

INVESTIGATION OF THE NIXON FORK AREA,
KUSKOKWIM RIVER BASIN, ALASKA

by Raymond P. Maloney

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UNITED STATES DEPARTMENT OF THE INTERIOR

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ABSTRACT

Work on the copper-gold-silver deposits of the Nixon Fork area consists of two parts; a metallurgical section and a reconnaissance examination. The metallurgical work was done to develop a method suitable for extraction of gold and copper from the complex silicate ores. Results indicated that additional research is required. Caustic leaching is a potential method for recovery of copper from chrysocolla ores associated with basic minerals; ammonia leaching and flotation methods were ineffective. A high gold recovery is not possible without simultaneous recovery of copper. Gold recovery methods include tabling, corduroy matting, flotation, and barrel amalgamation. Work was done in Juneau with commercially available reagents and equipment.

The reconnaissance examination was made to determine the feasibility of additional work by the Bureau in determining the mineral potential of the area. Paleozoic limestone and Cretaceous sandstones have been intruded by quartz monzonite. Copper, gold, and silver mineralization were found in limestone and granite in an area about 1 mile wide and 2 miles long. Mineralization occurred chiefly as copper silicate but minor amounts of copper sulfides were found. Gold and silver were associated with copper mineralization; minor amounts of bismuth were found. Mineralization was still present at approximately 600 feet below the surface in the deepest underground workings.

INTRODUCTION

The work on the copper-gold-silver deposits in the Nixon Fork area was done as part of the Bureau's continuing program for the development of Alaska's resources. The metallurgical research was done in 1954-57 and the reconnaissance examination was made in 1964. The Nixon Fork area was the scene of considerable mining and prospecting activity for gold from 1917-33, but little interest was shown in the other minerals; since then, such activity has been sporadic and sharply curtailed. Very little data is available from these previous mining operations, and a dense cover of brush and moss effectively conceals most of the bedrock. Copper

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mineralization was found in numerous old prospect pits, shafts, and trenches over most of this area.

ACKNOWLEDGMENTS

Appreciation is expressed to Theodore J. Almasy and Margaret Mespelt of McGrath, Alaska for information on the prospect. Maps, except for figures 3 and 4, are modified from U.S. Geological Survey topographic series.

LOCATION AND ACCESSIBILITY

The Nixon Fork mine is in the Kuskokwim River basin, 8-1/2 airline miles north of Madfra (figs. 1 and 2). A 12-mile road formerly connected Madfra and the mine, but both bridges and much of the road are now washed out; most of the last 6 miles of the road are beyond repair. Madfra, located on the north bank of the Kuskokwim River, has a post office, small trading post, several cabins, a 2,500-foot airstrip, and about 10 permanent residents. It is used as a summer fish camp by the Nikolai Natives, an Indian tribe of about 100, who live 60 miles upriver. Ocean going freighters dock at Bethel near the mouth of the Kuskokwim River; heavy freight and supplies can be shipped from there by river barge. Large multi-engine planes make daily scheduled stops at McGrath, about 30 airline miles from Madfra, and small planes can land at Madfra. An airstrip suitable for small planes would not be difficult to construct near the Nixon Fork mine.

PHYSICAL FEATURES AND CLIMATE

Low rolling hills, with an occasional sharp peak, are the general features of this section of the Kuskokwim Mountains-Nixon Fork area. The valley of the Nixon Fork River a few miles to the north is broad and swampy, meanders are common. The highest peak is about 1,800 feet in altitude and most of the rest of the area is between 1,000 and 1,500 feet above sea level. The valley of the Nixon Fork River is about 600 feet in altitude.

Spruce, cottonwood, and birch form patches of forest; alder and willow are found along the streams. Much of the timber in the vicinity of the mine workings has been cut and this section is now covered with a dense second growth of trees and brush. Permafrost is probably present over much of the area. The moss covering appears to be exceptionally thick.

The climate is sub-Arctic; temperatures probably reach 80° F in the summer and below -60° F in the winter. The rainfall averages about 20 inches with much of this precipitation coming in the summer months of June, July, and August as a slow drizzle.

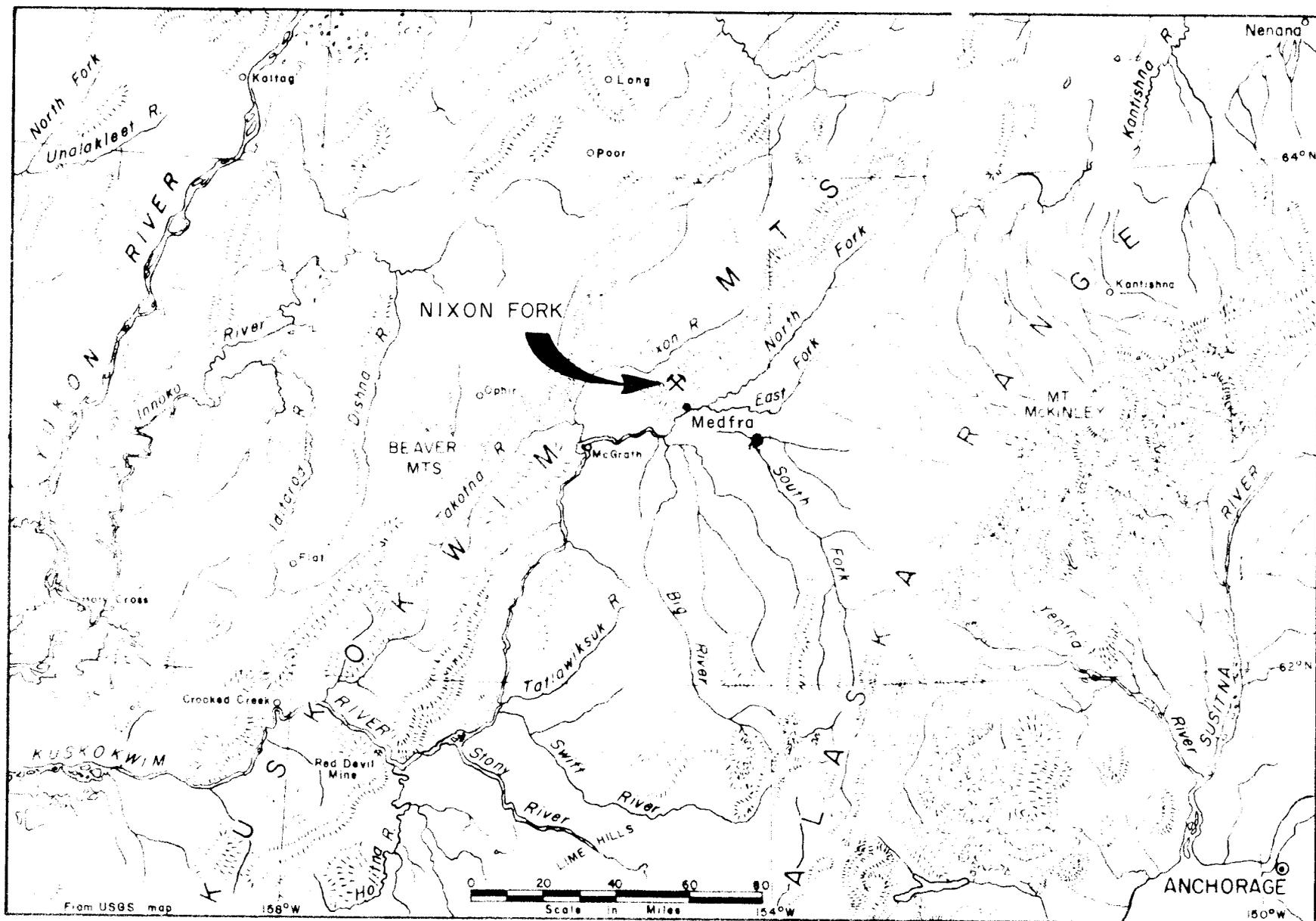


FIGURE 1.-Index Map, Nixon Fork Area, Alaska.

HISTORY

The history of the area is taken from U.S. Geological Survey reports by Brown (1),^{2/} Martin (5), Martie (6), and Jasper's (3) report on the Mespelt mine, and from verbal reports from the present owners. Contradictory statements were heard and read regarding early ownership, but the following information is believed to be generally correct.

Placer gold was first discovered in the Nixon Fork area on Hidden Creek in 1917 by F. E. Matthew. Further prospecting found placer gold in Ruby, Mystery, and Submarine Creeks. The first bedrock source of gold, the Crystal lode, was found at the head of Ruby Creek in 1918 by Pearson and Strand. In 1919-20 several hundred tons of ore were shipped by Thomas Eakin from this property to the Tacoma smelter. Other claims were staked and in 1921 the Threadwell Yukon Co., Ltd. (locally called the Threadwell Co. and owned and controlled by the Alaska Threadwell Gold Mining Co.) installed a 10-stamp mill and began mining and milling operations, particularly from three groups of claims, the Walen and Griffin group, the Pearson and Strand group, and the McGowan and Mespelt group. In 1923 the Threadwell Co. discontinued all operations and the various claims reverted back to the original owners.

The Walen lode (Walen and Griffin group) at the head of Holmes Gulch reverted back to E. M. Walen, who leased the mill in 1924 and milled some easily accessible ore. The mine caved in from the surface about this time and left a glory hole about 50 feet deep and 200 by 100 feet at the surface.

The McGowan and Mespelt group (often called the Southern Cross) on the slope leading to Mystery Creek and several hundred feet northeast of the Pearson and Strand group at the head of Ruby Creek reverted back to its namesakes.

The Pearson and Strand group of claims and eventually the 10-stamp mill were first taken over by Pearson and Strand and then passed into the hands of the Mespelt brothers who operated them continuously from 1926-33. They were leased to H. G. Wilcox and Associates in 1950-51. From 1952 until recently, the property has been leased by Strandberg and Sons, Inc. Some underground mining from the Crystal lode and milling of the old tailings was done by the Strandbergs. The property now has reverted back to the Mespelt brothers and heirs.

Numerous other claims, both placer and lode, have been staked and restaked by various prospectors, but at present almost the entire area appears to be in the hands of the Mespelt brothers and heirs, and Margaret Mespelt and T. Almasy of McGrath.

^{2/} Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

GEOLOGY

The geology of the area has been mapped and described by Brown (1), Martin (5), Mertie (6), and Jasper (3) and the following description is summarized from their reports.

Early Paleozoic limestone and Cretaceous sandstone and shale have been intruded by a roughly oval shaped mass of quartz monzonite considered to be of Tertiary age, about 2 by 5 miles in dimensions. The limestone and shale underlie a large area in this region and are probably intruded by other monzonite masses not yet discovered. The thickness of the limestone is estimated to be at least 5,000 to 7,000 feet. Porphyry, closely related to the monzonite, occurs as dikes and in places as a chilled border zone between the monzonite and sedimentary formations. The contact is probably very irregular in outline and has numerous apophyses. Mineralization occurs at or near the contact and mostly in the limestone; ore-bearing solutions probably followed both fault and contact planes.

The ores are described as gold-bearing copper sulfides.

MINE WORKINGS

Old trenches, incomplete trenches, shafts with head frames, open shafts, even shafts in cabins, numerous prospect pits (some as much as 15 to 20 feet deep), placer cuts, water ditches, glory holes, and small cleared areas are scattered over an area about 3 miles long and 2 miles wide covered with dense brush, second growth timber, and exceptionally thick moss. A location map showing all of these workings is not available, but U.S. Geological Survey Bulletins (1, 5, 6) give the location of a few shafts, and Jasper (3) has mapped the 460-foot level of the Maspelt mine. The shaft of this mine is now iced up but is reported to be in good condition. Figures 3 and 4 are copies of old maps of the Walen shaft and the Crystal Knob shaft; both maps are probably incomplete.

There are at least 15 shafts in the area varying in depth from about 600 feet (the Maspelt mine shaft) to probably 50 feet. All are inaccessible and the depths of most are unknown. Three shafts near the Maspelt mine are reported to be 310, 150, and 100 feet in depth. The Walen shaft at the glory hole is reported to be about 200 feet deep.

The mill is still standing but in need of repair, especially the roof. The steam boilers are in poor condition and the diesel power plant used to run the mill in recent years has been removed. The 50-ton stamp mill, settling tanks, crushers, tables, etc., are in fair shape and could be put back in use. An estimated 10,000 tons of tailings are held by a deteriorating log and brush dam.

A good log and frame hoist house at the Mespelt mine houses a new 365 cubic foot air compressor powered by a D-8 diesel, a good 37.5 kw diesel generator, a hoist powered by a V-8 gasoline motor, and a collection of drills and other tools. The hoist and cable are old. A blacksmith shop and forge occupy a separate building. There is a wood powder house containing about 50 cases of dynamite near the mine shaft.

Near the mill, about a half mile from the Mespelt shaft, there is a good 3-room cabin, several small shops, warehouses, cabins, and caches, all in fair condition, and a bunkhouse and cabin in poor condition.

WORK BY THE BUREAU OF MINES

Reconnaissance

A reconnaissance was made of the area to determine the problems and possible potential of an additional investigation. The logistics of getting equipment into the area, route, water supply, location and suitability of airstrips, amount of permafrost, overburden, etc., were considered as well as potential mineralization.

Chemical and petrographic analyses of numerous samples taken over the area are listed in tables 1 and 3. Analyses of grab samples taken of the mill tailings are shown in table 2. Locations are shown on figure 5.

Mineralization appears to be widespread over the area, but as mentioned before, little record has been kept of past developments. Gold, copper, and silver are the principal minerals; bismuth is present in minor amounts, and a trace of scheelite was found. A copper silicate (chrysocolla) and unidentified copper silicates were the chief ore-bearing minerals found. However, minor amounts of bornite, azurite, chalcopyrite, and malachite were also present.

Most samples were float taken from old shaft tailings, pits, trenches, etc., but those taken in the glory hole (46 through 53) at the Walen mine were in place.

Samples assayed as much as 24.34 ounce Au, 17.26 ounce Ag, 11.69 percent copper, and 1.4 percent bismuth. Usually these minerals are associated with one another and good values of one meant good values of another. The exception was silver, where the highest silver value had little of anything else.

TABLE 1. - Chemical analyses of samples

Sample No.	Description	Percent		Oz per ton	
		Cu	Bi	Au	Ag
1	Quartz diorite float from Twin shaft dump...	<0.01	<0.002	Nil	Nil
2	Granitic diorite float from Twin shaft dump.	<.01	<.002	Trace	0.02
3	Quartz float from McGowan shaft dump.....	<.01	.002	0.02	17.26
4	Skarn float from Twin shaft dump, pet. only.				
5	Diorite and skarn from garnet trench, pet. only.				
6	Asbestos float from garnet trench area, pet. only.				
7	Skarn and altered rhyolite from large dump near McGowan shaft, pet. only.				
8	Skarn from top of Crystal Knob.....	1.65		.24	.62
9	Hydrothermal rock from Red lode.....	<.01			
10	Altered limestone float from glory hole.....	10.33	.47	11.28	3.16
11	Altered andesite float from Hi-Grade shaft dump.	8.19	.09	7.26	2.22
12	Black, altered andesite with garnet crystals about 300 feet east of Hi-Grade shaft.	<.01	<.002	Nil	.06
13	Gossan float from dump of shaft and small glory hole on Ruby Creek.	.01		Nil	.08
14A	.....do.....	<.01		Nil	.12
15A	Altered and decomposed granite at same locations as 13 and 14A.	1.93		Trace	.44
25	Altered limestone from Mespelt shaft dump..	.02		.04	Nil
26	Hydrothermal rock from Mespelt shaft dump..	.06		Nil	Nil
27	.....do.....	10.44	.64	24.34	7.26
28	.....do.....	4.93		2.02	9.62
29	.....do.....	.42		.10	.02
30	.....do.....	.08	.002	Trace	Nil
31	Skarn-type waste from Tiney Gulch pit.....	.06			
32	Skarn from Tiney Gulch pit; minor copper....	.77		Trace	1.80
33	Jaspers 5 Acres, skarn float, visible copper	2.90		1.18	1.56
34	Jaspers 5 Acres, siliceous dolomite.....	.27			
35	Jaspers 5 Acres, black skarn or serpentine..	.16			
36	Jaspers 5 Acres, type limestone.....	<.01			
37	Limestone boulder with copper, 1,500 feet north of camp.	11.54			
38	Type country rock at airstrip (quartzite)...	.02			
39	Shale and gossan from Birch Creek placer....	.01		Nil	Nil
40	Quartz and dolomite near limestone-granite contact.	.02		Nil	Nil
41	Siliceous dolomite, quartzite from dump of inclined shaft in glory hole.	11.42		10.16	5.58
42	Same as 41, but dark brown color.....	6.47		.58	2.64

TABLE 1. - Chemical analyses of samples--continued

Sample No.	Description	Percent		Oz per ton	
		Cu	Bi	Au	Ag
44	Copper mineralization in 15-foot wide section of granite in glory hole at north end near inclined shaft.	1.33		0.32	1.04
45	Limestone, hydrothermal rock in north wall of glory hole near shaft.	1.35	0.004	.54	.80
46	Blue-white skarn in north wall of glory hole near shaft.	.03		Nil	Nil
47	Altered limestone, skarn on west wall of glory hole on left side of shaft.	1.34	.002	.26	.48
48	Type brown dolomite on west wall of glory hole	.16	<.002	Nil	.02
49	1-foot wide zone of gossan in about center of west wall of glory hole, copper visible.	11.69	1.40	6.48	4.04
50	Type brown gossan, limestone west wall glory hole.	.60	.003	Trace	.14
51	Brown gossan with visible copper mineralization in west wall glory hole.	5.25		.16	.98
52	Lens of hydrothermal rock with mica in west wall of glory hole.	.18		.04	.08
53	Similar to 52 but on east wall of glory hole..	.04		Nil	.10
54	Skarn with mica at shaft dump about 300 feet north of glory hole, greenish cast.	.40		Trace	.70
55	Green-black skarn and mica with copper stringers on same shaft dump.	5.04		1.48	8.68
56	Type of copper-bearing skarn on above shaft dump.	6.16	.16	.40	4.64
57	Large tailings pile near above shaft type sample (skarn).	.38	.003	.02	.32
66	Greenish decomposed material in old prospect pit above (east) main campsite.	7.89	.09	1.26	4.64

TABLE 2. - Chemical analyses of mill tailings

Sample No.	Description	Percent		Oz per ton	
		Cu	Bi	Au	Ag
22	Tailings pile.....	3.45		1.04	0.88
23	.....do.....	1.36		.90	.52
24	.....do.....	2.51		1.22	.74
58	.....do.....	2.34	0.04	1.18	.98
59	.....do.....	2.88	.05	.02	2.20
60	.....do.....	3.50		1.10	.96
61	.....do.....	3.08		1.08	1.42
62	.....do.....	2.61		1.28	1.02
63	.....do.....	3.16		1.10	.86
64	.....do.....	2.26	.05	1.08	1.10
65	.....do.....	<u>2.41</u>		<u>.98</u>	<u>1.32</u>
	Average.....	2.7		1.0	1.1

TABLE 3. - Petrographic analyses of samples

Sample No.	1	2	3	4	5	5A	6	7	7A	8	9	10	11	12	13	26	27	29	30	31	32	
Rock classification:																						
Andesite	-	-	-	-	-	-	-	-	-	-	-	-	C	C	-	-	-	-	-	-	-	-
Diorite	C	-	-	C	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dolomite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gossan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-
Hydrothermal rock	-	-	-	-	-	-	-	-	C	C	-	-	-	-	-	C	C	C	C	-	-	-
Kaolinized granite	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limestone	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-
Mill tailings	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quartzite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skarn	-	-	-	-	-	C	C	C	-	C	-	-	-	-	-	-	-	-	-	-	C	C
Vein quartz	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Minerals:																						
Actinolite	-	-	-	-	-	-	P	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-
Actinolite+tremolite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Albite-oligoclase	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Andesine	A	-	-	A	-	-	-	-	-	-	-	-	A	S	-	-	-	-	-	-	-	-
Apatite	-	-	-	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	T	-	S	-
Augite	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Asurite	-	-	T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	T
Biotite	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bornite	-	-	T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calcite	-	-	S	-	-	F	-	-	-	P	-	S	-	S	-	-	-	-	-	S	-	-
Carbon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chalcopyrite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	T
Chlorite	S	S	T	-	-	F	F	F	S	S	-	-	P	-	S	-	T	S	-	-	-	-
Chrysocolla	-	-	A	-	-	T	A	-	-	S	S	-	-	-	-	S	-	-	-	-	-	-
Diopside	-	-	A	-	A	M	-	-	P	-	-	-	-	-	-	-	-	-	-	-	A	P
Dolomite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epidote	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	A	P	-	A	-	-	-	-	-	-	-	-	-	-	-	-	P	A
Goethite-limonite	-	S	M	-	-	F	F	F	S	M	S	S	M	S	P	S	A	S	S	-	S	F
Hornblende	S	-	-	-	T	-	-	-	-	-	-	-	-	F	-	-	-	-	-	-	-	-
Ilmenite	T	-	-	-	-	-	-	-	-	-	-	-	-	M	-	-	-	-	-	-	-	-
Kaolin	-	A	-	-	-	-	-	-	-	A	-	A	-	M	P	A	P	P	-	-	-	-
K-feldspar	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	-
Magnetite	-	-	-	T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Malachite	-	-	S	-	-	T	-	M	-	S	-	-	-	-	-	M	-	-	-	-	-	F
Muscovite	-	-	-	-	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quartz	A	A	P	T	-	S	-	A	T	A	S	M	-	S	A	S	S	A	-	-	-	-
Scheelite	-	-	-	-	-	T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphene	T	-	-	-	-	T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	T	-	-	-	-	-	-	-	-	-	-	-	-	T	-	-	-	-	T	T	-	-

Legend: P - Predominant more than 50 percent
A - Abundant 10 - 50 percent
S - Subordinate 2 - 10 percent
M - Minor .5 - 2 percent
F - Few .1 - .5 percent
T - Trace less than .1 percent
C - Rock classification.

Metallurgical Section

Introduction

Laboratory beneficiation studies were made by the Bureau in Juneau of ore samples received from Strandberg and Sons in 1954 from an ore shoot on the 460-foot level of the Mespelt mine and from the tailings at the mill site. This work was done by R. R. Wells, Chief, Laboratory Investigations, and E. G. Erspamer, Metallurgist, both of the Bureau of Mines in Juneau. This work was completed in 1957. Four samples were received, Nos. 1 through 3 from an ore shoot on the 460-foot level of the Mespelt mine, and No. 4 from the mill tailings. Testing all four samples by each method tried was considered impracticable. Sufficient correlation of the various samples and methods was conducted; however, to make general conclusions as to the results that may be obtained by different treatments. There are two parts to this section of the report, Mineral Dressing by Mr. Wells and Caustic Leaching of Chrysocolla Ore by Mr. Erspamer.

The following section of this report is by R. R. Wells.

Mineral Dressing

Abstract.

In general, the samples tested contain 2.5 to 6.1 percent copper and 1 to 12 ounces gold per ton. The copper occurs almost entirely as the hydrous copper silicate, chrysocolla, and no treatment method was found to be suitable for economic copper recovery. The gold occurs, in part, as fine metallic particles. A part of the gold, however, appears to be in intimate association with the copper mineral so that liberation and recovery were not achieved even after extremely fine grinding. Only 60 to 75 percent of the gold in the ore samples was recovered in high-grade concentrates; best results obtained from treatment of the tailing sample showed a recovery of 35 percent of the gold in a product that assayed 20.7 ounces of gold per ton.

Physical Characteristics of Samples

The ore samples submitted are similar mineralogically and vary only in the relative amounts of the mineral components. Each contains quartz and calcite with associated limonite, goethite, chrysocolla, and clay minerals and minor amounts of malachite and chalcopryrite. The tailing sample is similar except that, in addition, small amounts of garnet, feldspar, and biotite were noted. The gangue of one ore and the tailing sample was chiefly quartz; a second ore sample was composed chiefly of calcite; the third ore contained calcite and quartz in approximately equal amounts.

In all samples, the chrysocolla, malachite, and chalcopryrite are partially liberated in the minus 100 plus 200-mesh fraction. Because of the fine-grained

grained nature and intimate association of the copper minerals with limonite and goethite; however, liberation is not complete even in the minus ²⁰⁰plus 400-mesh size range.

It is worthy of note that, although some of the samples contain 10 to 12 ounces gold per ton, microscopic study revealed only trace amounts of gold and in no case was the amount of gold observed sufficient to determine liberation data for this material.

Petrographic analyses of these samples are as follows:

No. 1 mine sample--this sample contains calcite with some associated limonite and goethite, quartz, chrysocolla, clay minerals, and a small amount of malachite.

Much of the chrysocolla and malachite is liberated in the minus 100 plus 200-mesh fraction. However, because of the intimate association of some of the chrysocolla and malachite with limonite and goethite, complete liberation of the copper minerals does not take place even in the minus 200-mesh.

No. 2 mine sample--this sample essentially contains quartz, some associated calcite, goethite, and limonite, chrysocolla, clay minerals, and small amounts of malachite and chalcopryrite. Also observed was a very small amount of free gold.

Liberation data is the same as for mine sample No. 1; except that, in addition, the chalcopryrite is not completely liberated even in the minus 200-mesh fraction. The amount of gold observed was so small that liberation data was not readily obtainable.

No. 3 mine sample--this sample essentially contains calcite and quartz, some limonite, goethite, chrysocolla, and small amounts of clay minerals, chalcopryrite, and malachite. Also present is a very small amount of gold.

The identity of the chrysocolla was confirmed by x-ray analysis.

The chrysocolla, malachite, and chalcopryrite are partially liberated in the minus 100 plus 200-mesh fraction. However, because of the fine-grained nature and intimate association of the copper minerals with the other minerals of the sample, complete liberation does not take place even in the minus 200-mesh fraction.

No. 4 mill tailings sample--this sample essentially contains quartz, limonite and goethite, some associated calcite, chrysocolla, garnet, feldspar, and small amounts of malachite, clay minerals, and biotite.

Liberation data is the same as for mine sample No. 1.

Chemical Characteristics of the Samples

Representative head samples, prepared from each sample submitted, had the following partial chemical analyses:

TABLE 4. - Chemical analyses of 1954 metallurgical sample

Sample	Assay, percent						Ounce per ton	
	Cu	Oxide Cu	Fe	Pb	Zn	SiO ₂	Au	Ag
No. 1 mine	4.15	3.9	10.9	*0.05	0.4	34.4	6.99	1.9
No. 2 mine	6.12	6.0	12.3	* .05	.4	34.7	12.18	5.3
No. 3 mine	5.2	5.0	-	* .05	-	43.9	10.31	2.9
No. 4 tailing	2.54	2.2	11.4	* .05	.8	57.6	1.02	.9

* Less than.

Semi-quantitative spectrographic analyses, made of representative portions of the various samples submitted, revealed the presence and approximate amounts of the metals listed in the following table. Any other elements if present, are in amounts lower than the minimum detectable by the routine technique employed.

TABLE 5. - Spectrographic analyses of 1954 metallurgical sample

Sample	Ag	Al	As	Au	B	Bi	Ca	Co	Cu	Fe	Mg	Mn	Mo	Ni	Pb	Si	Ti	V	Zn
No. 1 mine	F	C+	D-	E-	F	E	A	E	C	A	E	D	F-	F	-	A	E	E	E
No. 2 mine	F	C+	D-	D-	F	E	A	E	C+	A	E	D	F	F	E	A	E	E	E
No. 3 mine	E	C	D	-	-	E	A	-	A	A	E	D	F	E	-	A	E	-	E
No. 4 tailing	F	B	D-	-	F	E	A	E	C	A	E	C	E	F	E	A	E	E	E

Legend: A more than 10 percent

B 5 to 10 percent

C 1 to 5 percent

D 0.1 to 1 percent

E 0.01 to 0.1 percent

F 0.001 to 0.1 percent

G less than 0.001 percent.

Methods of Concentration

All of the standard beneficiation techniques were used in the attempt to produce a copper concentrate with acceptable recovery. Gold recovery methods included tabling, corduroy matting, flotation, and barrel amalgamation.

Sizing.--A portion of each of the ore samples was roll-crushed to minus 10-mesh and screen sized wet using standard Tyler sieves. The tailing sample was screen sized without crushing. The results are shown in table 6. These results, obtained by screen sizing sample No. 3 mine, are illustrative of the results obtained.

TABLE 6. - Screen analysis, sample No. 3 mine

Product	Weight, percent	Percent Cu	Assay		Distribution, percent		
			Ounce per ton		Cu	Au	Ag
			Au	Ag			
Plus 20-mesh	30.88	5.6	9.34	2.7	32.3	28.7	27.8
20/35-mesh	35.45	5.4	9.65	3.2	35.7	34.1	38.3
35/48-mesh	9.54	5.3	10.15	3.0	9.5	9.7	9.4
48/65-mesh	7.07	5.1	10.26	2.9	6.7	7.2	7.0
65/100-mesh	5.29	4.9	10.78	2.9	4.8	5.7	5.2
100/200-mesh	5.05	5.0	12.71	3.4	4.7	6.4	5.7
Minus 200-mesh sand	4.63	4.9	15.40	3.6	4.2	7.1	5.7
Slime	2.09	5.5	5.30	1.3	2.1	1.1	.9
Calc. head	100.00	5.4	10.03	2.9	100.0	100.0	100.0

It will be noted in the above table that there is no significant concentration of copper in any sized fraction. The grade of gold and silver, however, showed a definite increase in the minus 100 plus 400-mesh sand and a sharp decline in the slime fraction. This indicates at least minus 100-mesh grinding is required for liberation of gold and silver from the copper minerals.

Flotation of Copper.--At the inception of the investigation, the chief copper mineral was tentatively identified as malachite and a number of flotation tests were made employing techniques commonly used for flotation of oxide and carbonate copper minerals. Sulfidization and fatty acid flotation methods were investigated but results obtained were not encouraging and no significant concentration of copper minerals was made. Subsequent petrographic study and substantiating x-ray data positively identified the dominant copper mineral as chrysocolla. This information led to the investigation of the use of cationic reagents for selectively floating the copper silicate from the gangue minerals. These studies were also unsuccessful.

Acid Leaching of Copper.--A series of agitation leaching tests were conducted on Mespelt sample No. 2 using dilute sulfuric acid as the lixiviant. Copper extractions greater than 90 percent were obtained in a 2-hour leach with 10 percent acid. Indicated acid consumption was 4 to 5 pounds per pound of copper dissolved.

Ore samples 1 and 3 contain a greater proportion of calcium carbonate than the sample tested and, therefore, would consume a larger amount of acid.

Attempts to remove the bulk of the calcite by flotation prior to leaching were unsuccessful since the calcite concentrate carried an average of 15 ounces gold per ton.

Leach-Precipitation-Flotation.--In spite of high acid consumption indicated by the preliminary leaching tests, one test was run employing a laboratory adaptation of the process usually known as leach-precipitation-flotation (LPF). A portion of sample No. 2 was ground to minus 48-mesh and leached for 2 hours with a 10 percent sulfuric acid solution. Powdered iron was added to precipitate metallic copper, and the copper, gold, and silver were floated using standard sulfide collectors. Examination of the products indicated that the leaching and precipitation stages were reasonably complete. Flotation, however, was hampered by excessive sliming characteristics of the ore and results were not satisfactory. Only 30 percent of the copper and 43 percent of the gold were recovered in a rougher concentrate that assayed 51.6 percent copper and 93.55 ounces gold per ton.

Ammonia Leaching.--A series of tests were made to determine the feasibility of leaching copper from Mespelt ore using ammonia or ammonia-ammonium carbonate solutions. Best results, obtained by leaching 14 hours, indicated an extraction of only 40 percent of the copper in the ore.

Segregation Process.--A process that has been successfully used for treatment of certain copper ores containing chrysocolla was described by Maurice Rey, noted French metallurgist, and repeated in some detail on page 542 of Liddell's "Handbook of Non-Ferrous Metallurgy," 1945 edition.

The technique, known as the "Segregation Process" involves reduction roasting of the ore with carbon in the presence of a small amount of chlorine, i.e., about 10 percent of the chlorine that would be required for complete chloridization of the ore. The copper is supposedly reduced to the metallic state and is recovered by grinding and flotation.

Tests employing this treatment were made on samples of Mespelt ore with complete lack of success.

Flotation of Gold.--A series of tests were made on ore ground to minus 100-mesh to determine the recovery of gold possible by flotation methods without regard to recovery of copper. The following table shows typical results for each sample.

TABLE 7. - Flotation of gold

Sample	Recovery, percent		Grade, ounce per ton	
	Au	Ag	Au	Ag
No. 1 mine	62.8	55.8	146.52	38.5
No. 1 mine	71.9	68.8	40.26	9.0
No. 2 mine	58.6	59.2	383.60	87.8
No. 2 mine	69.4	61.8	80.46	18.2
No. 3 mine	75.0	67.1	55.87	13.6
No. 3 mine	77.5	68.4	69.01	14.4
No. 4 tailing	35.5	35.8	20.70	6.2
No. 4 tailing	54.0	42.8	4.62	2.45

By flotation methods 60 to 75 percent of the gold can be recovered from mine ore in high-grade concentrate. Similar treatment of tailing recovered only 35 percent of the gold at 20.7 ounces gold grade.

Flotation tailings from tests with highest recovery on each sample were passed over a corduroy-lined launder. In each case an additional approximate 15 percent recovery of gold was made in relatively low-grade concentrates (3 to 5 ounces gold per ton). The reject from the combined flotation-corduroy treatment averaged 2 to 3 ounces gold per ton for the mine ores and about 0.6 ounce gold per ton for the tailing sample.

Gravity Treatment for Recovery of Gold.--Several table tests were run on sample No. 3 to evaluate this method of treatment. Tailings from the table were passed over corduroy matting. Typical results are given in the following table which shows data obtained by tabling ore ground to minus 65-mesh.

TABLE 8. - Tabling sample No. 3 mine

Product	Weight, percent	Assay, ounce per ton		Distribution, percent	
		Au	Ag	Au	Ag
High riffle	0.16	2449.89	529.31	33.1	14.5
Table conc.	9.42	16.03	10.9	15.2	21.0
Matting conc.	17.02	9.79	4.7	16.7	16.3
Tailing	45.87	5.00	3.0	23.0	28.0
Slime	<u>27.53</u>	<u>4.30</u>	<u>3.6</u>	<u>11.9</u>	<u>20.1</u>
Calc. head	100.0	9.94	4.9	100.0	100.0
Comb. conc.	26.60	24.34	9.6	65.0	51.8

Tabling tests indicated that this method, like flotation, will recover about two-thirds of the gold in the ore.

Barrel Amalgamation.--Preliminary amalgamation tests were run on ore No. 3 and the tailing sample in a manner to simulate barrel amalgamation. These tests indicated that approximately 75 percent of the total gold can be removed from the ore by this method; however, only 11 percent of the gold in this material was collected in amalgam. This would indicate that the previous amalgamation treatment of the ore left little of the gold that will respond to this method of recovery.

Assay of Selected Chrysocolla.--A sample of ore was crushed to minus 35-mesh and grains of chrysocolla were hand picked to prepare a sample for analysis. The material was inspected at 45 magnifications and no gold was identified. Fire assay, however, showed that the selected mineral contained 12.0 ounces gold per ton. It was concluded, therefore, that high recovery of gold is not possible without simultaneous recovery of copper.

Cyanidation.--It is barely possible that a method of cyanidation might be worked out that would recover the bulk of the gold without excessive cyanide consumption by the copper. The investigation would require considerable time, however, and satisfactory results are doubtful because of the high gold content of the chrysocolla. It was decided, therefore, that research along these lines is not warranted at this time.

Caustic Leaching of Chrysocolla Ore

Abstract

Petrographic analysis disclosed that the copper is present mainly as the hydrous silicate mineral chrysocolla. Because of the extremely intimate association of chrysocolla with other mineral constituents of the ore, liberation is inadequate at particle sizes practicable for gravity separation. Chrysocolla is not amenable to recovery by presently known flotation methods. It is soluble at room temperatures in acids of concentrations ordinarily used for leaching, e.g., 5 percent sulfuric acid. The Mespelt samples, however, contain a considerable amount of acid-consuming calcite which renders acid leaching uneconomical.

Ammonia leaching of the Mespelt ores proved to be ineffective; attention was directed toward caustic leaching agents. C. T. Baroch, in the caustic electrolytic-zinc project at the Boulder City, Nevada Experiment Station of the Bureau of Mines, noted that the caustic lixiviant also solubilized oxide copper. Because of time limitations, however, no investigation of caustic leaching of copper was undertaken at Boulder City (7). This report covers a series of laboratory leaches of chrysocolla ore conducted to determine whether feasible extractions of the contained copper can be made at atmospheric pressure. These tests have shown that elevated temperatures and high caustic strengths are necessary to achieve considerable solubilization of the copper. A proportional amount of silica also is solubilized. A 2-hour leach in a 35-percent sodium hydroxide solution at 80° C gives an extraction of 91 percent of the contained copper and 28 percent of the contained silica. Further investigation would be necessary to determine the extractions which can be obtained by autoclaving; to devise methods to extract the solubilized copper from the pregnant liquor; and to regenerate the caustic lixiviant for recycling in the process.

Experimental Procedure

Samples.--Tests were made on two samples of ore, one in which calcite is the principal constituent, one in which silica is the principal constituent with an appreciable quantity of calcite as revealed by petrographic analysis. The chemical analyses are shown in table 9.

TABLE 9. - Chemical analyses of samples, No. 2 and No. 3 mine

Sample	Assay, percent					Ounce per ton	
	Total Cu	Oxide Cu	Fe	Zn	SiO ₂	Au	Ag
No. 2 mine	4.15	3.93	10.9	0.4	34.4	6.99	1.86
No. 3 mine	6.12	5.95	12.3	.4	54.7	12.18	5.28

Leaching.--Ore samples ground in minus 10 mesh were leached at atmospheric pressure in pyrex beakers using various concentrations of sodium hydroxide. Other variables were temperature of the pulp, ratio of NaOH to feed, and duration of leach. The pulps were agitated continuously during the leaches by an electric stirrer. After digestion the slurries were filtered on a suction filter. The residues were washed and dried; residues and filtrates were submitted for chemical analysis. All leaches were single-stage leaches.

Results.--A series of leaches were made to investigate the effect of temperature, with other variables held constant. Table 10 contains the data from this series of tests.

TABLE 10. - Effect of temperature on leaching, No. 2 mine sample

Temperature, °C	Extraction, percent of total	
	Cu	SiO ₂
20	42.7	5.8
40	66.1	8.8
60	74.1	11.3
80	72.4	15.4
98	83.8	28.3

400 ml 20 percent NaOH for 2 hours

Increased temperature produces an increased extraction of copper with a parallel increase in the amount of silica extracted. The maximum recovery of copper obtained in this series of tests was 84 percent.

A second series of tests was executed to isolate the effect of digestion time on leaching. These data are shown in table 11.

TABLE 11. - Effect of digestion time on leaching, No. 2 mine sample

Digestion time, hour	Extraction, percent of total	
	Cu	SiO ₂
1/2	65.0	10.6
1	69.5	12.9
2	72.4	15.4
3	80.4	15.8
4	79.0	37.4

400 ml 20 percent NaOH at 80° C

An increase in time of digestion causes an increase in the amounts of copper and silica extracted from the ore. At the caustic concentration and temperature used in these tests, increasing the duration of leach beyond three hours apparently increases only the amount of silica extracted. The maximum recovery of copper obtained in this series of tests was 80 percent.

To determine the caustic strength necessary for copper extraction, a third series of tests was made. Table 12 shows the extractions obtained.

TABLE 12. - Effect of caustic strength on leaching, No. 2 mine sample

Caustic strength, percent NaOH	Extraction, percent of total	
	Cu	SiO ₂
6	34.9	6.3
8	44.6	8.1
10	55.3	4.5
15	70.1	9.2
20	77.8	16.4
25	85.4	21.6
30	89.1	22.3
35	90.7	28.5

400 ml of solution at 30° C for 2 hours

Table 12 shows the expected increase in extraction of both copper and silica with increase in caustic strength. The extraction of copper was only 91 percent even after the ore had been leached in a 35 percent sodium hydroxide solution at 80° C for two hours. The data of tables 10, 11, and 12 are shown graphically in figures 6, 7, and 8, respectively.

In the course of this investigation, various other exploratory tests were made under varying conditions. Data for these tests are presented in table 13.

TABLE 13. - Miscellaneous leach tests, No. 2 mine sample

Lixiviant		Sample particle size	Temp., °C	Time, hours	Extraction, percent of total	
Strength, NaOH, per- cent	Quantity, ml				Cu	SiO ₂
20	200	-100	20	67	28.6	1/
20	200	-100	60	3	73.0	1/
20	400	-10	80	3	79.2	16.7
25	200	-48	80	4	95.3	1/
30	400	-10	80	3	89.8	32.3
30	200	-48	80	5	90.0	1/
30	400	-10	98	1	92.8	60.4

1/ Not determined.

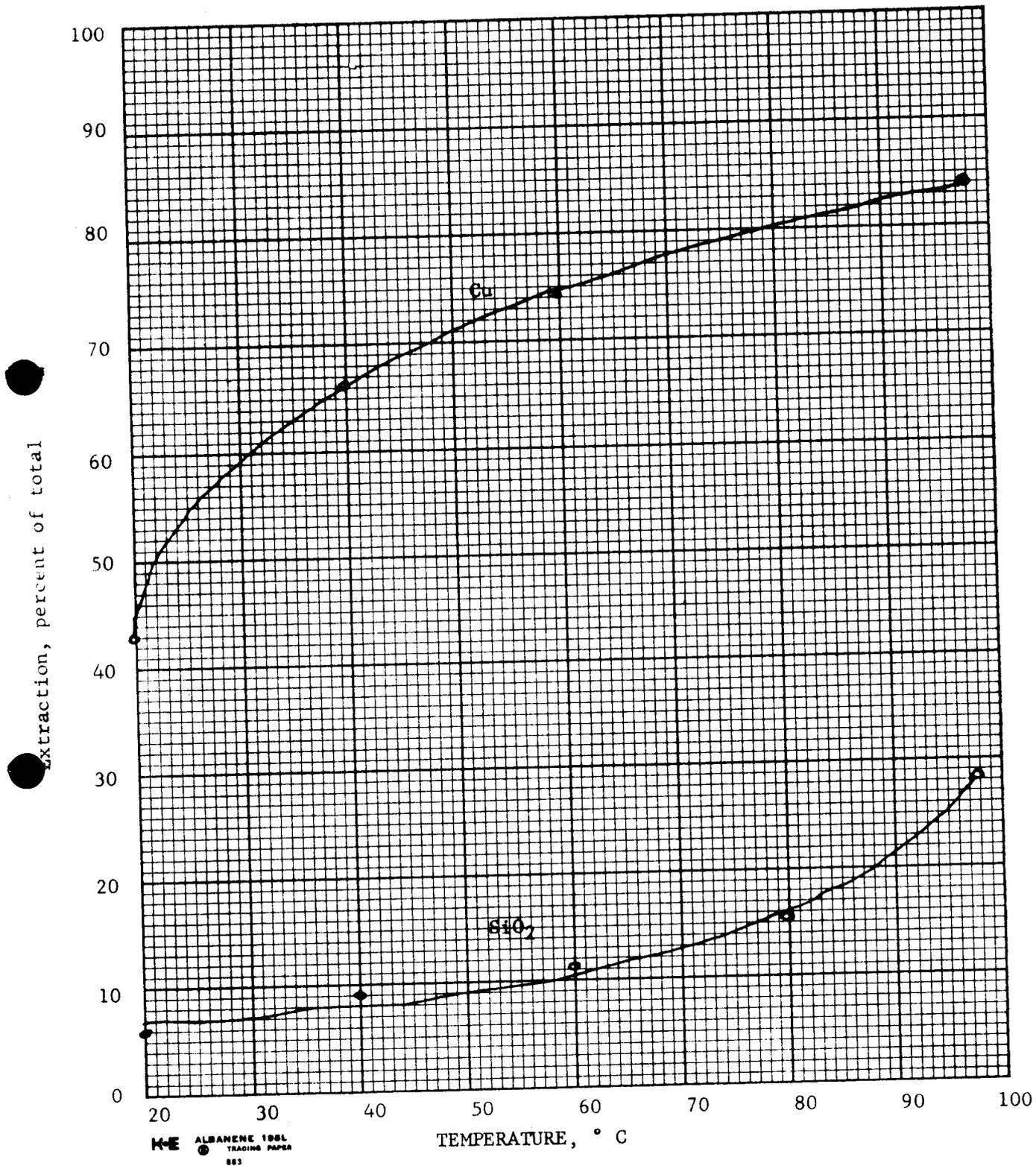


FIGURE 6. - Effect of Temperature.

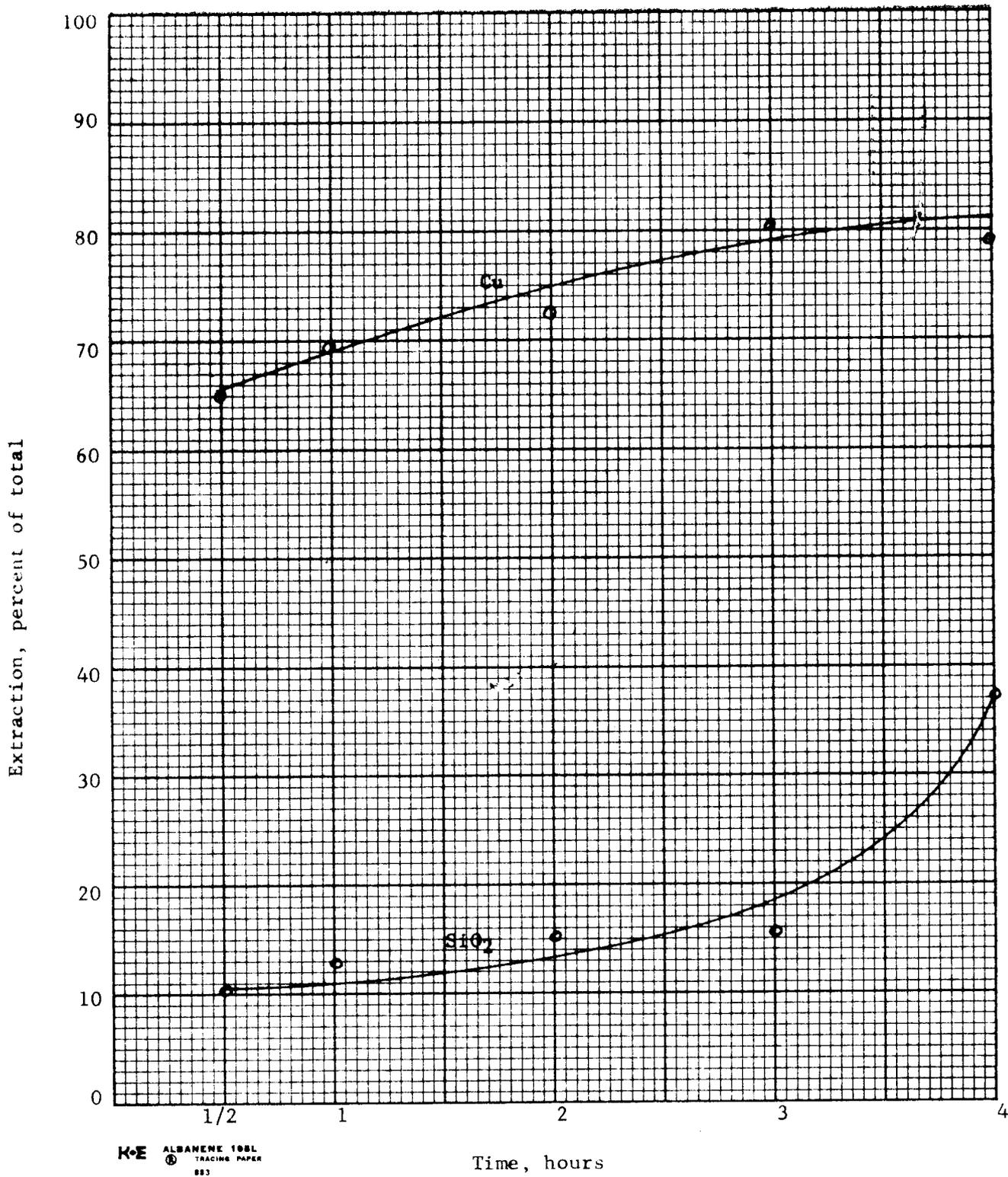


FIGURE 7. - Effect of Digestion Time.

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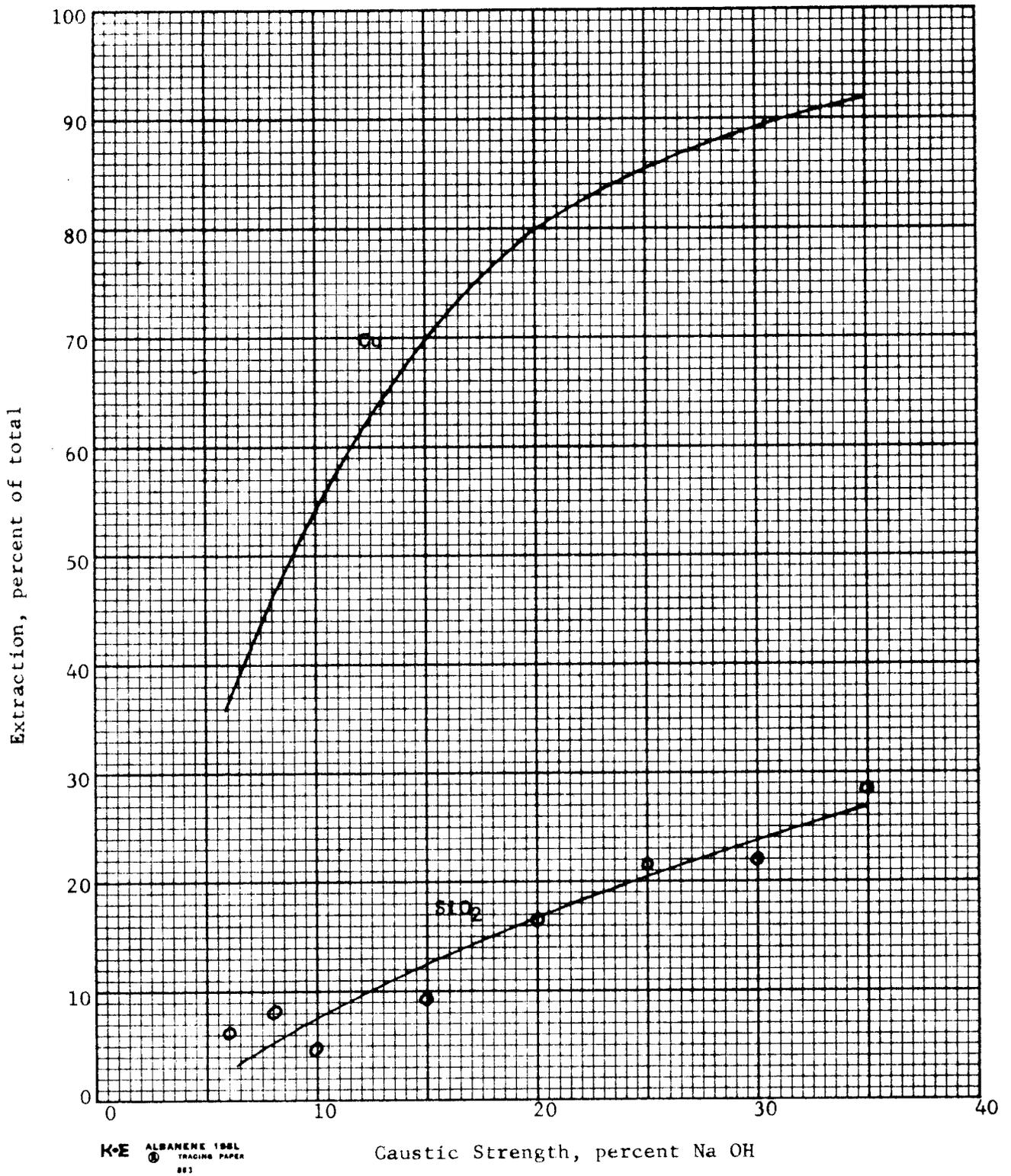


FIGURE 8. - Effect of Caustic Strength.

Discussion and Conclusions

This investigation has shown on a laboratory scale that a caustic leach is a potential means for recovery of copper from chrysocolla ores associated with basic minerals. The following reaction is hypothesized for the solubilization of chrysocolla by sodium hydroxide:



It is believed that a soluble sodium-copper complex is formed, analogous to sodium aluminate, Na AlO_2 , and sodium zincate, $\text{Na}_2 \text{Zn O}_2$.

To reach extractions of 80 percent or higher, however, temperatures approaching the boiling point and concentrations of lixiviant of 20 percent or higher are required. Sodium hydroxide in these concentrations presents difficulties in handling and filtration; furthermore, if silica also is present in the ore in appreciable quantities, the caustic solubilizes the silica. The handling and filtration problems then are intensified.

The scope of this study has been limited to leaches at atmospheric pressure and a 35 percent caustic concentration. Because elevated temperatures are necessary already under these conditions to obtain feasible extractions of copper, it would appear to be a short step to autoclaving the ore. With the higher temperatures and pressures, it is possible that a practically complete extraction of the copper could be made. Such a process would simulate the Bayer process for bauxite ores.

No investigation has been made of regeneration of the caustic which would be necessary for a continuous process. The regeneration of caustic with lime has been very successful in other laboratory investigations (2, 4). No attempt was made to investigate methods for recovery of the solubilized copper from the pregnant liquor. In one cursory test using iron filings to precipitate cement copper from solution, only 40 percent of the contained copper was recovered.

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