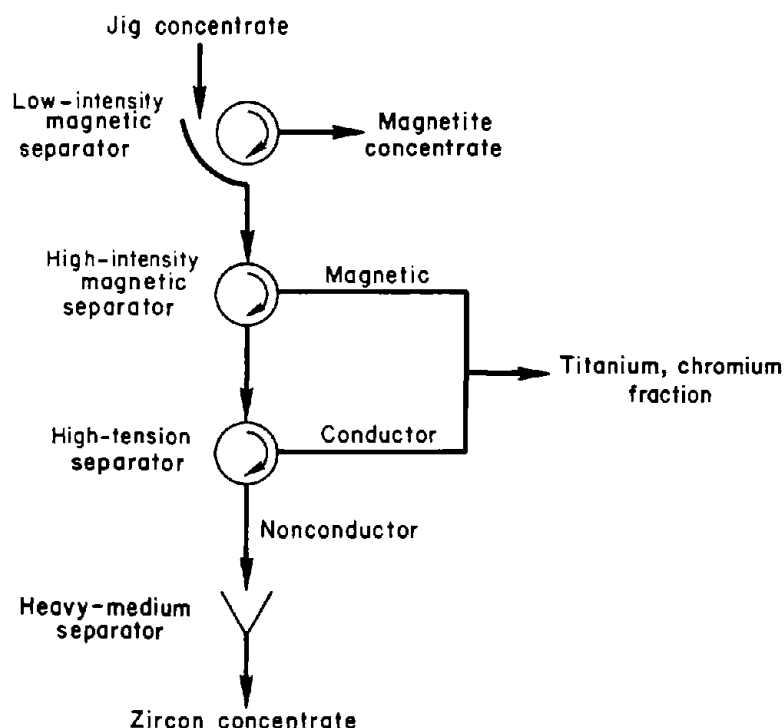


FIGURE 3. - Sequence for processing Cherokee tailings.

The recovery of gold was approximately 100 pct. Eighty-two percent of the iron was recovered in a magnetite product containing 51 pct of the heavy-mineral concentrate. This magnetite product was extremely high grade with the following analysis, in weight-percent: Fe_2O_3 , 96; TiO_2 , 0.7; Cr_2O_3 , 1.7; and SiO_2 , 1.9. Attempts to recover an ilmenite product were not successful as the magnetic fraction produced by high-intensity magnetic separation contained only 14 wt-pct TiO_2 .

Cherokee Tailings

The Cherokee tailings are the downstream waste material from the old hydraulic mining operation at Cherokee, Butte County. The

Baldwin Construction Co. presently operates a sand and gravel pit on the tailings. Analysis and preliminary study of the concentrate indicated that gold, zircon, and a high-grade silica product could be recovered. The processing sequence for preparing a cleaner concentrate, amalgamating the concentrate for gold recovery, and treating the concentrate with high-intensity magnetic and heavy-medium separations to recover a zircon product is shown in figure 3. Zircon recovery in the product was 98 pct; the results are shown in table 9.

TABLE 9. - Fractionation of Cherokee cleaner concentrate

Sample	Wt-pct	Analysis, wt-pct			Distribution, pct		
		Fe_2O_3	TiO_2	ZrSiO_4	Fe_2O_3	TiO_2	ZrSiO_4
Cleaner conc.....	100	13.6	8.5	17.0	100	100	100
High-intensity separation:							
Magnetic.....	29	44.0	26.0	.2	94	88	<1
Nonmagnetic.....	71	1.1	1.4	24.0	6	12	100
Heavy-medium:							
Sink.....	18	2.1	3.0	93.0	3	6	98
Float.....	53	.8	1.0	.5	3	6	2

Tailings from the primary spiral concentrator, containing about 96 wt-pct SiO_2 , were treated with high-intensity magnetic and high-tension separations to recover about 85 pct of the silica in a product with the following analysis, in weight-percent: SiO_2 , 99; Al, 0.1; Ca, 0.02; Fe, 0.07; Mg, 0.001; Ti, 0.1; and Zr, 0.1.

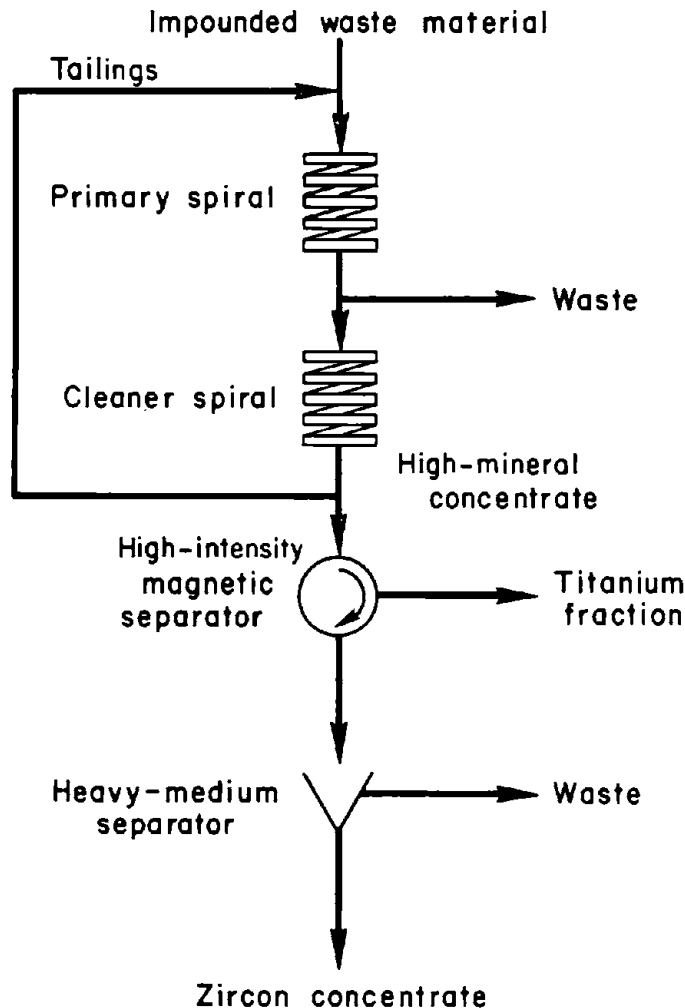


FIGURE 4. - Sequence for processing Ione waste material.

Ione Waste Material

The processing sequence used to upgrade and fractionate the waste material from the silica-clay operations at Ione, Amador County, is shown in figure 4. The cleaner concentrate containing 81 wt-pct heavy minerals was fractionated by high-intensity magnetic separation to yield a magnetic fraction containing 96 pct of the TiO_2 and a nonmagnetic fraction containing 97 pct of the zircon. The nonmagnetic fraction was treated by heavy-medium separation to yield a product assaying 89.6 wt-pct $ZrSiO_4$. Over 95 pct of the zircon in the nonmagnetic fraction was recovered in this product. The results are shown in table 10.

The ilmenite or titanium mineral fraction contained 63.5 wt-pct TiO_2 and 26.3 wt-pct Fe_2O_3 ratio of 2.4:1.0. Most commercial alluvial ilmenite has a $TiO_2:Fe_2O_3$ ratio of about 2.0:1.0. The major species identified by X-ray diffraction were a noncrystalline mineral and pseudorutile ($Fe_2O_3 \cdot 3TiO_2$). The product probably would be classified as leucoxene, a mixture of highly altered titanium minerals. This material could possibly be

used as a feed material for the preparation of titania pigment by the chloride process. About 95 wt-pct of the material is in the minus 65 plus 200-mesh size range, which is a suitable particle size for a fluid-bed reactor.

TABLE 10. - Fractionation of Ione concentrates

Sample	Wt-pct	Analysis, wt-pct			Distribution, pct		
		Fe_2O_3	TiO_2	$ZrSiO_4$	Fe_2O_3	TiO_2	$ZrSiO_4$
Cleaner conc.....	100	17.7	42.3	16.9	100	100	100
High-intensity magnetic separation:							
Magnetic.....	64	26.3	63.5	.6	95	96	3
Nonmagnetic.....	36	2.5	4.5	46.0	5	4	97
Heavy-medium:							
Sink.....	18	1.1	8.8	89.6	1	4	95
Float.....	18	3.9	.2	2.5	4	<1	2

Yuba Goldfields Black Sand

A jig concentrate containing 95 wt-pct heavy minerals was obtained from the Yuba Goldfields dredge at Hammonton, Calif. The concentrate was previously treated in amalgamation barrels for gold recovery. The material contained the following, in weight-percent: Cr_2O_3 , 2.5; Fe_2O_3 , 71; TiO_2 , 11.5; and ZrSiO_4 , 0.5. It also contained 0.08 oz/ton gold and 0.04 oz/ton platinum-group metals. The Yuba Goldfields concentrate was examined by electron microprobe to determine the mineralogical associations. The probe indicated a complex association between magnetite and titanium. Individual grains of magnetite contained from 0.2 to 16 wt-pct TiO_2 . Titanium in the major species was as follows, in

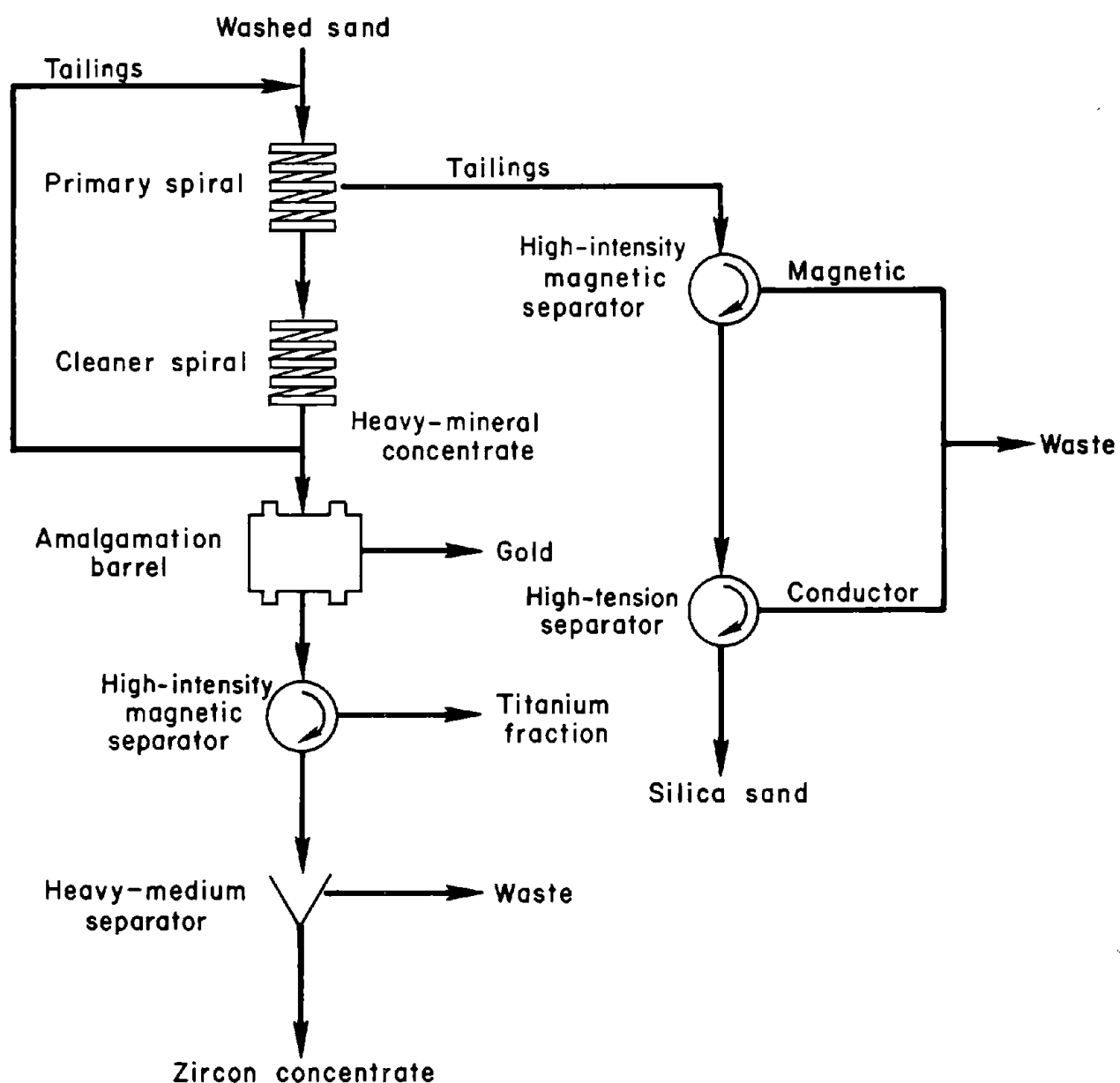


FIGURE 5. - Sequence for processing Yuba Goldfields jig concentrate.

weight-percent: magnetite, <0.2; zoned magnetite, 3 to 6; homogeneous magnetite, 3 to 16; and ilmenite, 31. The chromite grains showed a wide range of chromite content, ranging from 8 to 35 wt-pct. The ilmenite and zircon grains were totally liberated. This complex association indicated it would be difficult to separate the titaniferous and chromiferous minerals from one another and from the magnetite.

The processing sequence for fractionating the jig concentrate is shown in figure 5. The concentrate was fractionated by low-intensity magnetic separation to yield a magnetite fraction containing 67 pct of the feed material. The magnetite product had the following analysis, in weight-percent: Fe_2O_3 , 95; TiO_2 , 3.7; Cr_2O_3 , 1.9; and ZrSiO_4 , <0.1. The magnetite product contained 80 pct of the Fe_2O_3 , 55 pct of the Cr_2O_3 , and 24 pct of the TiO_2 in the jig concentrate.

Additional fractionation of the nonmagnetic fraction with the high-intensity magnetic and high-tension separators resulted in 80-pct recovery of the zircon in a product containing 63 wt-pct ZrSiO_4 . The separation of chromite from ilmenite in the high-intensity magnetic and high-tension conductor fractions was unsatisfactory.

DISCUSSION AND CONCLUSIONS

The occurrence of heavy minerals in materials handled by sand and gravel operations in northern California is widespread. The major minerals present are magnetite and ilmenite. In some localities, platinum-group metals, chromite, and zircon also occur in significant quantities. Recovery of 90 pct of the heavy minerals in bulk concentrates with an assay up to 90 wt-pct heavy minerals was achieved with a Humphreys spiral concentrator. Individual magnetite, ilmenite, and zircon concentrates were prepared by further treatments with low-intensity magnetic, high-intensity magnetic, high-tension, and heavy-medium separations.

Successful recovery of byproduct minerals will depend on the development of markets for the mineral concentrates and the incorporation of high-capacity concentrating equipment into the sand-washing circuit of the plants to prepare heavy-mineral concentrates. Equipment such as the Reichert cone or Cleveland jig with low initial and operating costs could be utilized. A plant utilizing relatively high-cost equipment to produce marketable mineral concentrates could be built in a central location to treat heavy-mineral concentrates obtained from several individual sand and gravel operations.

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