

DIVISION OF MINERALS AVAILABILITY
OPEN FILE REPORT

WASTE DISPOSAL ACTIVITIES AND PRACTICES

COPPER, LEAD, ZINC, GOLD, AND SILVER WASTE DISPOSAL
ACTIVITIES AND PRACTICES IN THE UNITED STATES

By Luis V. Coppa

November 1984

Bureau of Mines Open File Report 4-85

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5010-101

REPORT DOCUMENTATION PAGE		1. REPORT NO. BuMines OFR 4-85	2.	3. Recipient's Accession No. PB85 154706 TAS	
4. Title and Subtitle Copper, Lead, Zinc, Gold, and Silver Waste Disposal Activities and Practices in the United States				5. Report Date Nov. 1984	
7. Author(s) Luis V. Coppa				6.	
8. Performing Organization Name and Address Division of Minerals Availability Bureau of Mines U.S. Department of the Interior Washington, DC 20241				9. Performing Organization Report No.	
10. Sponsoring Organization Name and Address Office of Assistant Director--Mineral Data Analysis Bureau of Mines U.S. Department of the Interior Washington, DC 20241				11. Project/Task/Work Unit No.	
				12. Contract(s) or Grant(s) No. <input type="checkbox"/> N/A <input type="checkbox"/>	
				13. Type of Report & Period Covered In-house research, 1984	
14. Supplementary Notes Approved for release December 28, 1984.				16.	
15. Abstract (Limit 200 words) This Bureau of Mines open file report is an inventory of the amount and type of mill tailings created from the lode-mine commodities (copper, lead, zinc, gold, and silver) on a State and county basis between the years 1911 and 1981. The report contains tables and base maps cataloging the amounts of tailings created in each county on a decade basis. Mine waste and mill tailings disposal practices and technological advances and changes in the milling are discussed. Also included is a discussion of the material content typical to tailings produced from these five commodities.					
17. Document Analysis & Descriptors					
Copper Mining					
Lead Milling					
Zinc Mine waste					
Gold Mill tailings					
Silver					
18. Identifiers/Classification Terms					
Lode-mine					
Tailings					
Locations					
6. COSATI Field/Group 08I					
19. Availability Statement Release unlimited by NTIS.				13. Security Class (This Report) Unclassified	
				20. Security Class (This Page) Unclassified	
				21. No. of Pages 195	
				22. Price	



FOREWORD

This Bureau of Mines Open File Report is an inventory of the amount and type of mill tailings created from the lode-mine commodities (copper, lead, zinc, gold, and silver) on a state and county basis between the years 1911 and 1981. This report contains tables and base maps cataloging the amounts of tailings created in each county on a decade basis. Mine waste and mill tailings disposal practices and technological advances and changes in the milling are discussed. Also included is a discussion of the material content typical to tailings produced from these five commodities.

UNITS OF MEASURE ABBREVIATIONS USED IN REPORT

4-a

g	gram	mg	milligram
kg	kilogram	t	metric ton
ton	short ton	L	liter
mg/L	milligram per liter	kg/t	kilograms per metric ton
g/t	gram per metric ton	yd ³	cubic yard
pct	percent	wt pct	weight percent
ppm	part per million	IMPD	imperial gallon per day

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Copper, Lead, Zinc, Gold, and Silver Waste Disposal
Activities and Practices in the United States

By Luis V. Coppa^{1/}

INTRODUCTION

The Bureau of Mines conducted a study to estimate the amount, characteristic, and general location of the mill tailings produced from copper, lead, zinc, gold and silver lode-mine² operations. This study was developed to provide baseline data for assessments of environmental problems involving the relationship between the distribution of mill tailings deposition sites and the amount of tailings produced. The report considers tailings produced from 1910 to 1981 and is restricted to primary mined material in the continental United States.

From historical production records, it is estimated that approximately 9.2 billion tons of mill tailings have been created from lode-mine operations since 1910. Of that amount approximately 80 percent has been created from copper operations primarily in the southwestern United States. The mill tailings data have been aggregated on a 10-year basis and presented in tabular form by tonnage and volume for each county.

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^{2/} Lode-mine is defined as ore mined from primary copper, lead, zinc, silver, or gold operations; not including placer type deposits, ore shipped directly to a smelter, or tailings that have been reprocessed.

Additional analyses, based on the historical data, are included to help understand the magnitude and characteristics of the tailings. Included are an examination of the type of tailings produced over time, the type of mining method predominant in that county and the volume of voids left by mining, and the relation between mill tailings and mine waste material for each of the five commodities studied.

Also included are discussions on mining and metallurgical processing of the commodities. Descriptions are given of the technological changes in mining and milling techniques affecting the recovery of copper, lead, zinc, gold, and silver, tailing disposal practices, and materials that constitute the tailings.

Recognition must be made of the fact that in many instances the amount of tailings produced over time as a function of production can not be equated to the amount found upon site examination. This is due to the utilization of tailings material for other industrial purposes such as landfill, road surfacing and railroad ballast as well as the evaluation of tailings disposal to the now common tailing impoundments. Hence, the estimates made in this report are based on the approximated size and tonnages. Specific site inspection, would be required to better define these tonnage estimations.

ACKNOWLEDGEMENT

The author wishes to acknowledge and thank other Bureau of Mines personnel. Contributors were Roger Bloomfield of the Mining Research Directorate on the tailings disposal; David L. Barna, James T. Dunham, William N. Fitch, and Espiridion G. Valdez of the Minerals and Materials Research Directorate on the metallurgical sections; and Gertrude Greenspoon of the Minerals Information Directorate and Susan E. Douglas of the Division of Minerals Availability for help on data analysis.

METHODOLOGY

The Bureau of Mines has maintained historical mine production records since it was established in 1910. These data are collected through survey forms directly from operating mining companies, and are tabulated for inclusion in the Bureau's Minerals Yearbook series. In recent years these data have been stored on microfilm. Data from 1974 to 1981 have been incorporated into the Automated Mineral Information System (AMIS), a computerized data base which allows for easy access and retrieval of production statistics.

For this study, pre-1974 data from lode-mine operations were compiled from microfilm records, and the recent data by utilizing the AMIS. Beginning in 1911 and proceeding on an every-other-year basis through 1959, lode-mine data were extracted from microfilm records and compiled on a state and county basis. From 1960 to 1981, data were compiled for each year, again on a state and county basis. This production data was then incorporated into a separate computerized data base from which the amount of mill tailings produced was estimated.

Data elements retrieved from the lode-mine production records are:

Year	Gold-silver mills
State - county	Ore processed (tons)
County	Gold production mills (oz)
Number of mines	Silver production (oz)
Concentration mills	Direct to smelter
Ore processed (tons)	Ore shipped (tons)
Concentrates produced (tons)	Gold production (oz)
Gold production (oz)	Silver production (oz)
Silver production (oz)	Copper production (lbs)
Copper production (lbs)	Lead production (lbs)
Lead production (lbs)	Zinc production (lbs)
Zinc production (lbs)	

Tonnage of Mill Tailings

By summing the amount of ore processed by gold-silver mills and concentration mills and subtracting the amount of concentrate produced, the amount of mill tailings created was estimated for each given year. It was assumed that virtually all the material processed by gold-silver mills was left as mill tailings. For the period 1911 to 1959 annual data was compiled for every other year (1911, 1913, 1915,, 1959). The total amount of tailings produced for a ten-year period was then estimated using the tonnages from the five years within that decade. This was done by multiplying the sum of the tailings for the five years reported within a decade by a factor of two. Mill tailings were then aggregated on a 10-year basis for each state and county where there was appreciable production.

An example of this calculation is as follows. For the period 1950-59 data was compiled for Pima county, Arizona. To illustrate this, in 1951 approximately 9.0 million tons of tailings were produced, 9.3 million in 1953, 12.9 million in 1955, 12.5 million in 1957, and 16.6 million in 1959.

These annual values were summed and then multiplied by two arriving at an estimated amount of 120.6 million tons of tailing produced in Pima county during the 1950's.

For the period 1960 through 1981, data was compiled for each year, summed and aggregated accordingly.

Number of Mines Contributing to Tailings

Over the course of time, many mining operations have contributed to the tailings produced. The number of mines contributing to the mill tailings was estimated by taking the maximum number of reported active mines in a given year from a particular county (constrained by years falling within that decade) and assigning that number as the mines contributing to production for the decade. To illustrate this, during the 1950's in Pima county, Arizona 32 mines reported production in 1951, 19 in 1953, 21 in 1955, 22 in 1957, and 20 in 1959. For the purpose of this study 32 mines were assigned as the total number of mines contributing to the Gila county production for that decade. Although some complications may be encountered due to the opening and/or closing of different mining ventures, as well as the amount of tailings produced at a given site, it is felt the overall order of magnitude is representative.

Type of Tailings

The type of tailings for each county (expressed in terms of the major commodity produced), was determined based on the gross value of the commodities. This was done by using the average commodity selling prices for a given period (in current dollars) and multiplying by the amount of recovered product of primary copper, lead, zinc, silver, and gold respectively. In some instances where the value was distributed over more than one commodity, the most significant commodities were listed in order of their gross value.

A tabulation for each decade was developed for the major producing counties showing the major commodity produced, number of mines from which tailings were produced and tonnage of mill tailings.

Once each county was designated to have produced a given type of tailings during a 10-year time frame, the cumulative amount of tailings produced on a commodity basis was examined on a national perspective. Mill tailings tonnages were combined into three broad categories; copper tailings, zinc-lead-silver tailings and gold-silver tailings. This was done by examining the type of production designated as the major commodity produced in a county during a particular decade and aggregating the associated mill tailings tonnage into one of these three categories. This was repeated for each time frame and compiled in tabular form, as well as presented graphically.

Mine-Waste Material

Because mill tailings are not the only waste material produced from a mining operation, the amount of waste rock moved in the development and mining of a deposit was analyzed. For an eight-year period (1974-1981), data was compiled on the amount of ore mined, waste rock moved, and mill tailings produced. This time frame was used because data prior to 1974 was no longer readily available, and provides an indication of the magnitude of material required to be moved immediately prior to this 8-year time frame and what could be expected in the near future. The data was compiled on an annual basis for each of the commodities and tabulated showing the total amount of material moved, amount of waste rock moved, amount of mill tailings and total amount of waste material generated.

Mining Method

The predominant mining method that was used in the production of lode-mine commodities in each county over the 72-year study period was determined utilizing the Bureau of Mines, Minerals Availability System. The Minerals Availability System (MAS) is a computerized data base developed to provide location, and geologic, mining, metallurgical and economic analysis of the mineral industry. This data base contains over 180,000 mineral location entries of past, present and undeveloped mineral deposits for a wide variety of commodities, including the five lode-mine commodities being analyzed. From the mining data contained in MAS and an assessment of the principal mining methods employed (by county for each of the commodities) a determination of the predominant type of mining method was established. In some instances a combination of surface and underground methods were used in a given county over time and this was noted as such.

Mine Openings

The volume of underground and surface mine openings created in each county was determined by estimating the volume of mine openings from the amount of mill tonnages treated. By estimating the specific gravity of the material being mined (expressed as in situ cubic yards per ton) and multiplying the tonnage of ore fed to the mill by this factor the volumes of the mine openings were derived. This was done for each county and aggregated for the entire 72-year period.

Mill Tailings Volumes

The volumes of the mill tailings produced were estimated and included in this study. This was done by estimating the specific gravity of the mill tailings produced and multiplying the tonnage of mill tailings by this factor (expressed in cubic yards per ton). In this manner, the volume of mill tailings in cubic yards was derived. Again this volume was aggregated on a county basis over the full 72-year time frame.

The predominant type of mining method employed, and estimates of the mine opening volumes and mill tailings produced were summarized in tabular form and presented for the 72 year period of the study.

DATA ANALYSIS

From data compiled on historical production records four analyses were performed (1) aggregation of mill tailings produced on a county basis over a ten-year period beginning in 1910 and continuing through 1981; (2) classification of the major commodity(ies) produced in each county; (3) determination of the type of mining method predominant in each state and approximate volume of mine openings; and (4) determination of the ratio of mill tailings to mine waste for the period 1974 through 1981.

Amount of Tailings

On a decade basis, the amount of mill tailings produced has increased steadily from a little over a half a billion in the 1910's to over 3 billion tons between 1970-1981. The increase in mill tailings produced can be attributed to the technological advances in the recovery of these commodities, driven by the need to mine and process lower grade ores. Major technological advances were the use of flotation processes and increased capacity of mining equipment to move larger tonnages of material per unit of equipment (trucks, shovels, conveyor systems, etc.). This coupled with a growing demand for copper as an industrial material and the steady need for lead, zinc, silver, and gold, resulted in the creation of proportionally larger amounts of tailings per unit of commodity. Table 1 illustrates the increase in mill tailings over time.

TABLE 1. - Mill tailings produces from 1910-1981 from Cu, Pb, Zn, Au, and Ag lode-mine operations

Period	Mill tailings, 10 ⁶ tons	pct
1910 - 19...	572	6.2
1920 - 29...	649	7.0
1930 - 39...	573	6.2
1940 - 49...	1,102	12.0
1950 - 59...	1,274	13.9
1960 - 69...	1,739	18.9
1970 - 81...	3,297	35.8
Total..	9,206	100.0

The cumulative amount of mill tailings from the lode-mine operations from 1910 to 1981 and the annual mill tailings produced over the same period are illustrated in figures 1 and 2 respectively. As seen in these figures the rate of tailings produced remained relatively constant through the 1940's, with the exception of years of major depressions. However, beginning in the 1940's and continuing through the present an increase in the amount of mill tailings from lode-mine operations is seen. This increase is in large part due to the development of the large open-pit copper operations in Arizona, New Mexico, and, Nevada. To illustrate this, in the 1930's Arizona produced approximately 93 million (see Table 5) tons of mill tailings. In the period 1970 through 1981 the amount of mill tailings increased to 1,957 million (see Table 9), an increase of over 20 fold. As the grade of copper decreased more ore had to be mined to meet metal production demands; hence, more tailings and waste material were produced.

FIGURE 1. - Cumulative mill tailings produced from copper, lead, zinc, silver, and gold Lode mine operations from 1910 to 1981 in five-year increments

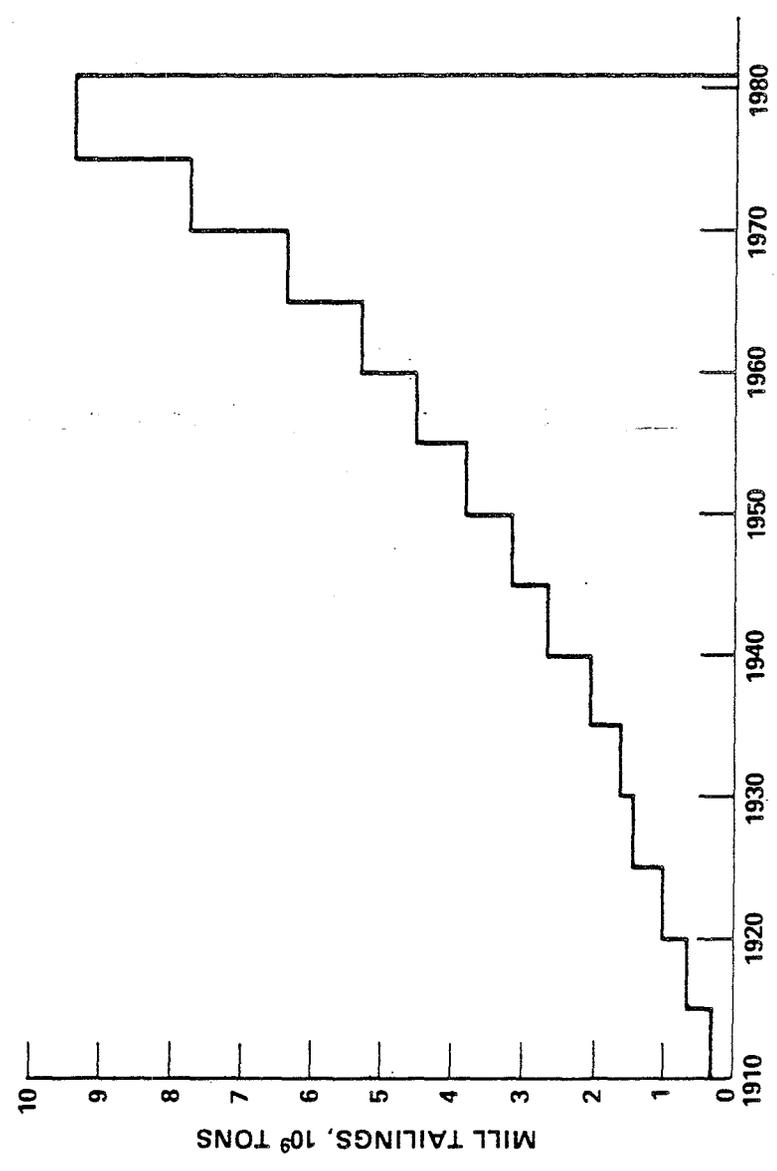
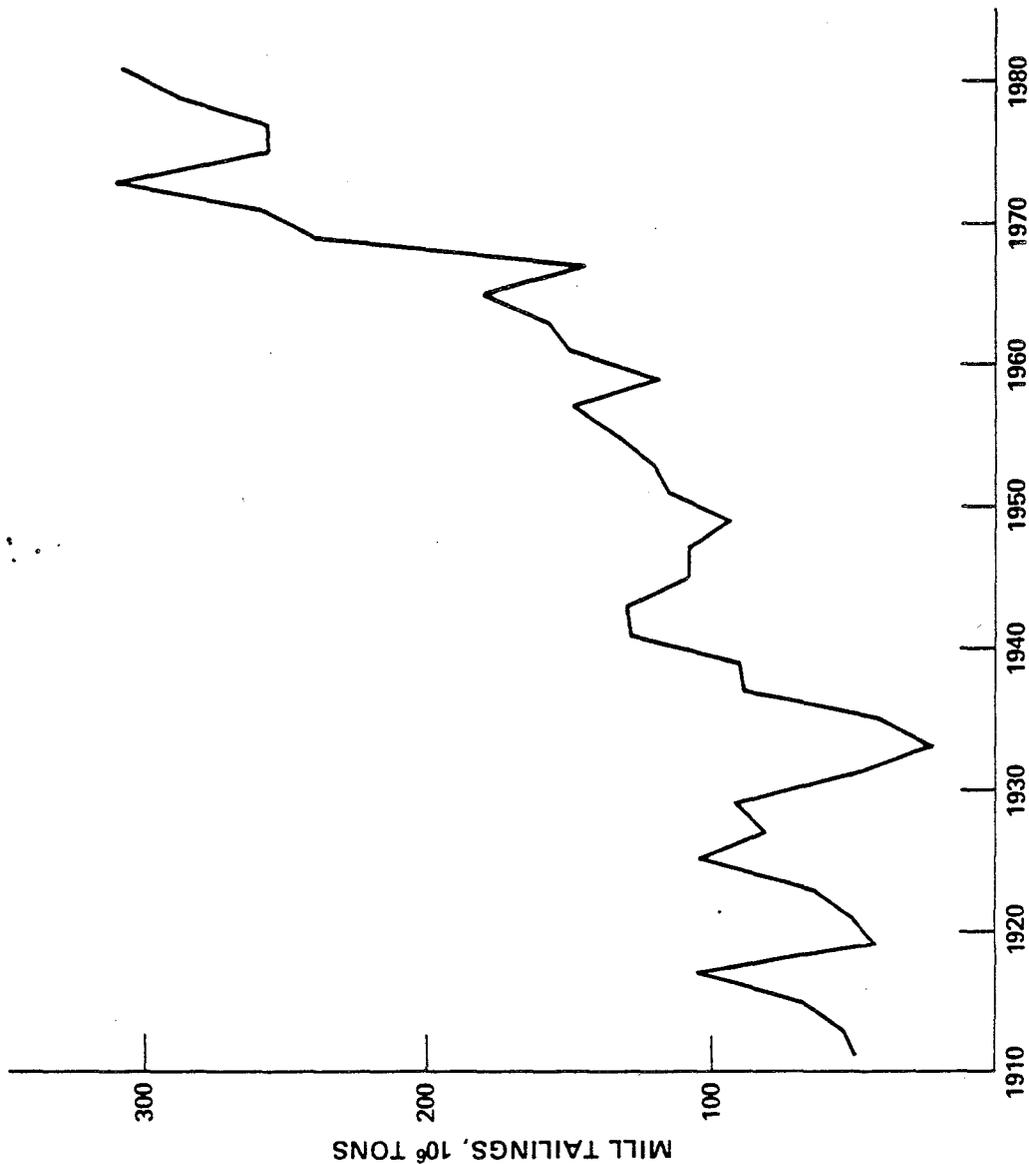


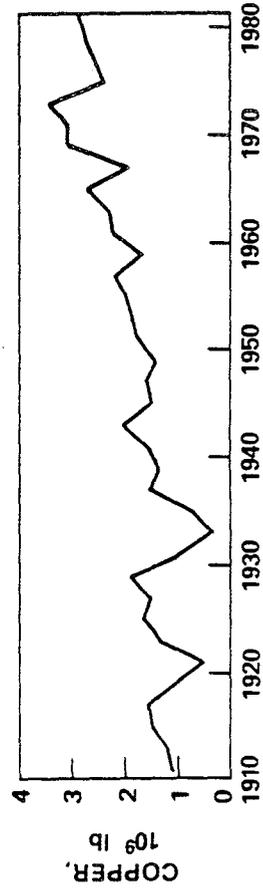
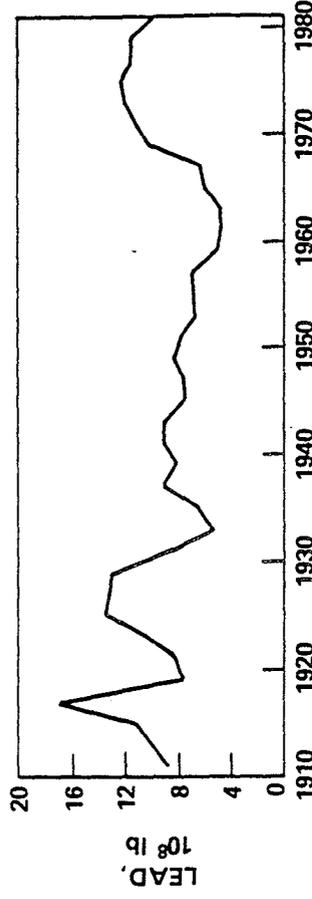
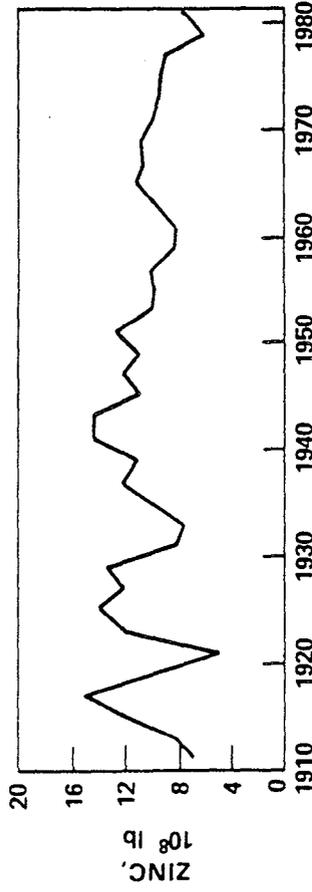
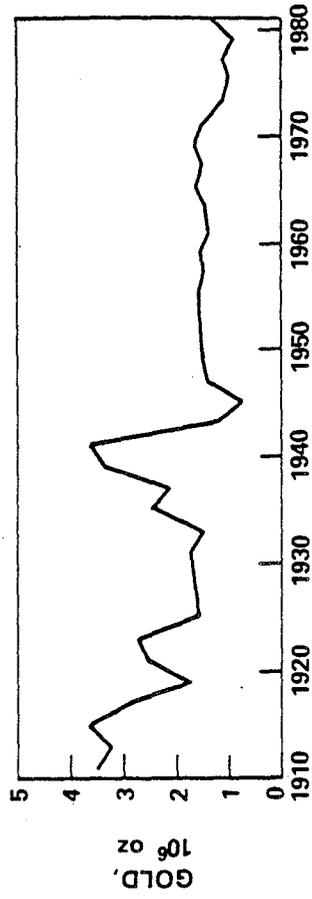
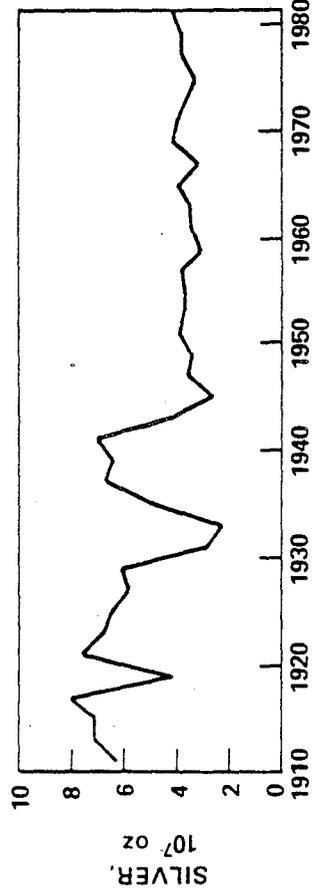
FIGURE 2. - Annual mill tailings produced over the period 1910 to 1981 from lode-mine operations



This was not the case with the other metals covered in this study. During the early part of this century production of gold, silver, lead, and zinc was somewhat greater than it is at present. A decline in the actual production of these commodities occurred during the late 1940's. Even though the overall ore grades for lead and zinc have decreased, demand for the primary metal has also decreased. This has, in effect, caused a leveling off of tailings produced over time. For the precious metals, depletion of high grade ore has made it necessary to use large scale, more capital intensive mining methods, which has eliminated many small mining operations which contributed significantly to the gold and silver production during the early part of the century. This is reflected in the decrease in precious metal production after World War II. Despite decreased metal production, an increase in the mill tailings produced since that period has been observed. The annual metal production since 1910 for the five commodities is shown in figure 3.

To illustrate the changes in the production of mill tailings since the early part of this century a compilation of mill tailings has been assembled and is presented in a set of tables and base maps. This tabulation provides information on the amount, type, and location of mill tailings produced throughout the past seven decades. For the purpose of this study, the 12-year period from 1970 to 1981 is defined as one of the decades.

FIGURE 3. - Annual production curve for copper, lead, zinc, silver and gold from lode-mine operations



The mill tailings data has been constructed both graphically, through the use of national and state-county maps, and in tabular form corresponding to the associated maps.

Figure 4 illustrates the cumulative amount of mill tailings produced over the entire 72-year period on a national basis broken down by state. This map is then further expanded into more detailed state-county maps. Each of the 28 states (figures 5 - 32) which had, over the past 7 decades, contributed in excess of 500 thousand tons of tailings shows graphically the approximate magnitude of tailings on a county basis. Also, included on each map is a table summarizing the amount of tailings produced in each state over the study period 1910-1981. In addition Table 2 summarizes the mill tailings produced in each county.

The data is then expanded to show the amount of mill tailings produced in 10 year increments (and one 12-year period) and is summarized in Tables 3 - 9 showing, by state and county, the amount of mill tailings produced, the type of tailings produced, and the approximate number of mines contributing to this tonnage. Each of the decade tabulations is preceded by a map of the continental United States (figures 33-39) that illustrates the relative magnitude of tailings deposition on both a national and state basis, as well as, any regional shifts over time.

FIGURE 5. - Map showing the cumulative tailings produced in the state of Arizona

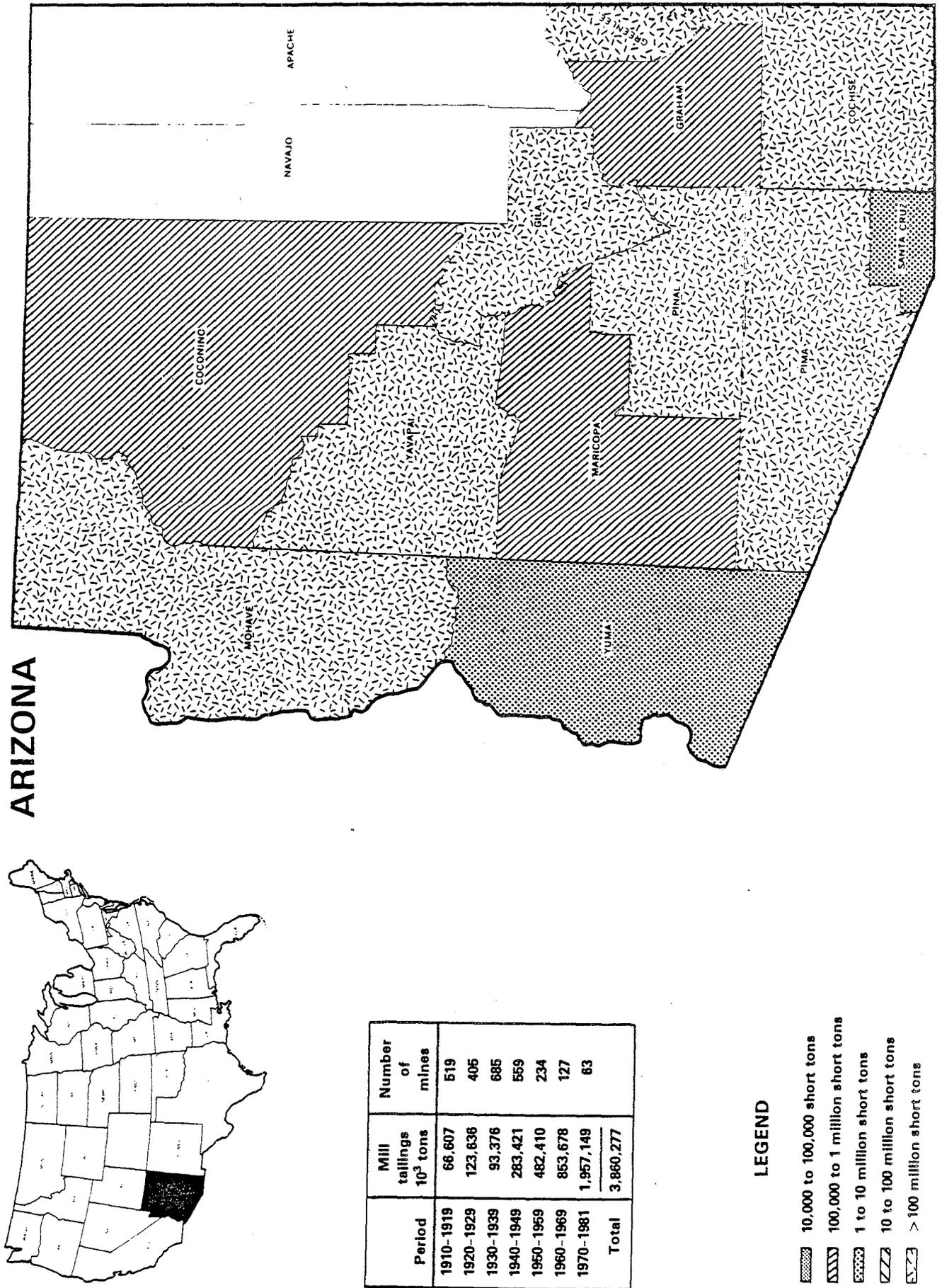
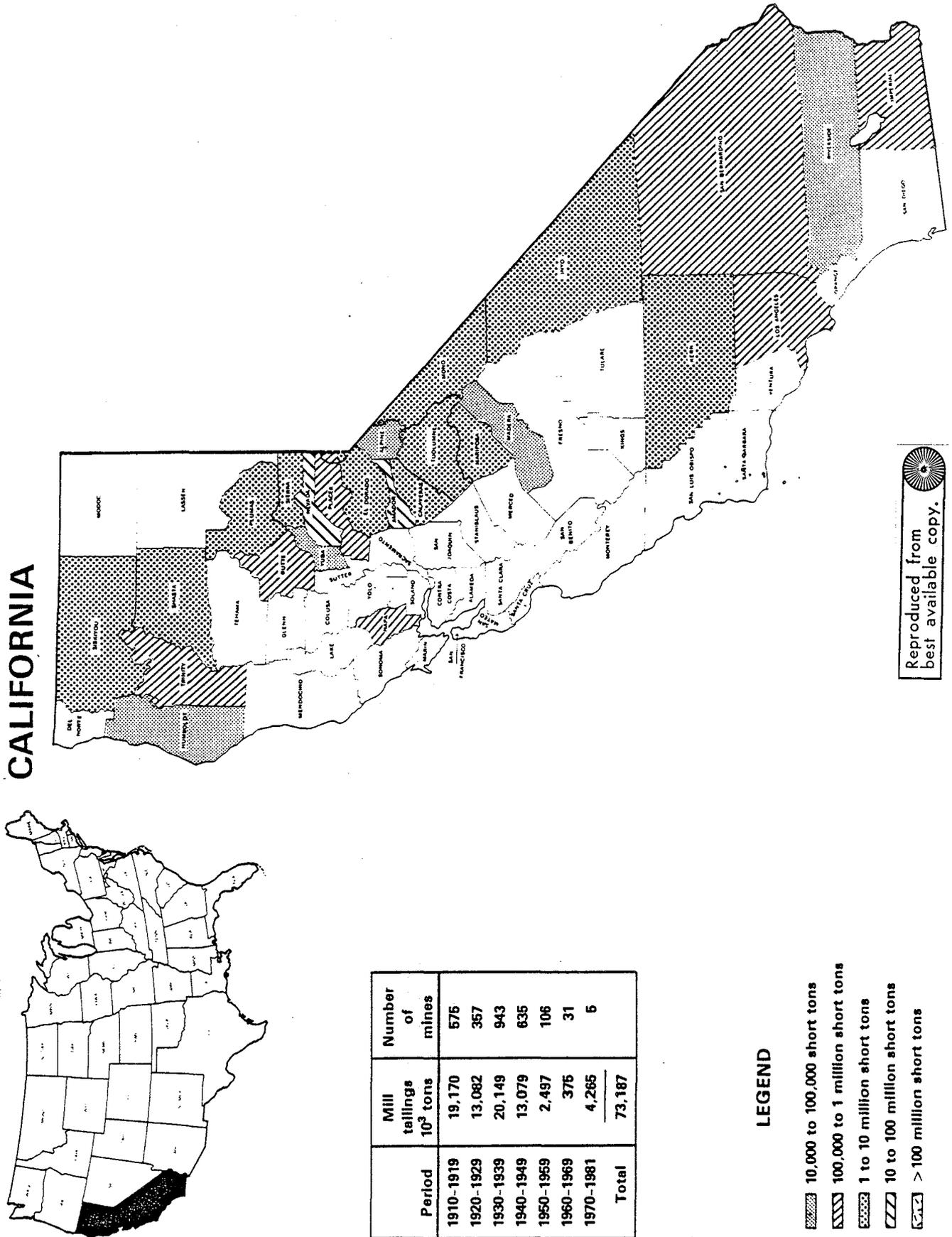


FIGURE 6. - Map showing the cumulative tailings produced in the state of California



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FIGURE 7. - Map showing the cumulative tailings produced in the state of Colorado

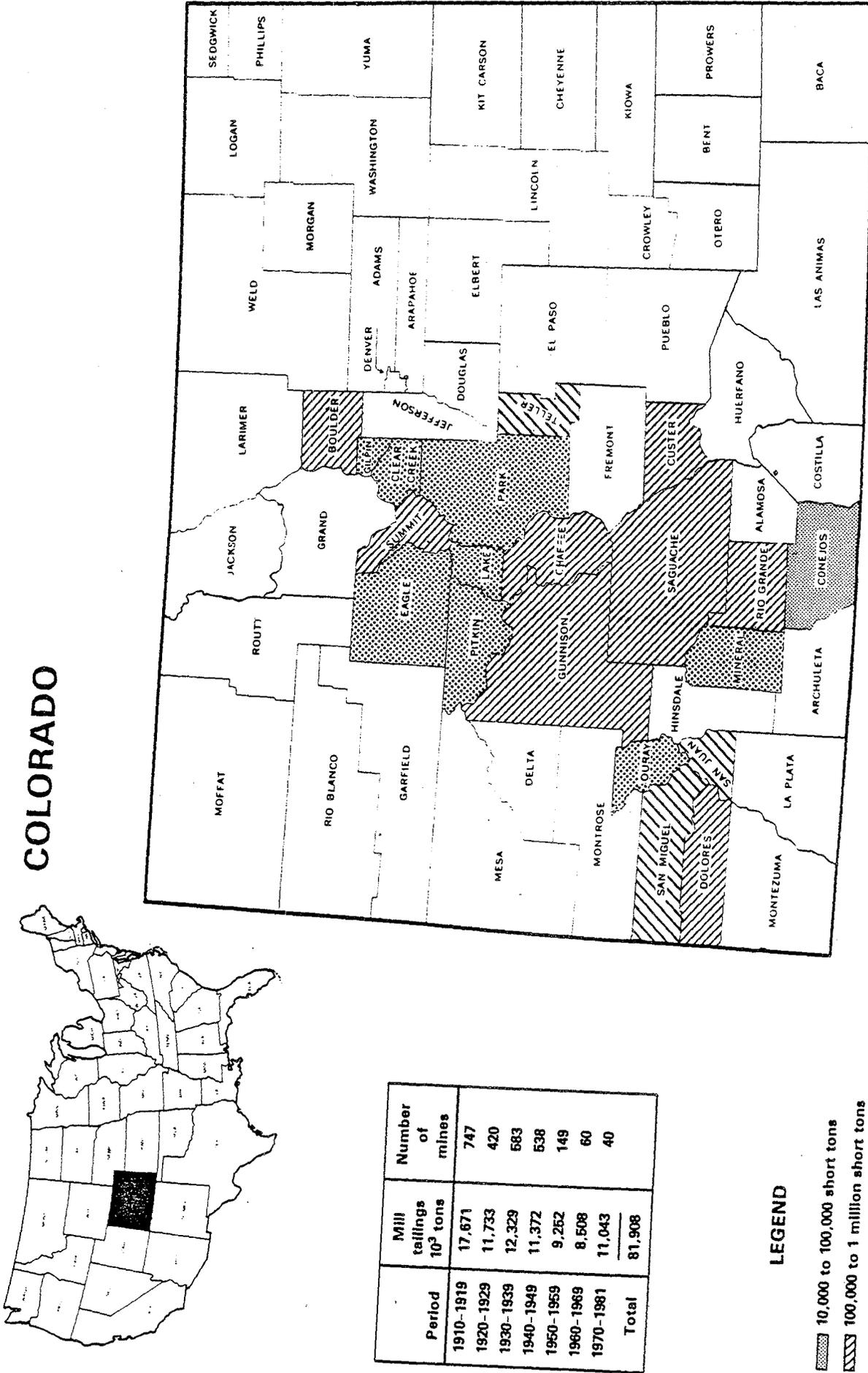
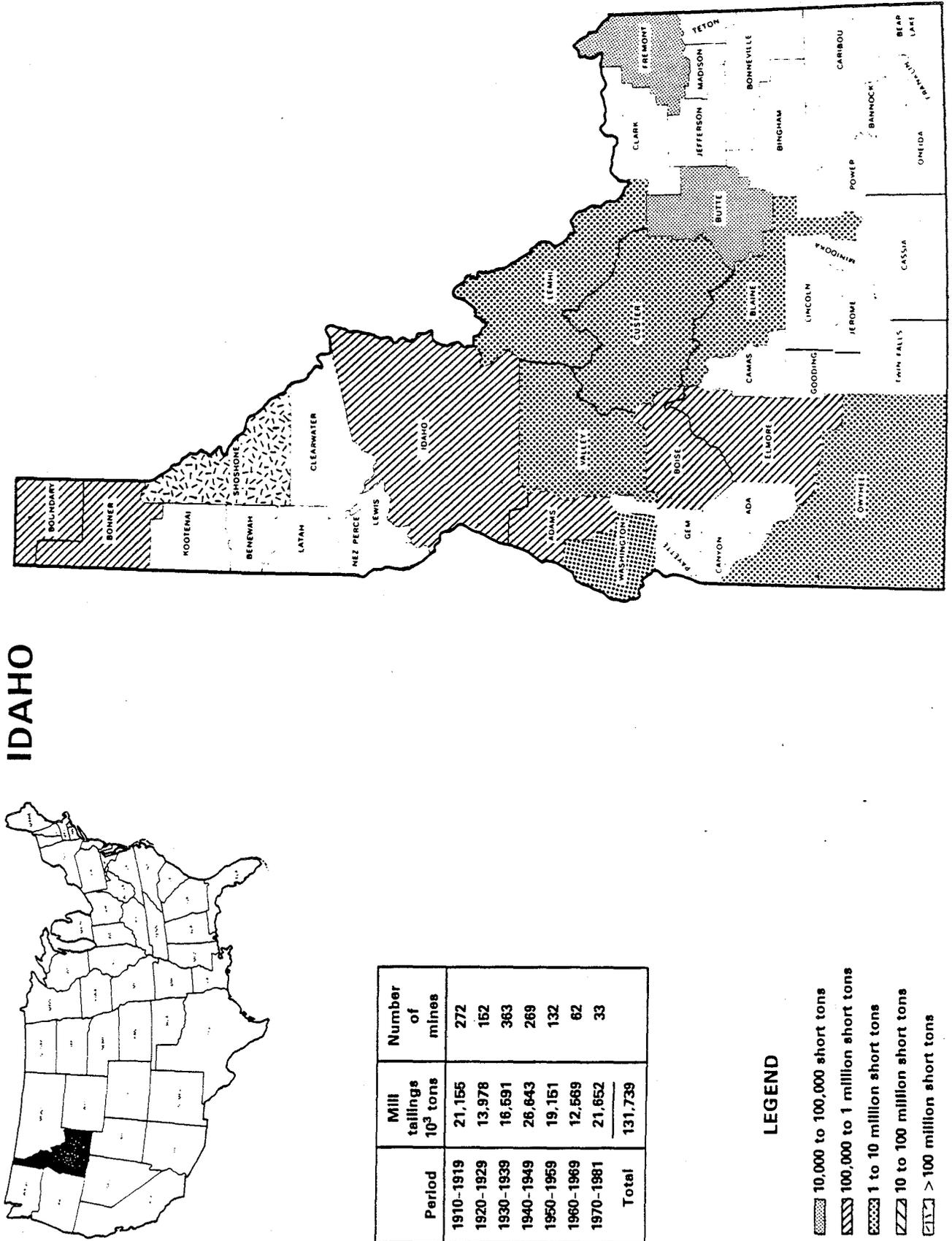


FIGURE 8. - Map showing the cumulative tailings produced in the state of Idaho



IDAHO

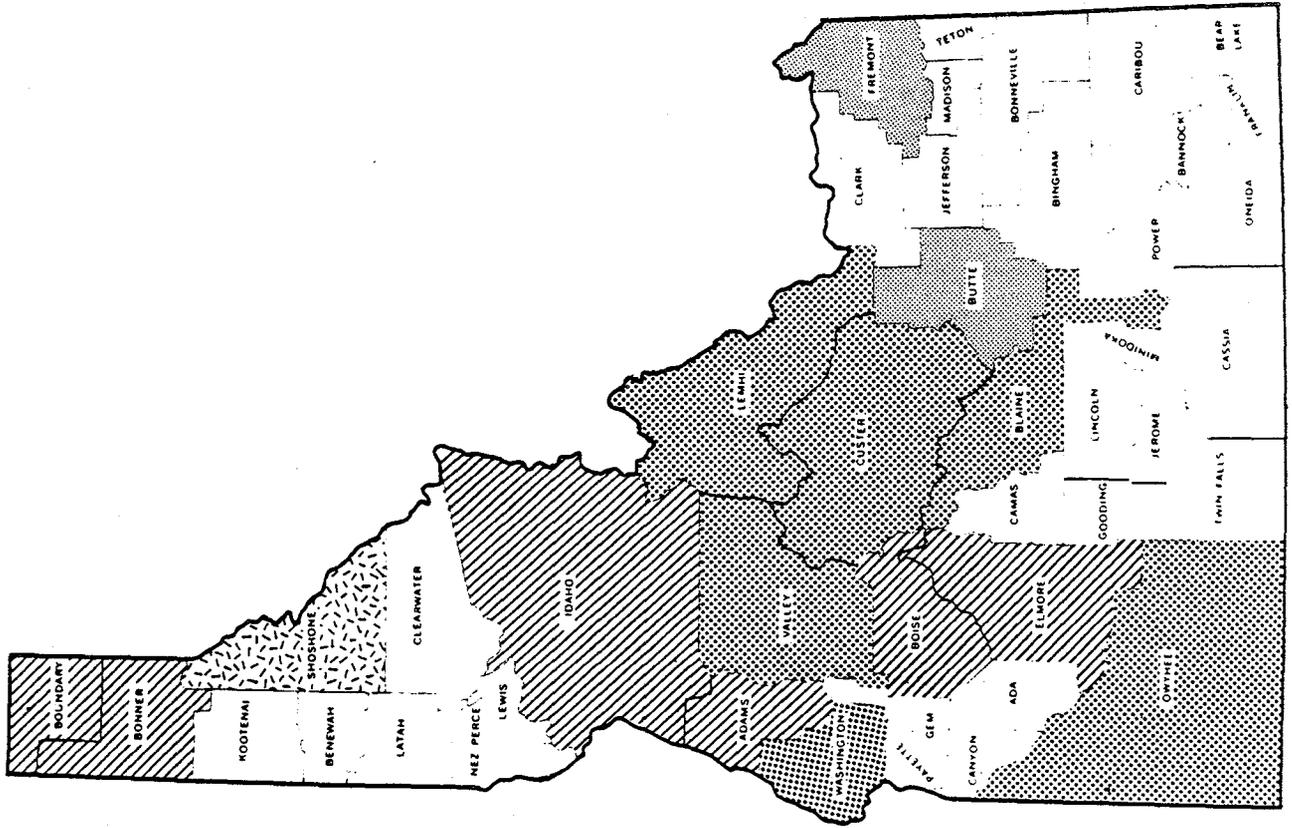
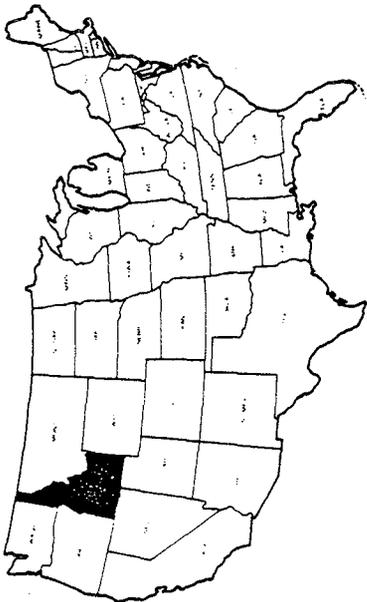


FIGURE 9. - Map showing the cumulative tailings produced in the state of Illinois

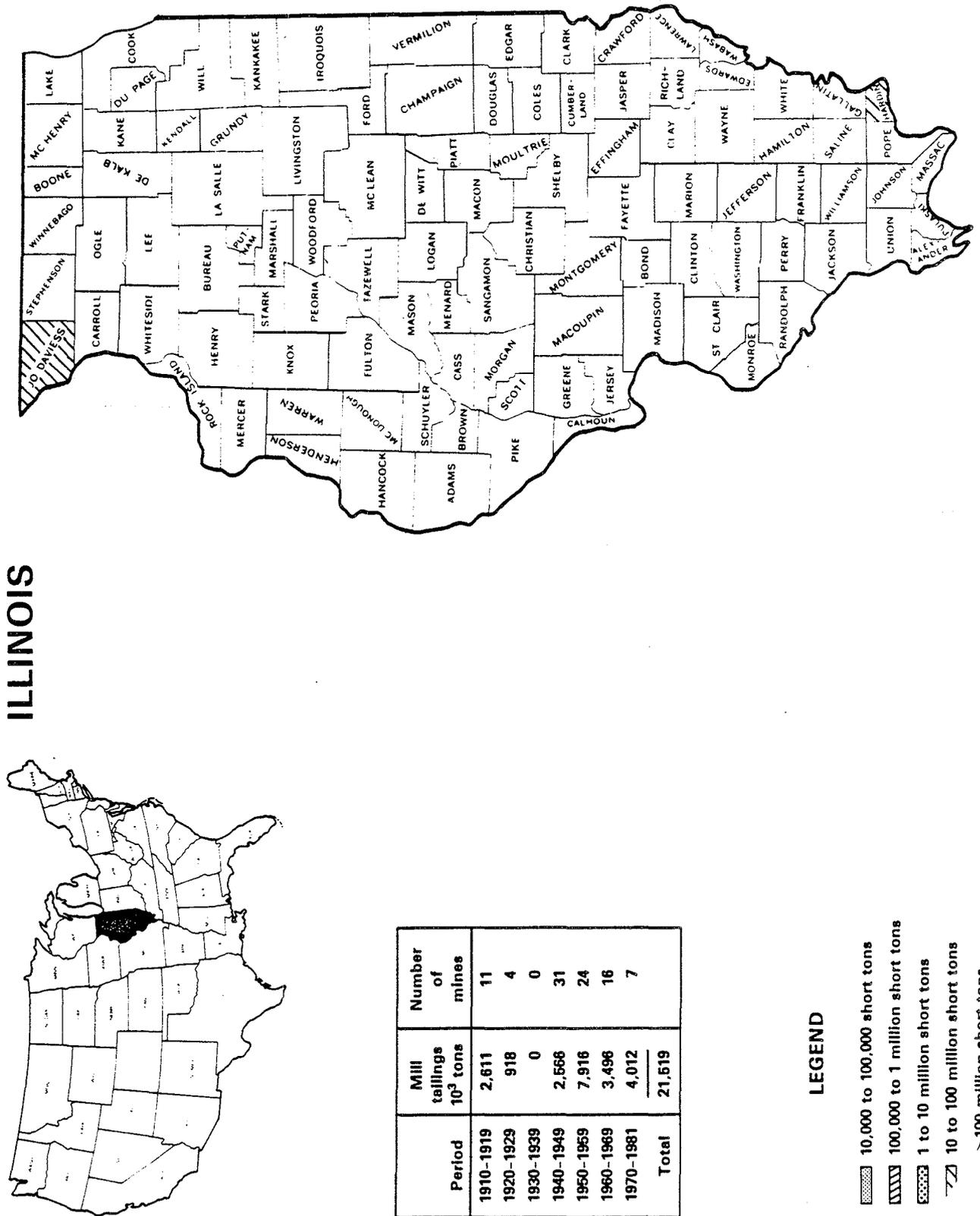
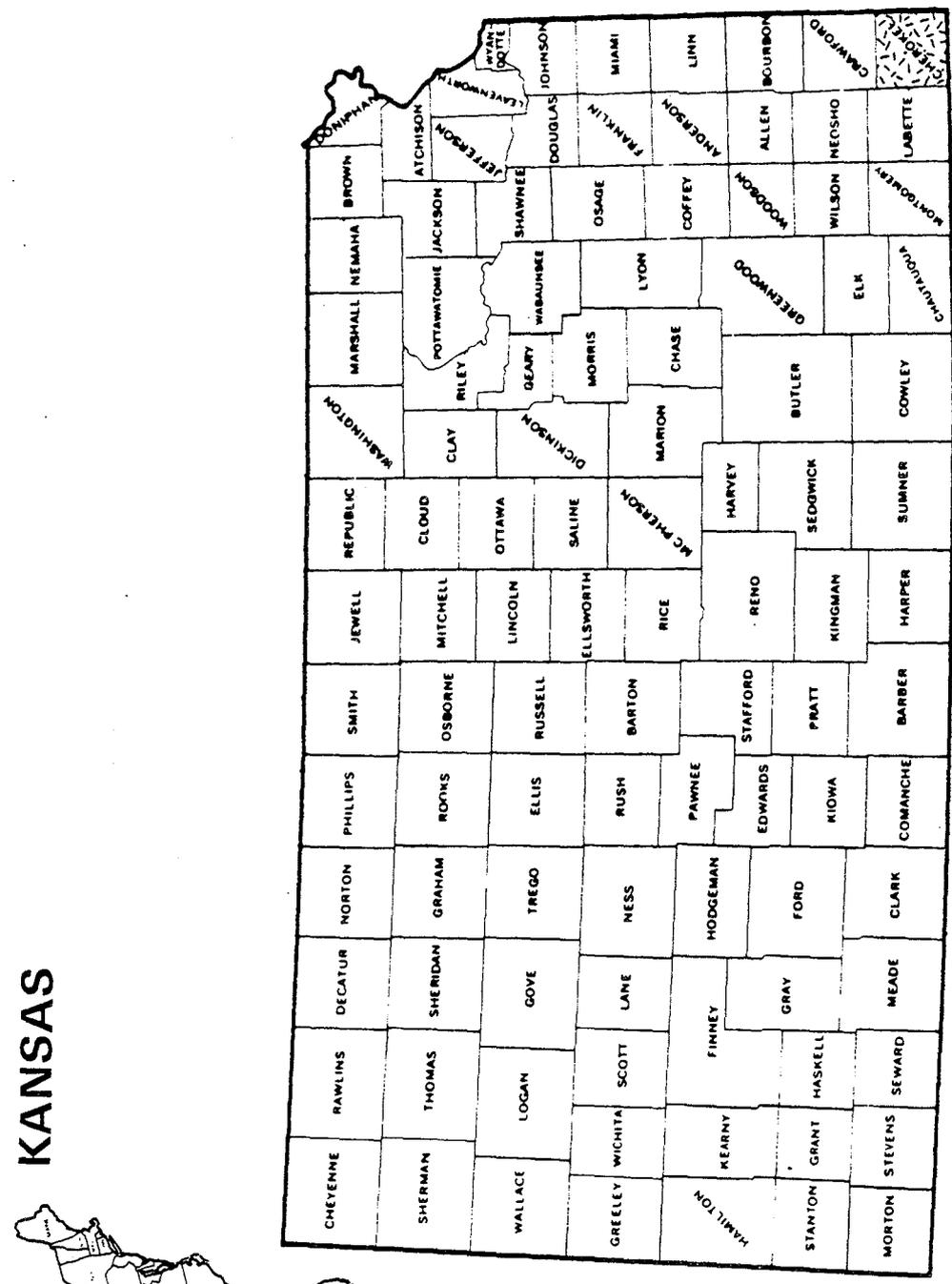
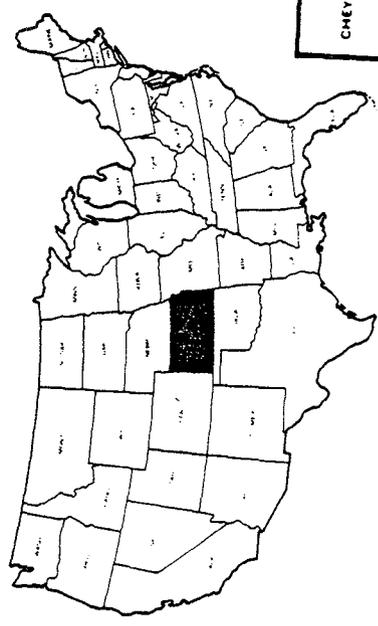


FIGURE 10. - Map showing the cumulative tailings produced in the state of Kansas



KANSAS

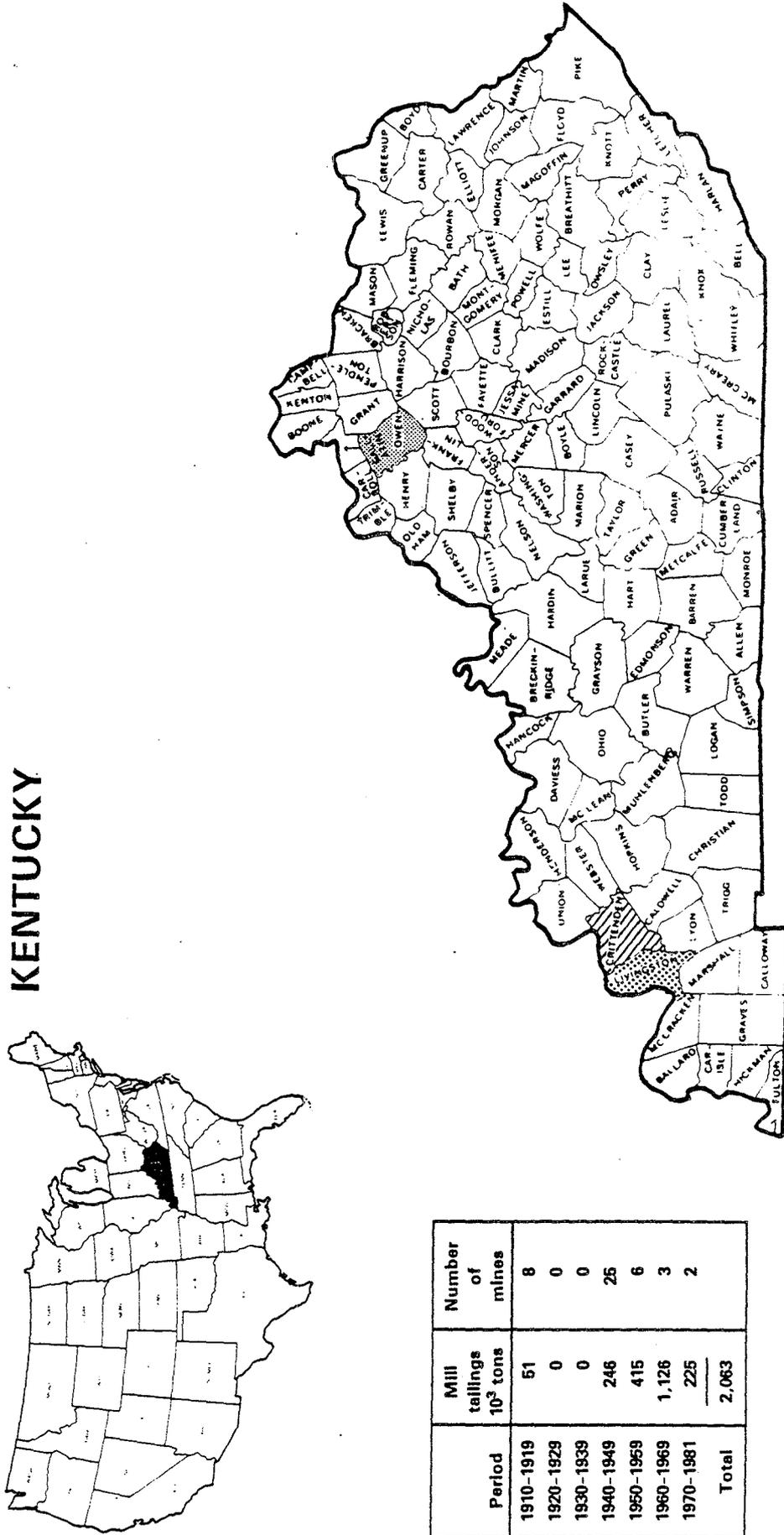


Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	8,286	60
1920-1929	33,501	70
1930-1939	29,502	50
1940-1949	32,171	82
1950-1959	9,832	67
1960-1969	1,560	12
1970-1981	60	2
Total	114,912	

LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 11. - Map showing the cumulative tailings produced in the state of Kentucky

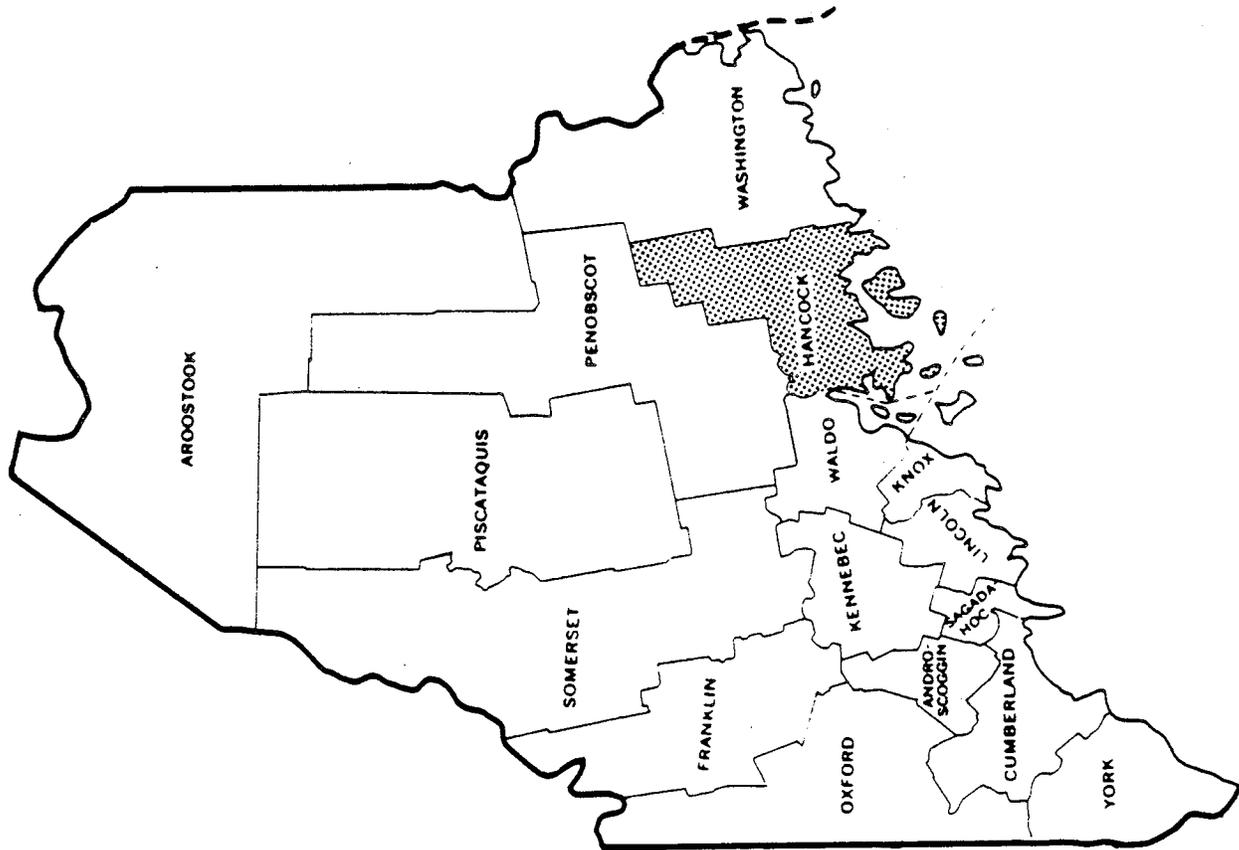
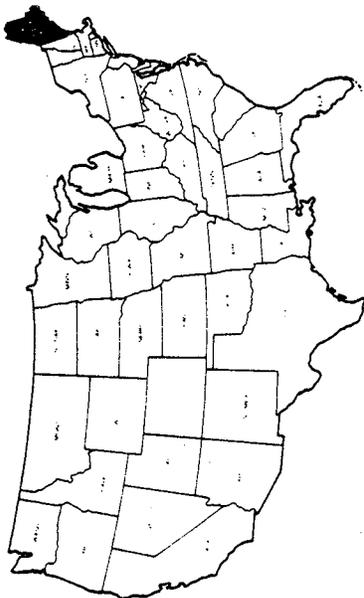


LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 12. - Map showing the cumulative tailings produced in the state of Maine

MAINE



Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	0	0
1920-1929	0	0
1930-1939	0	0
1940-1949	0	0
1950-1959	0	0
1960-1969	259	1
1970-1981	1,309	2
Total	1,568	

LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 13. - Map showing the cumulative tailings produced in the state of Michigan

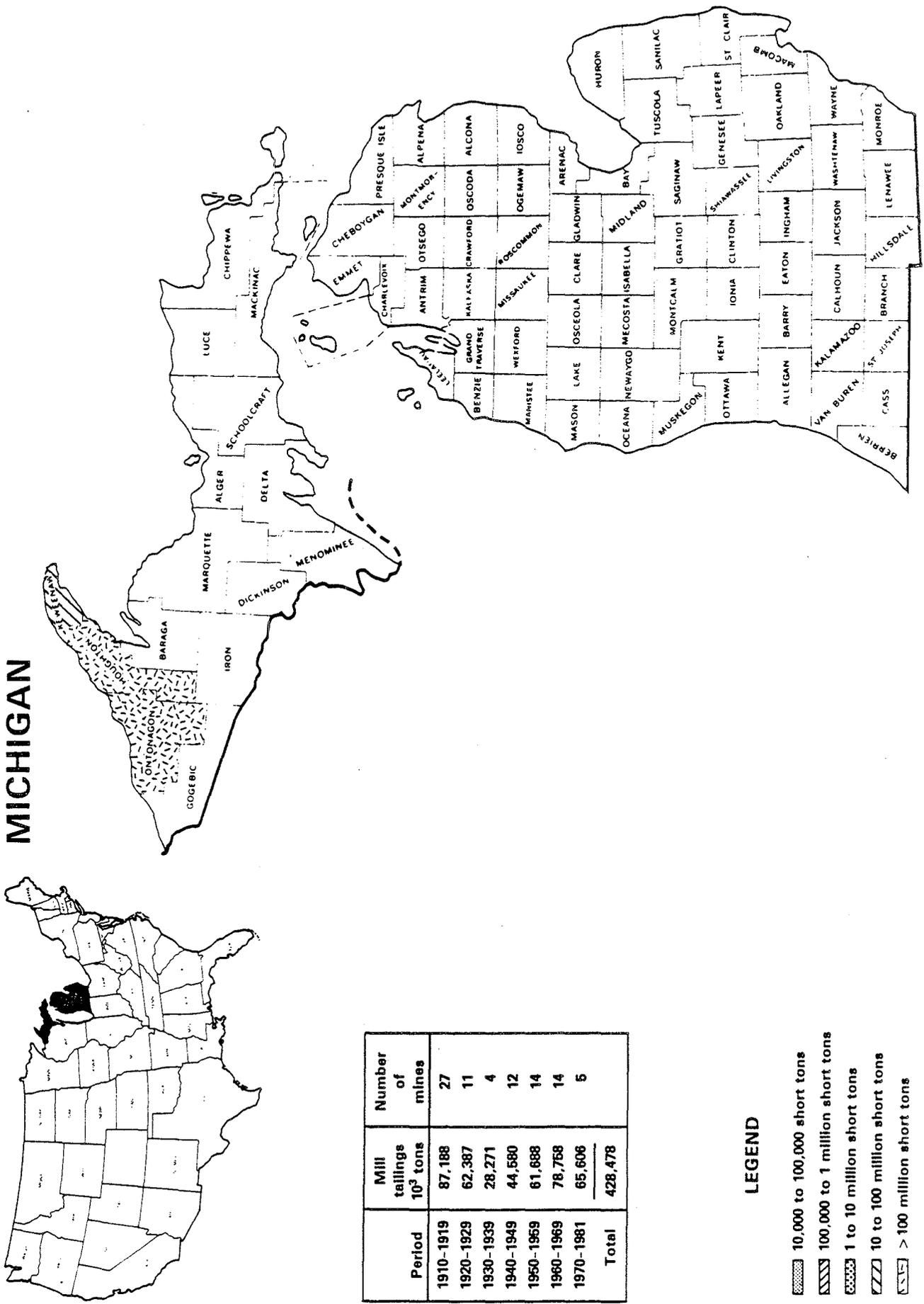


FIGURE 14. - Map showing the cumulative tailings produced in the state of Missouri

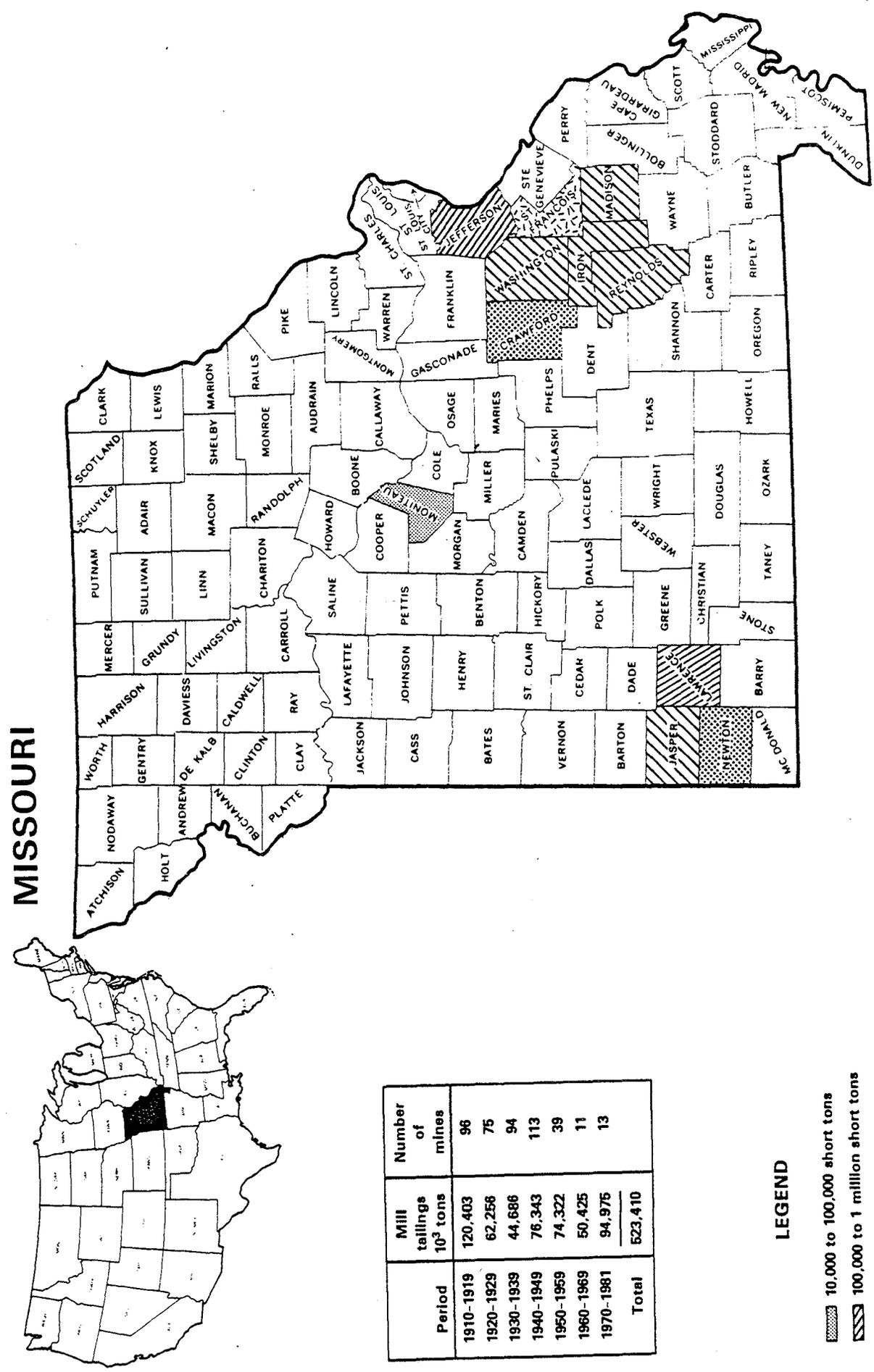
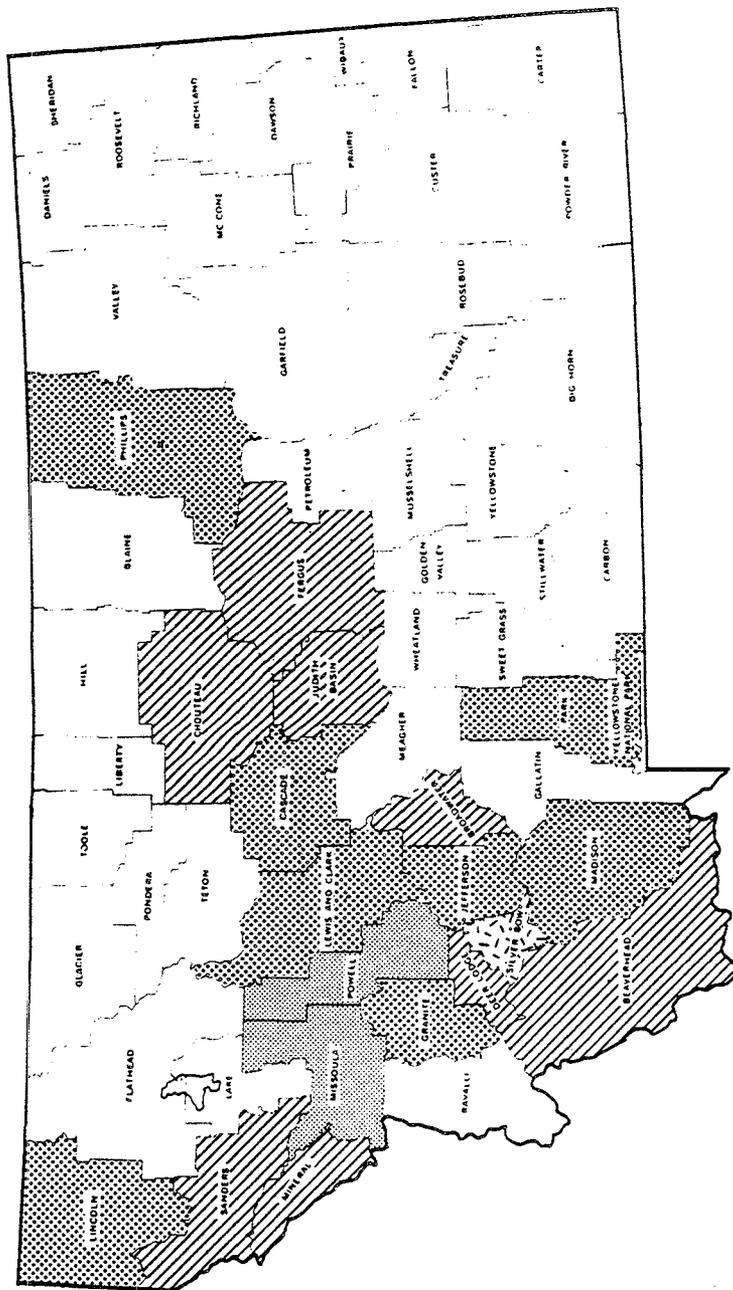
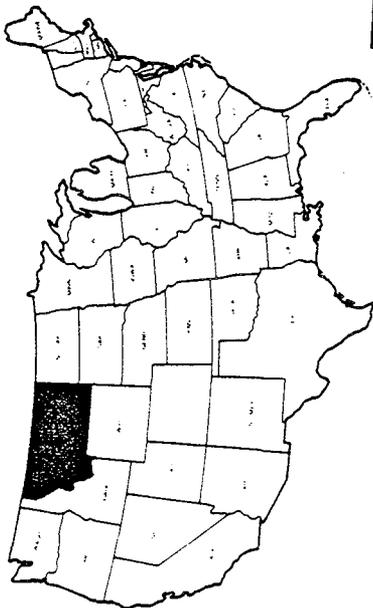


FIGURE 15. - Map showing the cumulative tailings produced in the state of Montana

MONTANA



Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	31,662	442
1920-1929	25,297	335
1930-1939	21,278	593
1940-1949	35,934	415
1950-1959	67,786	96
1960-1969	125,016	37
1970-1981	198,869	24
Total	505,842	

LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 1b. - Map showing the cumulative tailings produced in the state of Nevada

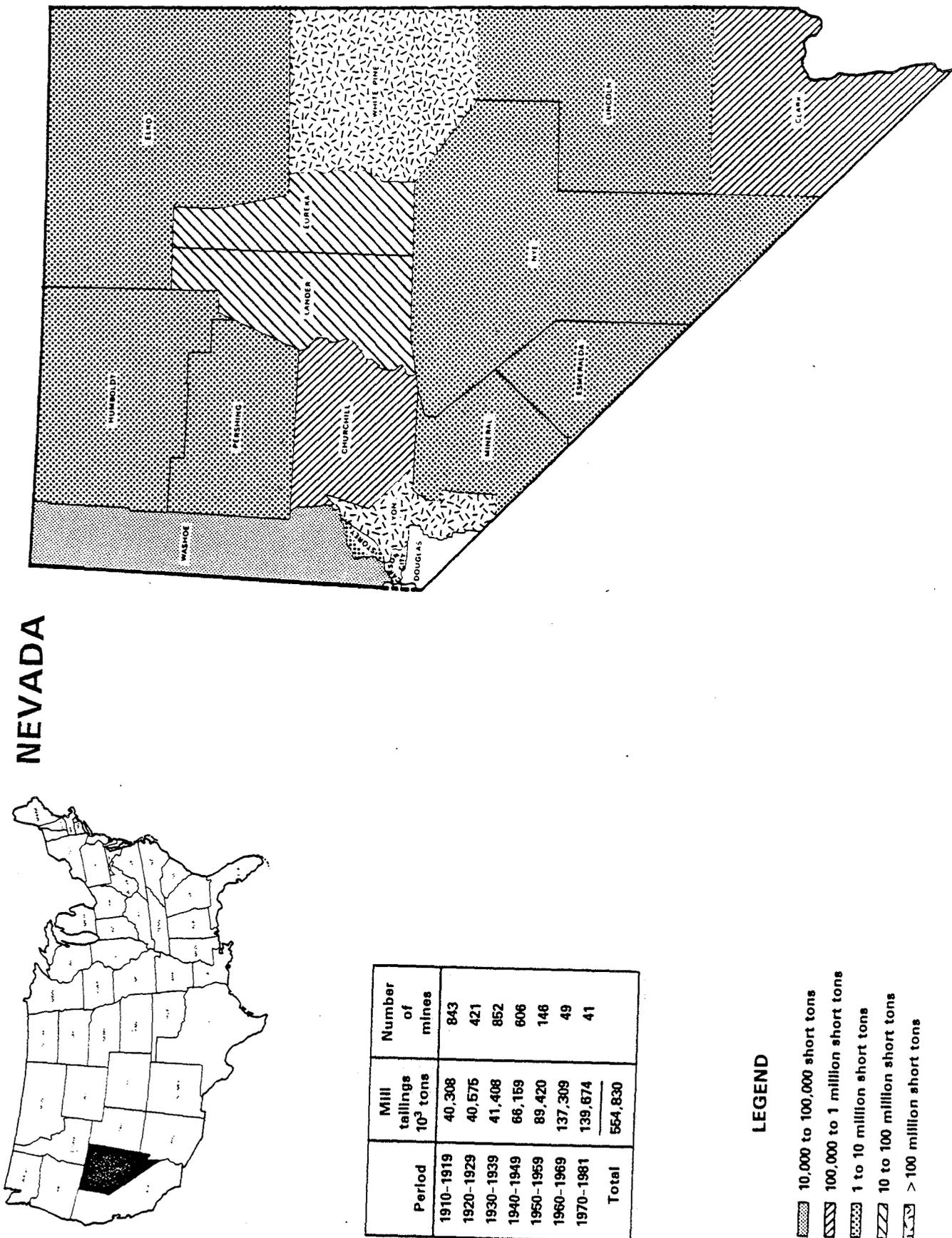
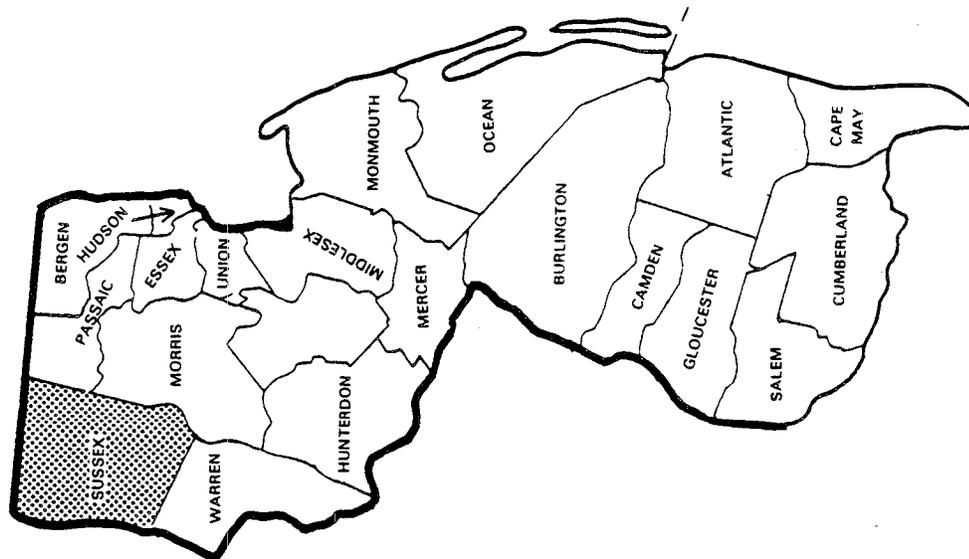
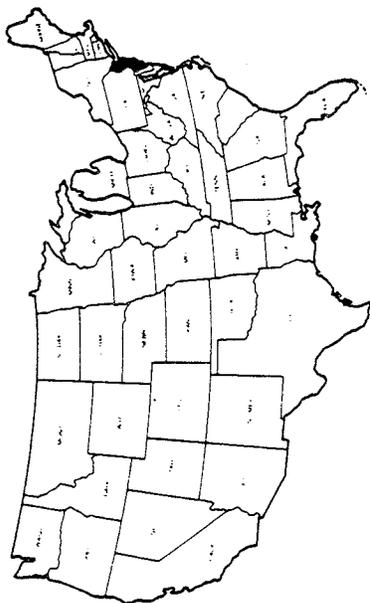


FIGURE 17. - Map showing the cumulative tailings produced in the state of New Jersey

NEW JERSEY



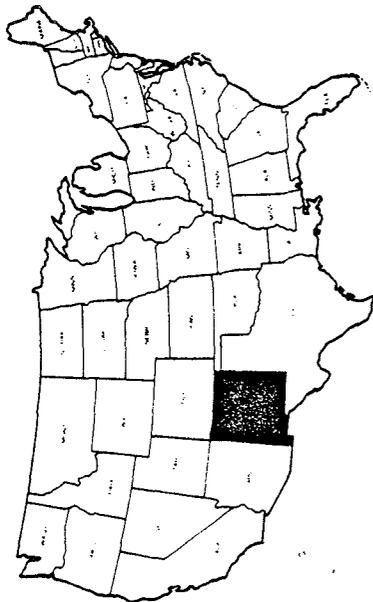
Period	Mill $\frac{1}{2}$ tailings 10 ³ tons	Number of mines
1910-1919	1,129	1
1920-1929	2,109	1
1930-1939	1,572	1
1940-1949	1,206	1
1950-1959	312	1
1960-1969	0	0
1970-1981	0	0
Total	6,328	

$\frac{1}{2}$ Majority of tonnage was shipped directly to smelter and not designated as mill tailings.

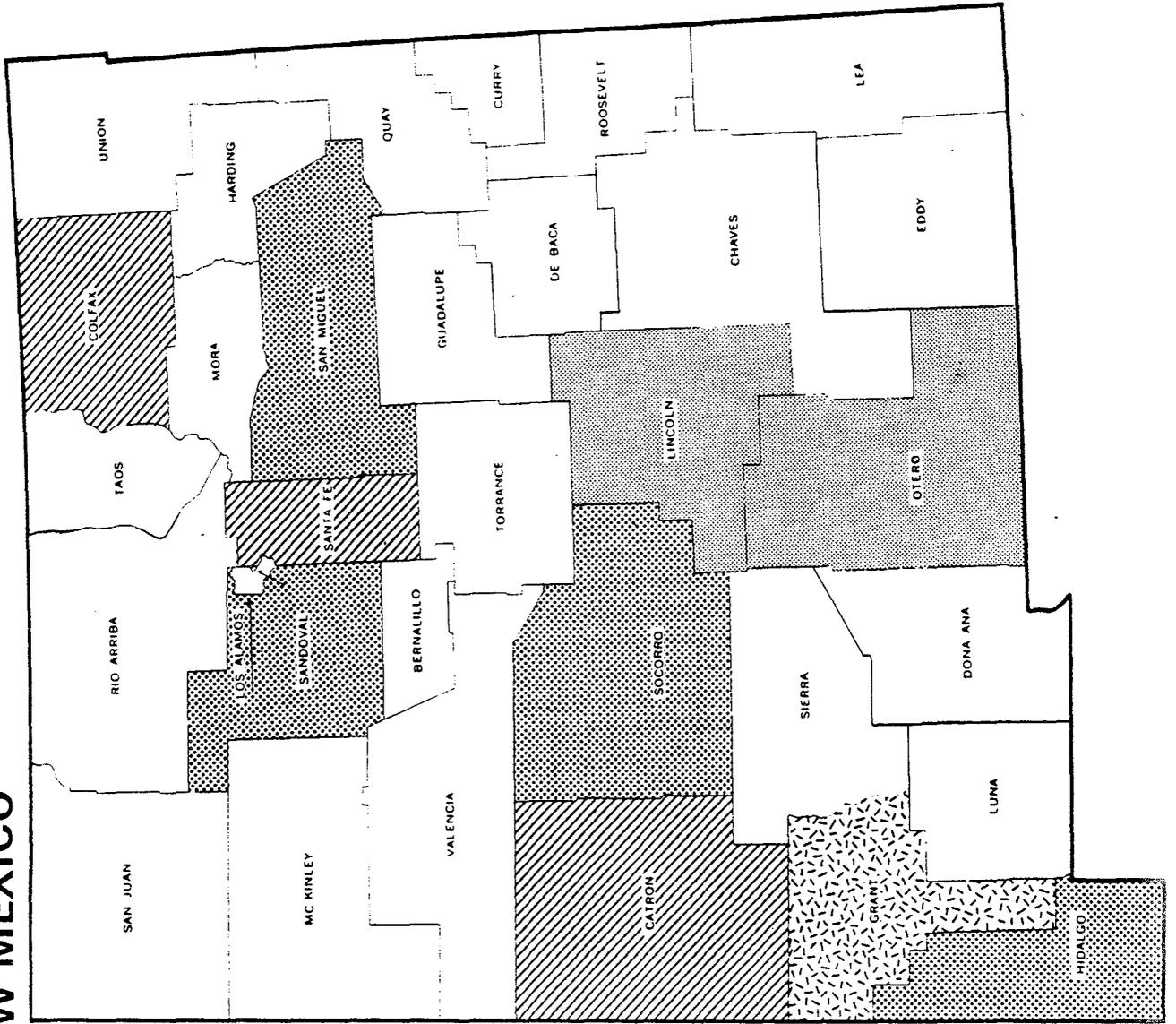
LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 18. - Map showing the cumulative tailings produced in the state of New Mexico



NEW MEXICO

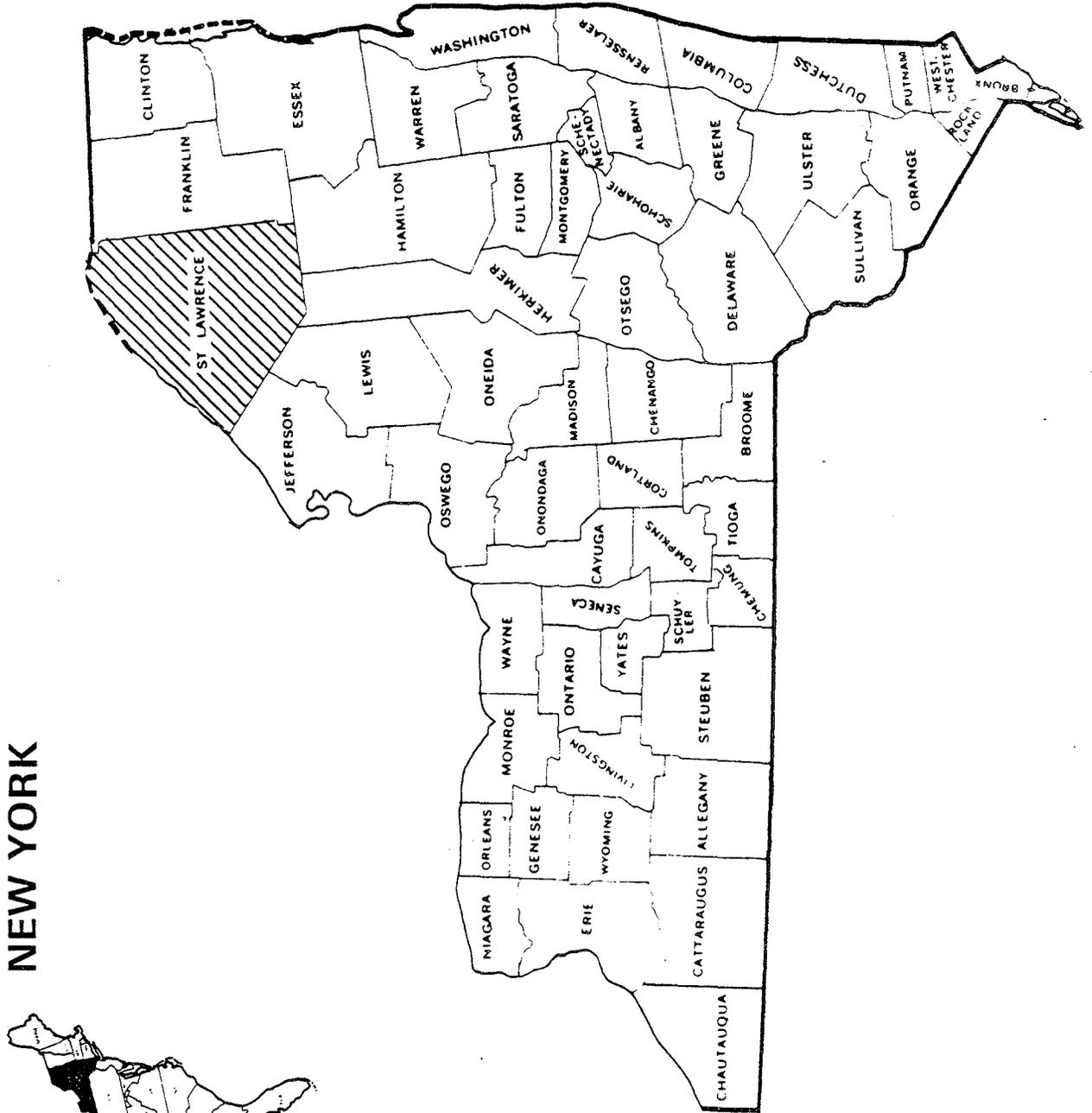


Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	20,661	142
1920-1929	27,206	96
1930-1939	26,014	153
1940-1949	69,177	113
1950-1959	70,583	54
1960-1969	76,739	44
1970-1981	270,100	17
Total	560,480	

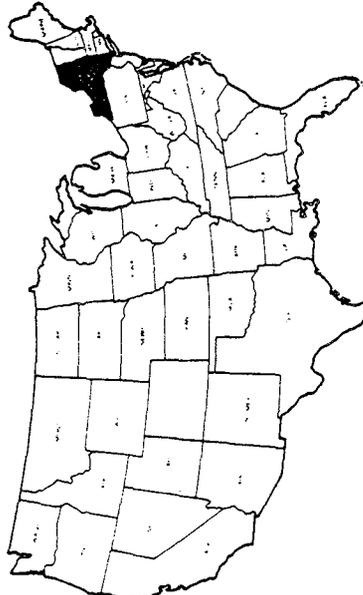
LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 19. - Map showing the cumulative tailings produced in the state of New York



NEW YORK



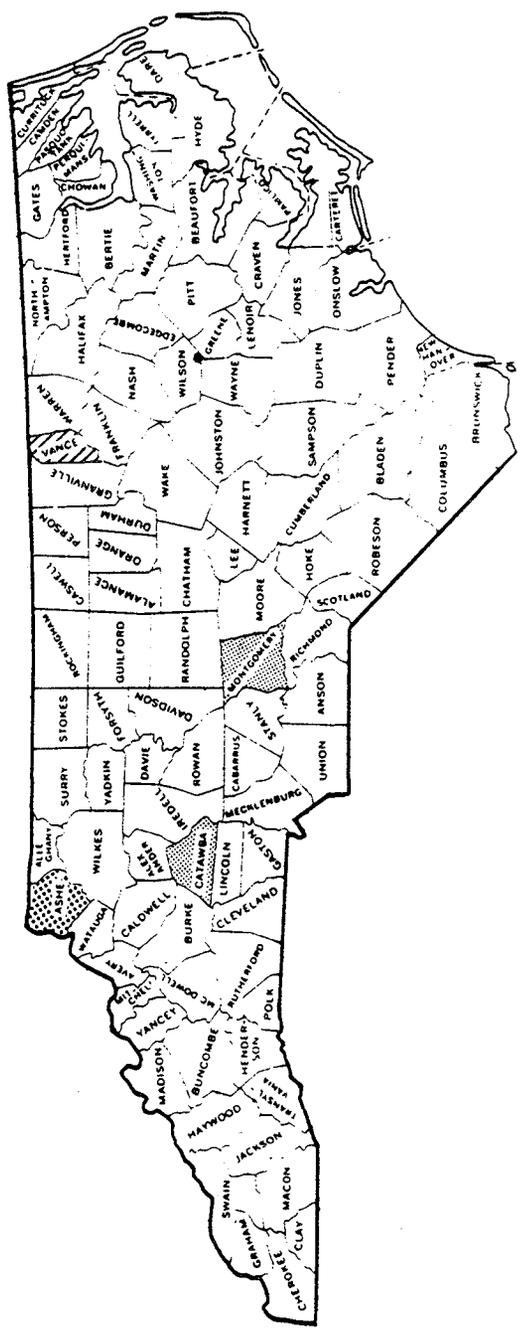
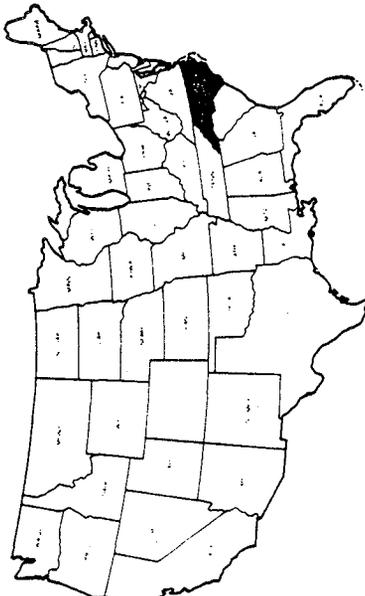
Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	167	1
1920-1929	1,327	1
1930-1939	2,700	2
1940-1949	3,805	3
1950-1959	4,863	2
1960-1969	5,918	2
1970-1981	8,638	4
Total	27,418	

LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 20. - Map showing the cumulative tailings produced in the state of North Carolina

NORTH CAROLINA



Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	103	5
1920-1929	0	0
1930-1939	0	0
1940-1949	0	0
1950-1959	621	1
1960-1969	1,380	2
1970-1981	0	0
Total	2,104	

LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 21. - Map showing the cumulative tailings produced in the state of Oklahoma

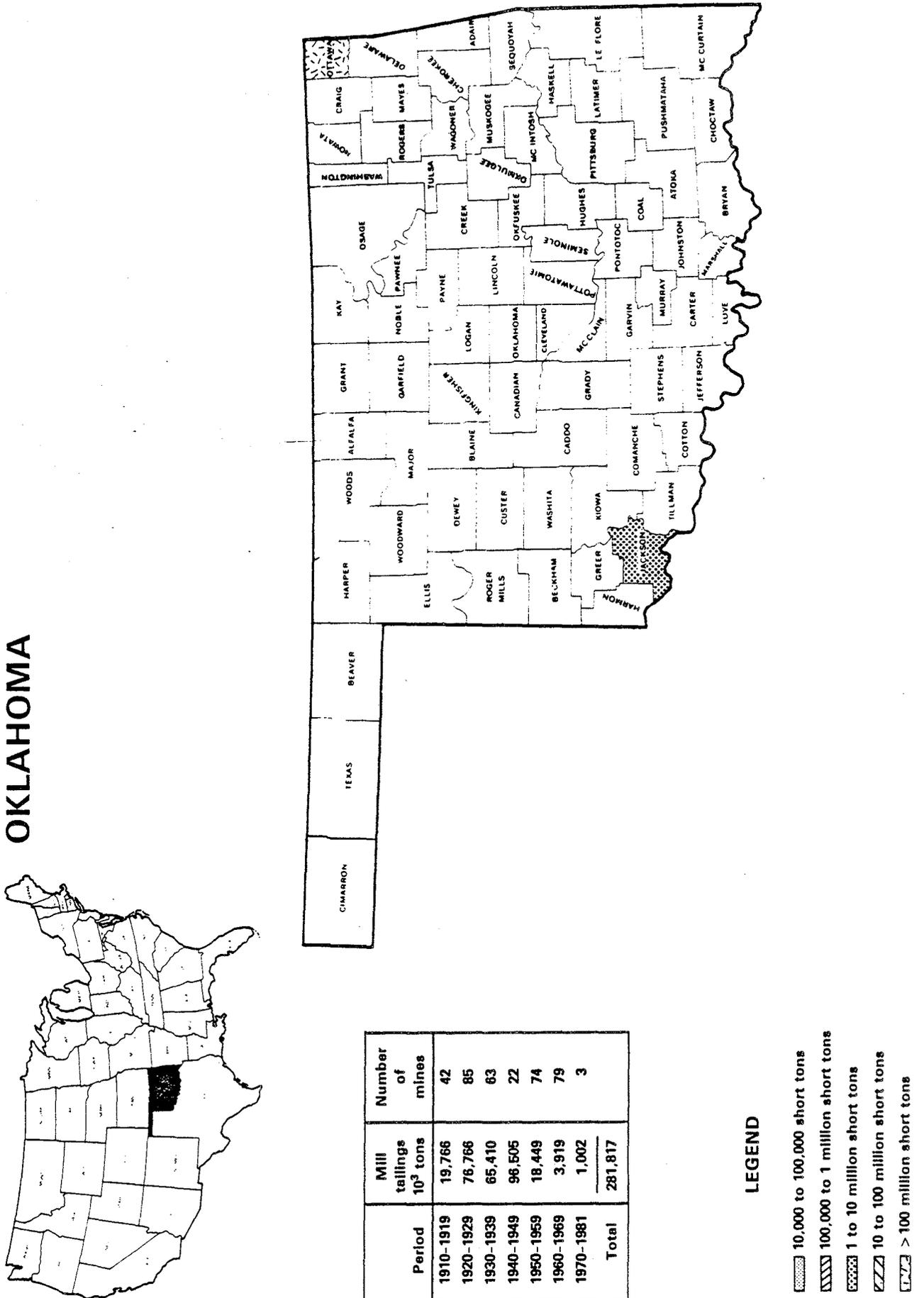


FIGURE 22. - Map showing the cumulative tailings produced in the state of Oregon

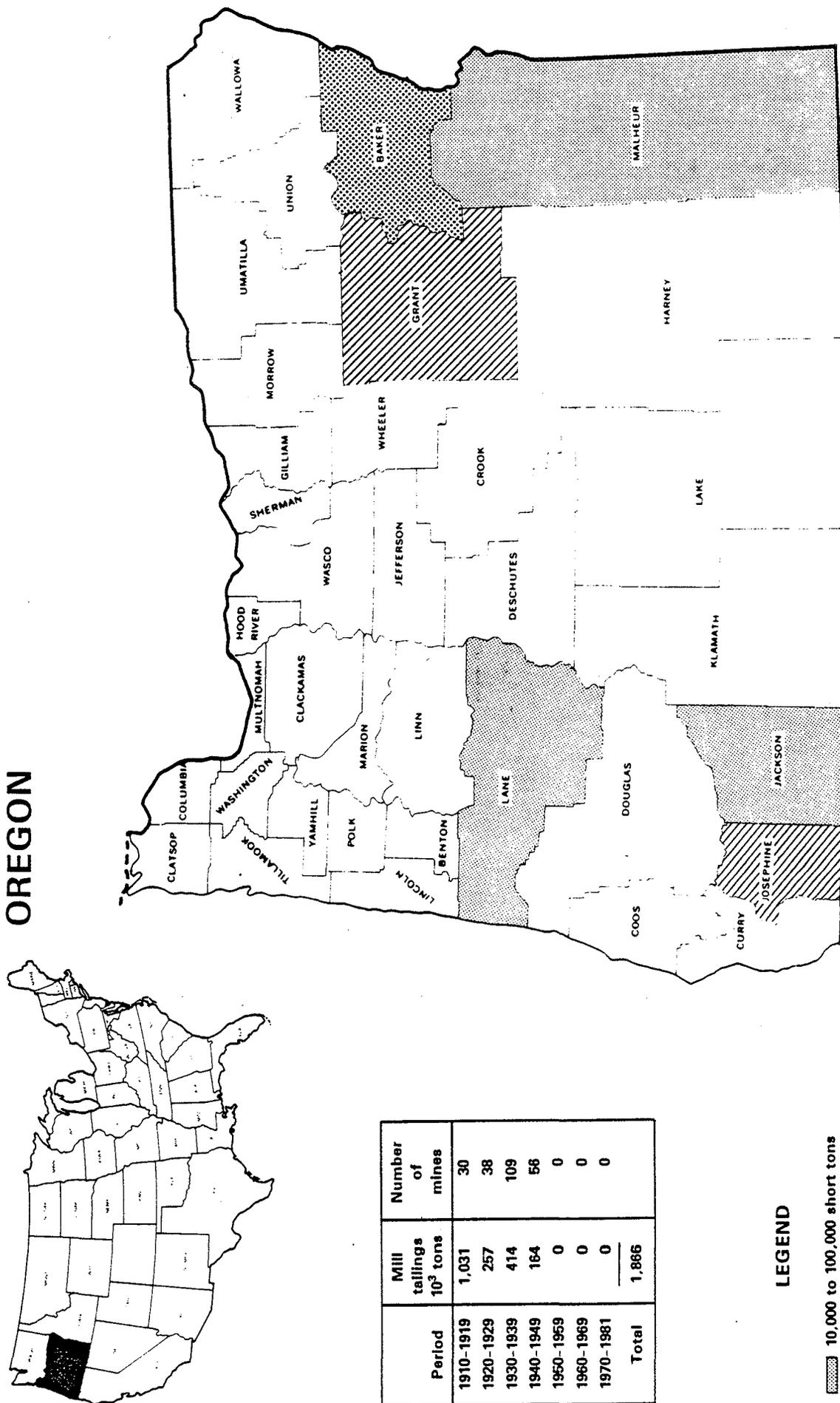
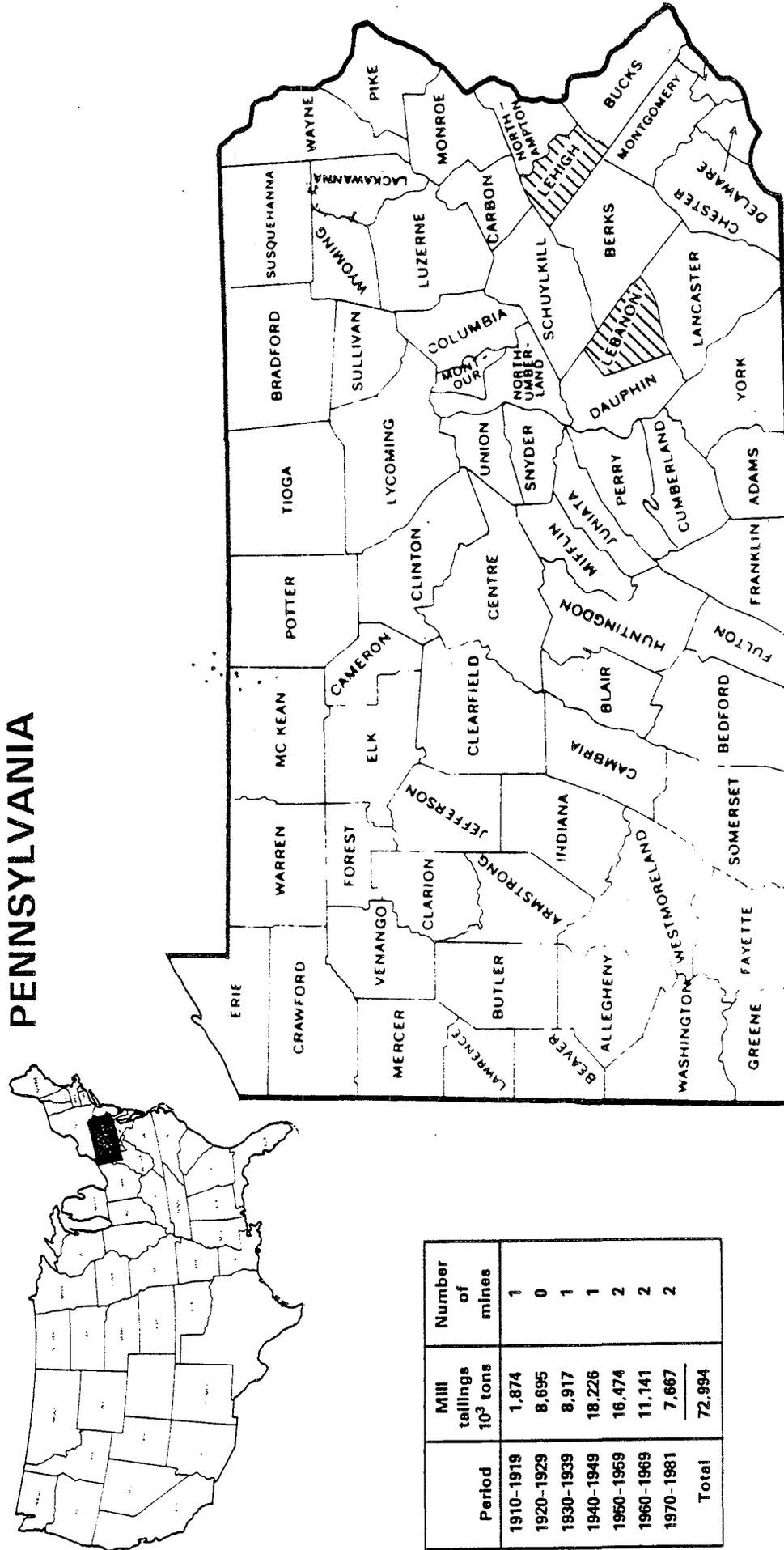


FIGURE 23. - Map showing the cumulative tailings produced in the state of Pennsylvania



PENNSYLVANIA

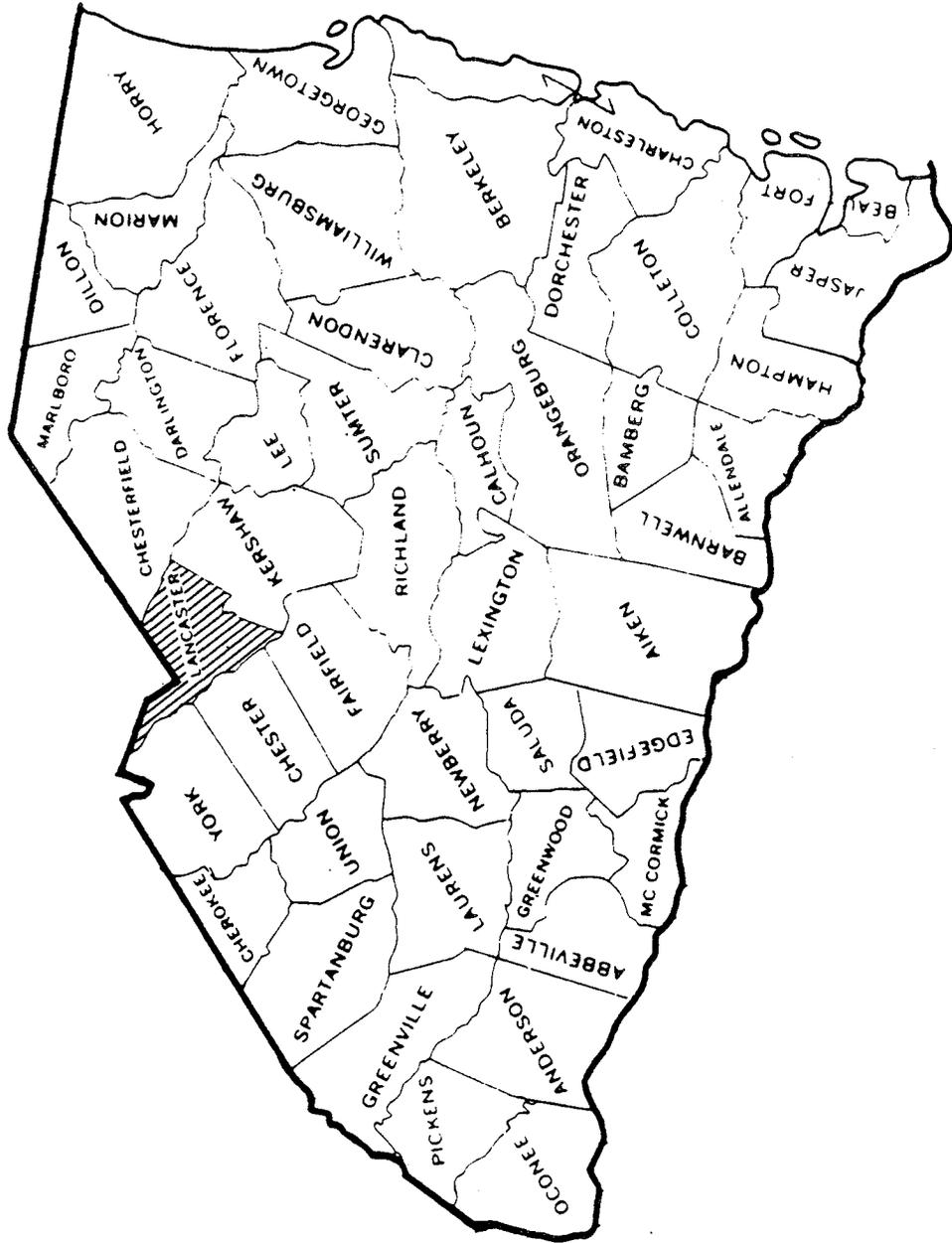
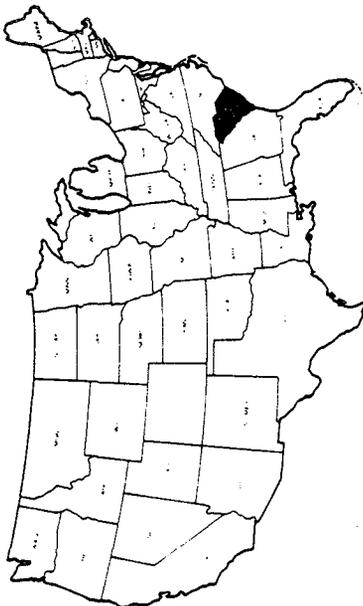
Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	1,874	1
1920-1929	8,695	0
1930-1939	8,917	1
1940-1949	18,226	1
1950-1959	16,474	2
1960-1969	11,141	2
1970-1981	7,667	2
Total	72,994	

LEGEND

-  10,000 to 100,000 short tons
-  100,000 to 1 million short tons
-  1 to 10 million short tons
-  10 to 100 million short tons
-  > 100 million short tons

FIGURE 24. - Map showing the cumulative tailings produced in the state of South Carolina

SOUTH CAROLINA



Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	0	0
1920-1929	0	0
1930-1939	299	2
1940-1949	270	3
1950-1959	0	0
1960-1969	0	0
1970-1981	0	0
Total	569	

LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 25. - Map showing the cumulative tailings produced in the state of South Dakota

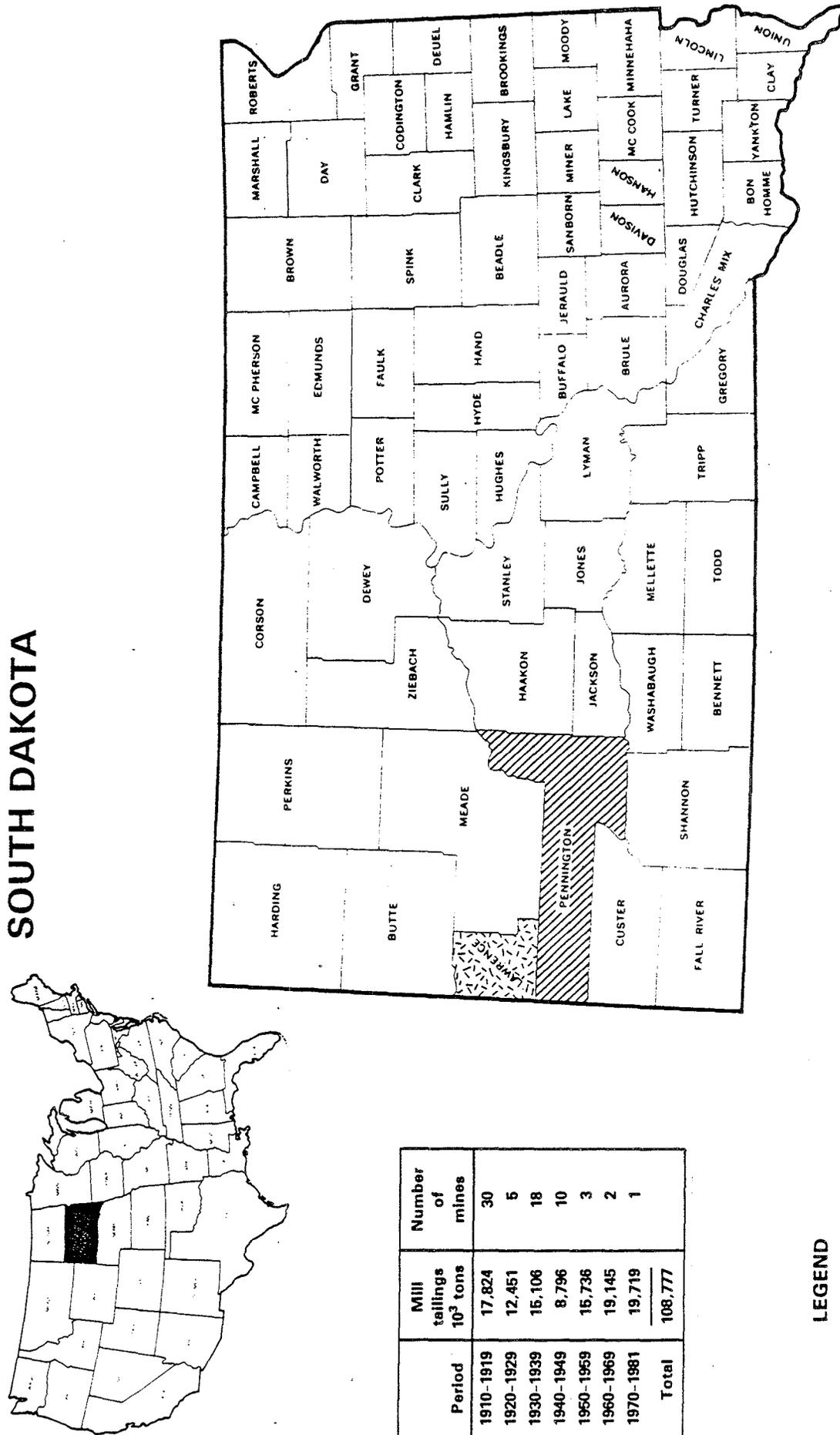


FIGURE 27. - Map showing the cumulative tailings produced in the state of Texas

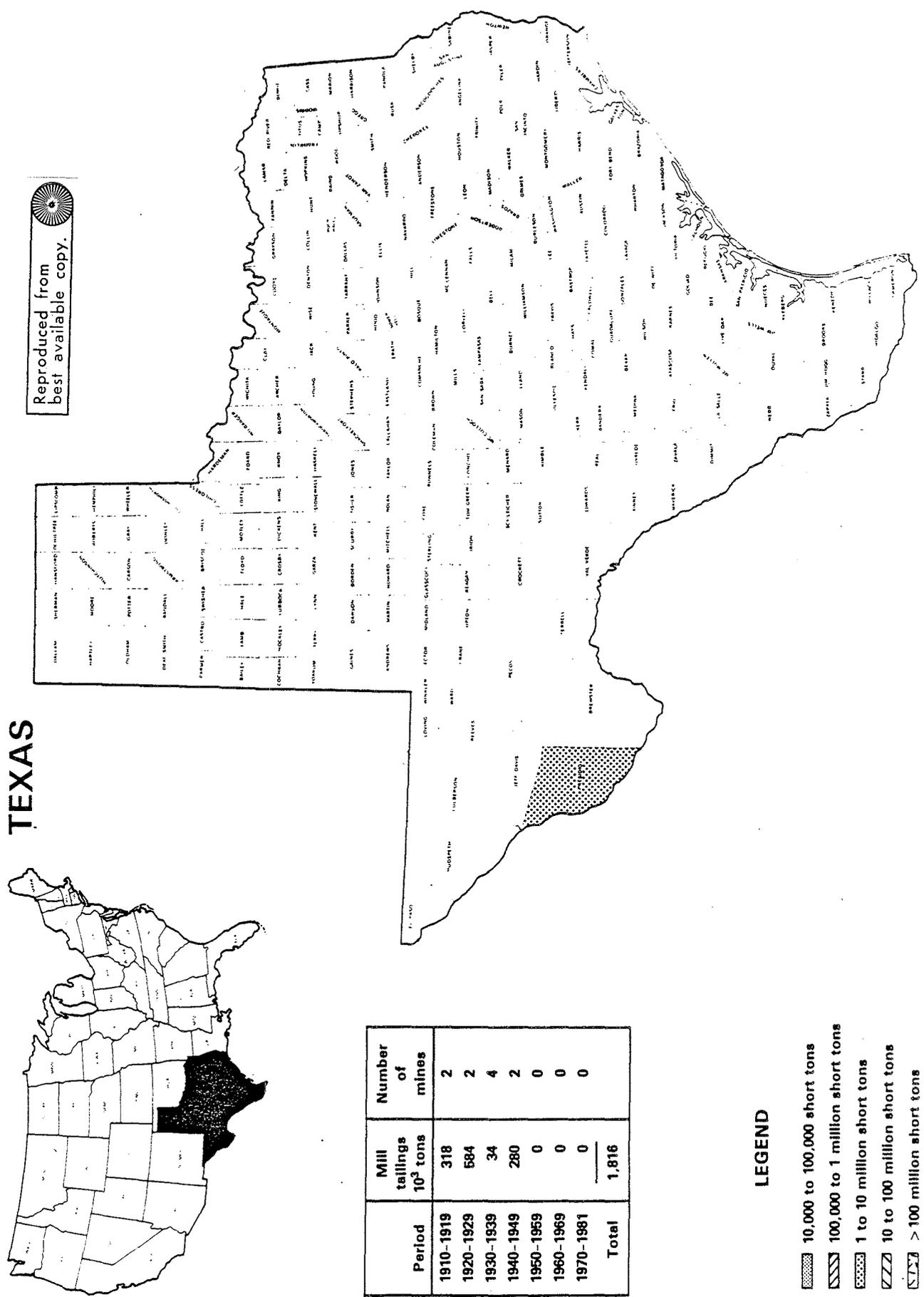
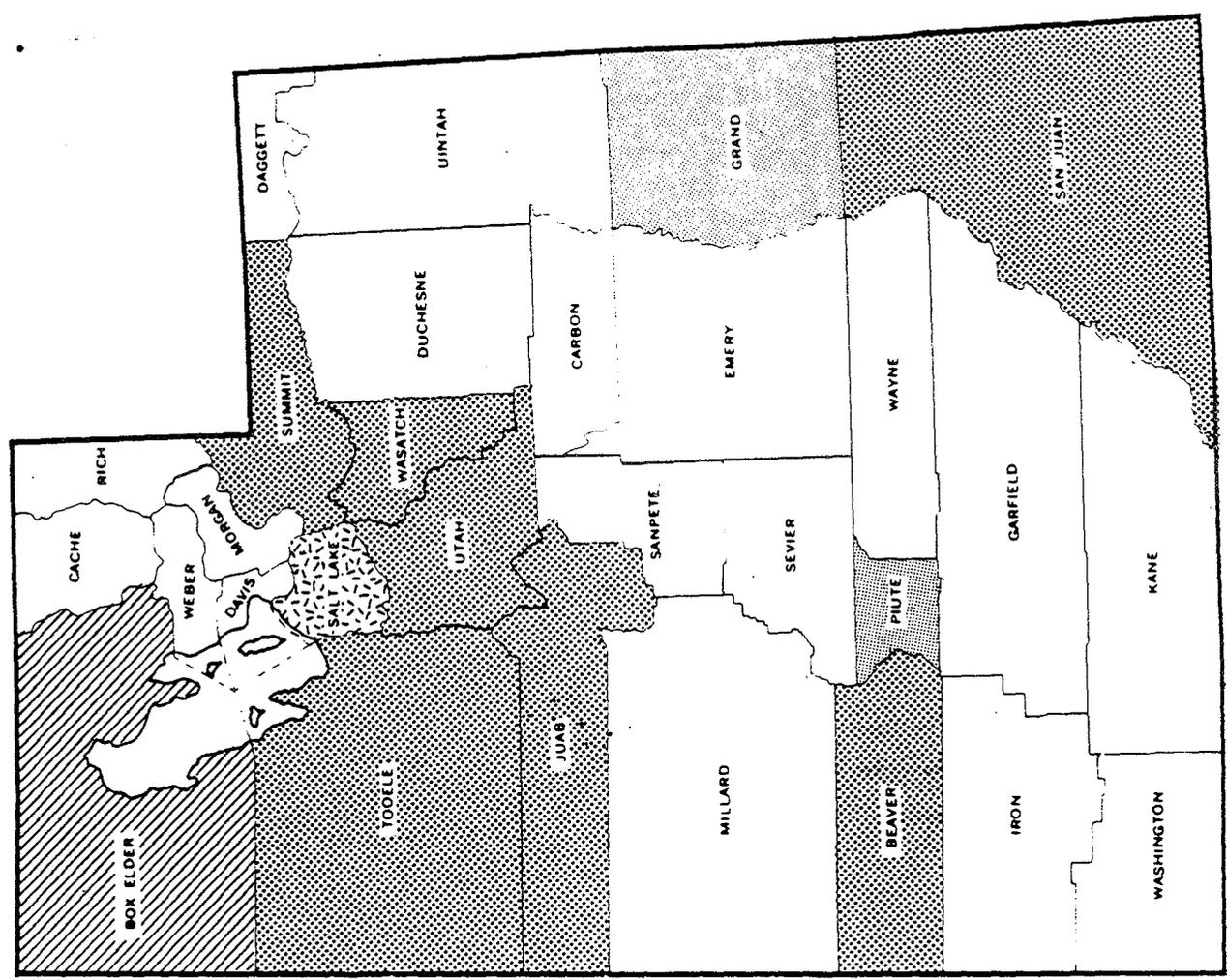
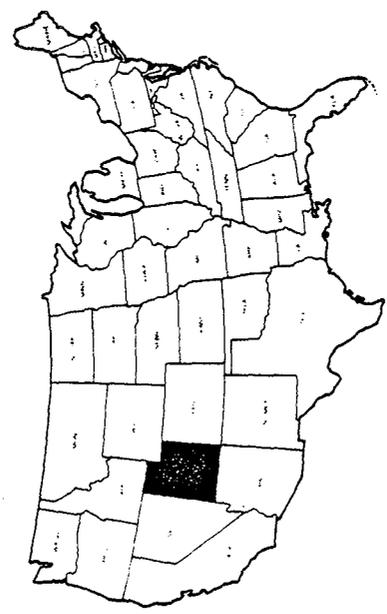


FIGURE 28. - Map showing the cumulative tailings produced in the state of Utah

UTAH



Period	Mill tailings 10 ³ tons	Number of mines
1910-1919	71,741	268
1920-1929	114,813	182
1930-1939	123,384	162
1940-1949	273,074	152
1950-1959	274,190	62
1960-1969	282,816	37
1970-1981	415,540	15
Total	1,555,358	

LEGEND

- 10,000 to 100,000 short tons
- 100,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

FIGURE 29. - Map showing the cumulative tailings produced in the state of Vermont

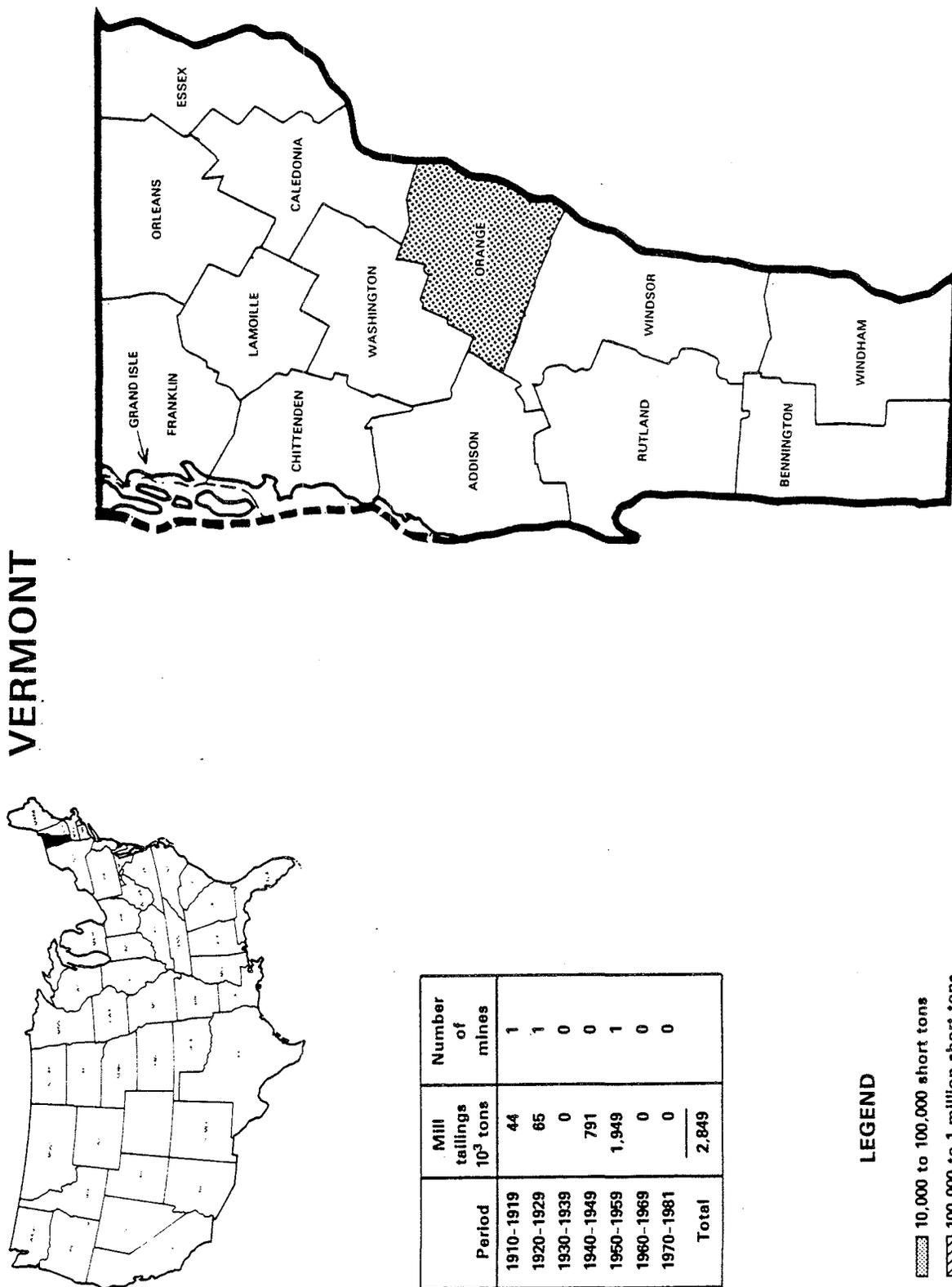


FIGURE 30. - Map showing the cumulative tailings produced in the state of Virginia

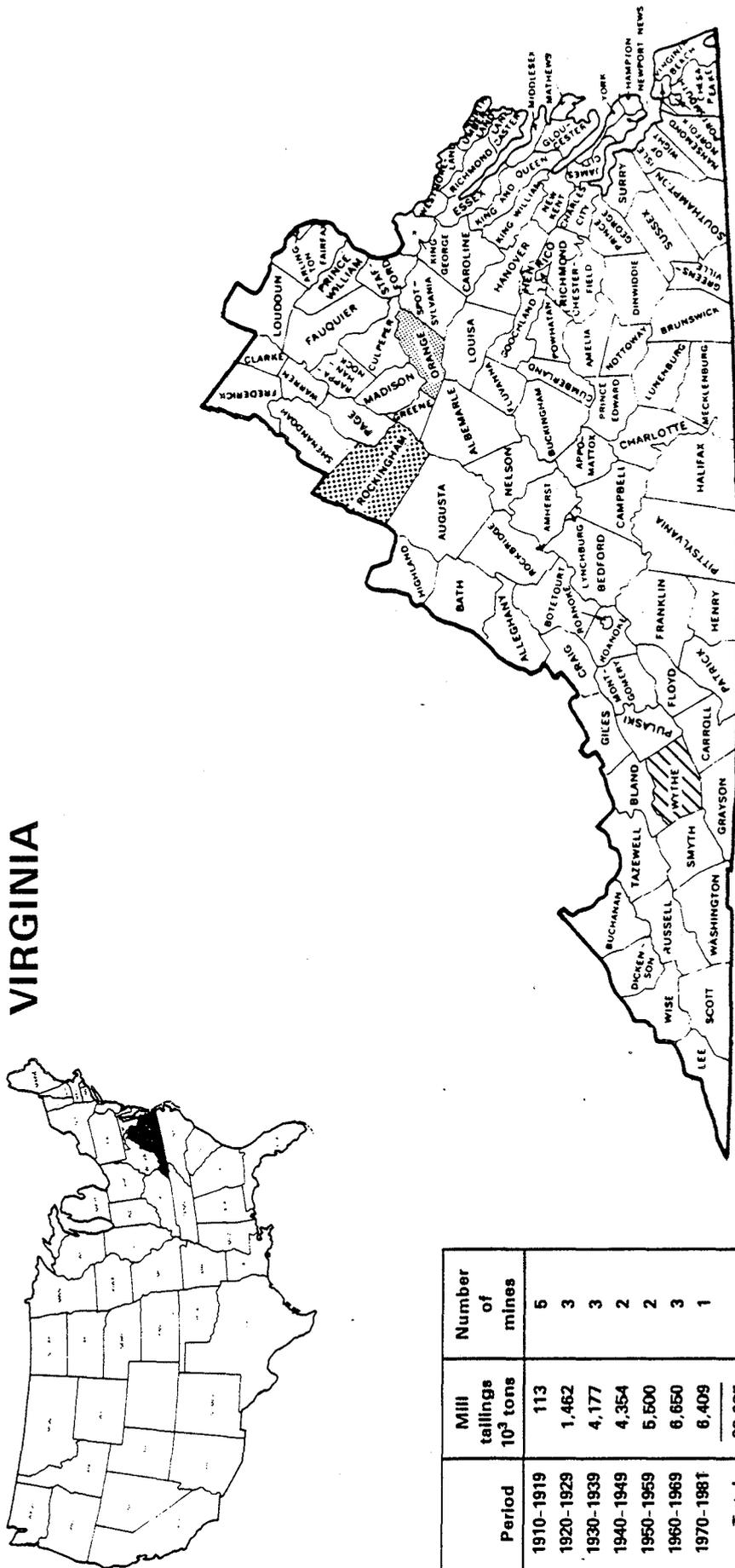


FIGURE 31. - Map showing the cumulative tailings produced in the state of Washington

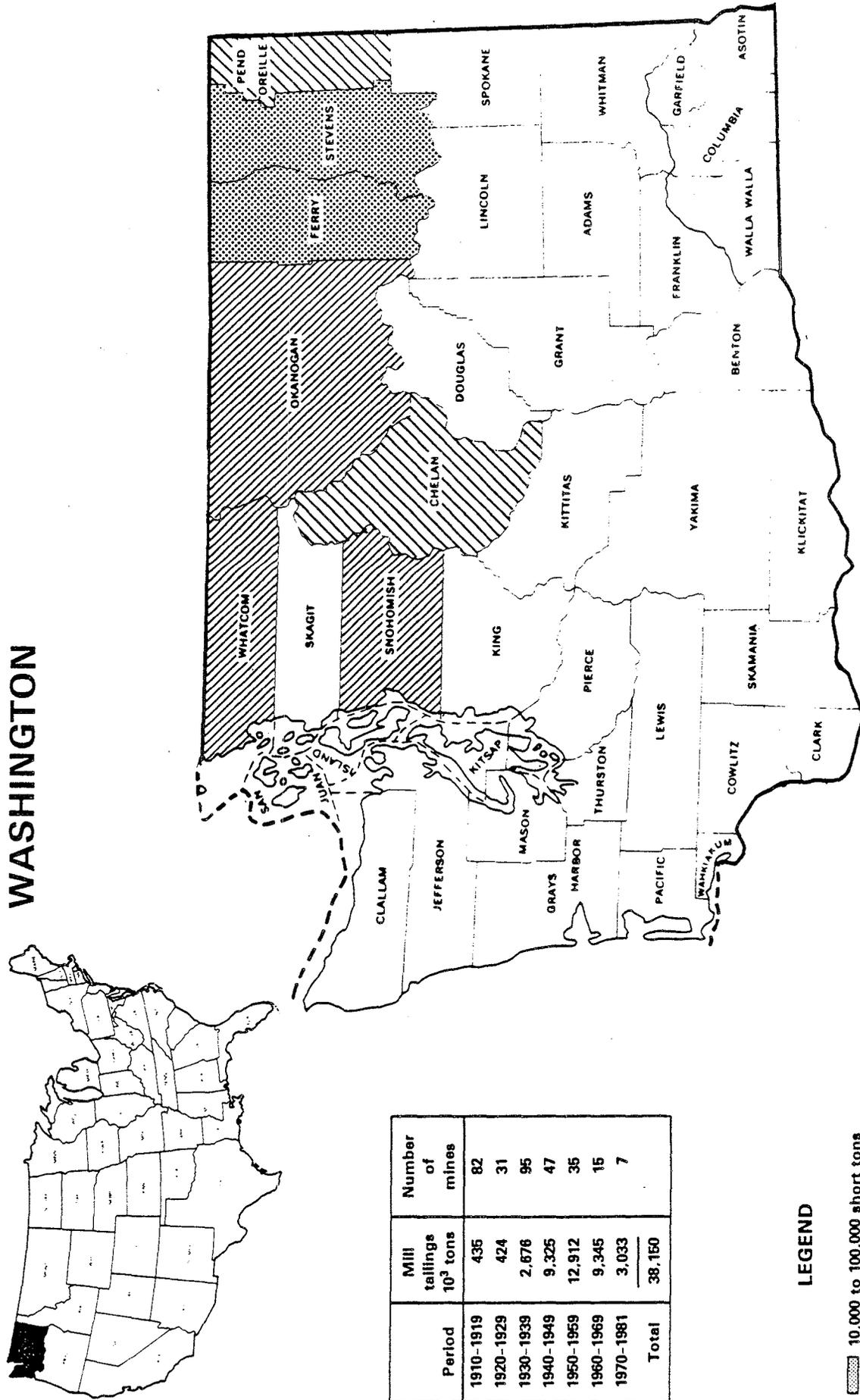


FIGURE 32. - Map showing the cumulative tailings produced in the state of Wisconsin

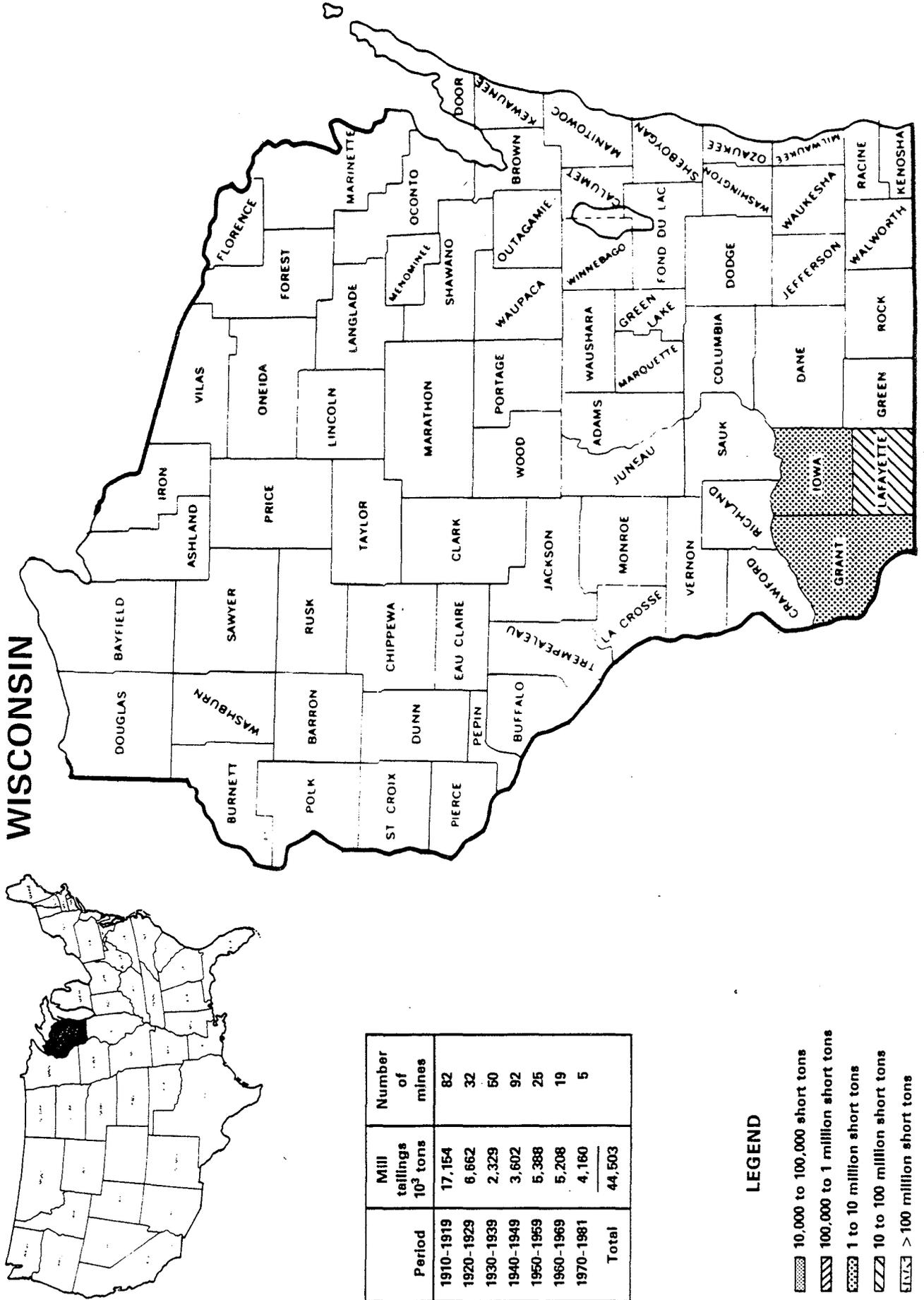


TABLE 2. - Cumulative mill tailings produced over the period
1910-81 from lode-mine operations

<u>State and</u> <u>county</u>	<u>Mill tailings,</u> <u>10⁶ tons</u>	<u>State and</u> <u>county</u>	<u>Mill tailings,</u> <u>10⁶ tons</u>
Arizona:		Colorado:	
Cochise.....	108,112	Boulder.....	985
Coconino.....	737	Chaffee.....	252
Gila.....	671,893	Clear Creek.....	2,772
Graham.....	487	Conejos.....	35
Greenlee.....	691,646	Custer.....	273
Maricopa.....	594	Dolores.....	899
Mohave.....	106,445	Eagle.....	7,188
Pima.....	1,426,078	Gilpin.....	1,969
Pinal.....	714,688	Gunnison.....	638
Santa Cruz.....	1,936	Lake.....	5,464
Yavapai.....	136,350	Mineral.....	2,602
Yuma.....	1,311	Ouray.....	4,321
Total.....	<u>3,860,277</u>	Park.....	1,202
		Pitkin.....	1,173
California:		Rio Grande.....	291
Alpine.....	22	Saguache.....	487
Amador.....	12,446	San Juan.....	10,514
Butte.....	355	San Miguel.....	19,094
Calaveras.....	9,508	Summit.....	842
El Dorado.....	1,342	Teller.....	<u>20,907</u>
Humboldt.....	30	Total.....	<u>81,908</u>
Imperial.....	197		
Inyo.....	5,906	Idaho:	
Kern.....	5,391	Adams.....	856
Los Angeles.....	123	Blaine.....	1,756
Madera.....	34	Boise.....	640
Mariposa.....	1,249	Bonner.....	411
Mono.....	1,062	Boundary.....	559
Napa.....	100	Butte.....	17
Nevada.....	14,234	Custer.....	2,679
Placer.....	790	Elmore.....	946
Plumas.....	9,521	Fremont.....	34
Riverside.....	45	Idaho.....	564
San Bernardino..	803	Lemhi.....	6,075
Shasta.....	3,510	Owyhee.....	3,711
Sierra.....	1,896	Shoshone.....	104,992
Siskiyou.....	1,330	Valley.....	4,450
Trinity.....	225	Washington.....	<u>4,049</u>
Tuolumne.....	3,001	Total.....	<u>131,739</u>
Yuba.....	67		
Total.....	<u>73,187</u>		

TABLE 2. - Cumulative mill tailings produced over the period
1910-81 from lode-mine operations - continued

<u>State and</u> <u>county</u>	<u>Mill tailings,</u> <u>10⁶ tons</u>	<u>State and</u> <u>county</u>	<u>Mill tailings,</u> <u>10⁶ tons</u>
Illinois:		Montana:	
Hardin.....	10,300	Beaverhead.....	302
Jo Daviess.....	<u>11,219</u>	Broadwater.....	623
Total.....	<u>21,519</u>	Cascade.....	1,760
Kansas:		Chouteau.....	139
Cherokee.....	<u>114,912</u>	Deer Lodge.....	238
Kentucky:		Fergus.....	892
Crittenden.....	309	Granite.....	1,057
Livingston.....	1,674	Jefferson.....	1,179
Owen.....	80	Judith Basin....	249
Total.....	<u>2,063</u>	Lewis & Clark...	2,594
Maine:		Lincoln.....	1,137
Hancock.....	<u>1,568</u>	Madison.....	1,245
Michigan:		Mineral.....	289
Houghton.....	263,966	Missoula.....	50
Keewanaw.....	21,451	Park.....	1,214
Ontonagon.....	143,061	Phillips.....	2,113
Total.....	<u>428,478</u>	Powell.....	31
Missouri:		Sanders.....	449
Crawford.....	8,141	Silver Bow.....	<u>490,281</u>
Iron.....	44,102	Total.....	<u>505,842</u>
Jasper.....	99,687	Nevada:	
Jefferson.....	167	Churchill.....	783
Lawrence.....	900	Clark.....	934
Madison.....	29,262	Elko.....	3,957
Moniteau.....	95	Esmeralda.....	6,334
Newton.....	1,191	Eureka.....	13,840
Reynolds.....	39,374	Humboldt.....	5,659
St. Francois....	274,652	Lander.....	29,653
Washington.....	25,839	Lincoln.....	5,841
Total.....	<u>523,410</u>	Lyon.....	143,637
		Mineral.....	1,286
		Nye.....	8,943
		Pershing.....	2,024
		Storey.....	6,862
		Washoe.....	77
		White Pine.....	<u>325,000</u>
		Total.....	<u>554,830</u>

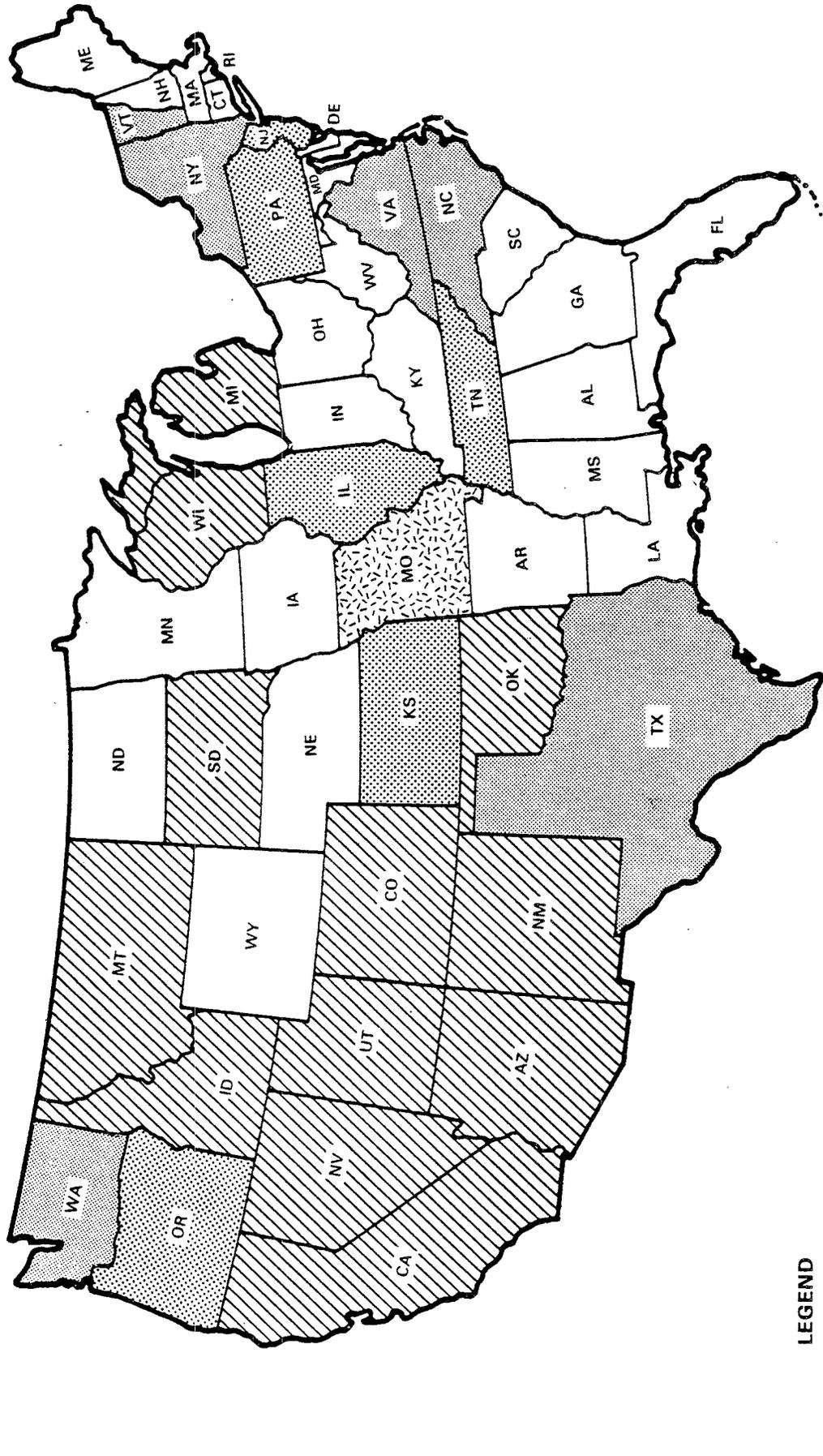
TABLE 2. - Cumulative mill tailings produced over the period
1910-81 from lode-mine operations - continued

<u>State and county</u>	<u>Mill tailings, 10⁶ tons</u>	<u>State and county</u>	<u>Mill tailings, 10⁶ tons</u>
New Jersey:		Pennsylvania:	
Sussex.....	<u>6,328</u>	Lebanon.....	61,949
New Mexico:		Lehigh.....	<u>11,045</u>
Catron.....	854	Total.....	<u>72,994</u>
Colfax.....	143	South Carolina:	
Grant.....	549,038	Lancaster.....	<u>569</u>
Hidalgo.....	2,676	South Dakota:	
Lincoln.....	48	Lawrence.....	108,580
Otero.....	25	Pennington.....	<u>197</u>
San Miguel.....	1,700	Total.....	<u>108,777</u>
Sandoval.....	3,525	Tennessee:	
Santa Fe.....	237	Grainger.....	1,203
Socorro.....	<u>2,234</u>	Hancock.....	4,733
Total.....	<u>560,480</u>	Jefferson.....	72,417
New York:		Knox.....	29,188
St. Lawrence....	<u>27,418</u>	Polk.....	61,816
North Carolina:		Smith.....	3,815
Ashe.....	1,373	Union.....	24
Catawba.....	28	Washington.....	<u>756</u>
Montgomery.....	75	Total.....	<u>173,952</u>
Vance.....	<u>628</u>	Texas:	
Total.....	<u>2,104</u>	Presidio.....	<u>1,816</u>
Oklahoma:		Utah:	
Jackson.....	1,676	Beaver.....	2,346
Ottawa.....	<u>280,141</u>	Box Elder.....	135
Total.....	<u>281,817</u>	Grand.....	76
Oregon:		Juab.....	1,063
Baker.....	1,424	Piute.....	95
Grant.....	184	Salt Lake.....	1,532,434
Jackson.....	75	San Juan.....	1,504
Josephine.....	108	Summit.....	5,920
Lane.....	41	Tooele.....	5,812
Malheur.....	<u>34</u>	Utah.....	1,463
Total.....	<u>1,866</u>	Wasatch.....	<u>4,510</u>
		Total.....	<u>1,555,358</u>

TABLE 2. - Cumulative mill tailings produced over the period
1910-81 from lode-mine operations - continued

<u>State and</u> <u>county</u>	<u>Mill tailings,</u> <u>10⁶ tons</u>	<u>State and</u> <u>county</u>	<u>Mill tailings,</u> <u>10⁶ tons</u>
Vermont:		Wisconsin cont:	
Orange.....	<u>2,849</u>	Pend Oreille....	18,784
		Snohomish.....	206
Virginia:		Stevens.....	5,591
Orange.....	25	Whatcom.....	<u>144</u>
Rockingham.....	1,234	Total.....	<u>38,150</u>
Wythe.....	<u>27,406</u>		
Total.....	<u>28,665</u>	Wisconsin:	
		Grant.....	7,277
Washington:		Iowa.....	7,759
Chelan.....	10,058	Lafayette.....	<u>29,467</u>
Ferry.....	3,132	Total.....	<u>44,503</u>
Okanogan.....	235		
National Total.....			9,207,379

FIGURE 33. - Map showing the tailings produced between 1910 and 1919



LEGEND

- 10,000 to 1 million short tons
- 1 to 10 million short tons
- 10 to 100 million short tons
- > 100 million short tons

TABLE 3. - Amount of mill tailings produced during the period 1910-19 from lode-mine operations

State and county	Major commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Arizona:			
Cochise.....	Cu-Ag.....	65	2,730
Gila.....	Cu.....	52	28,088
Graham.....	Cu-Pb.....	13	20
Greenlee.....	Cu.....	28	11,257
Maricopa.....	Au.....	22	145
Mohave.....	Au-Zn.....	59	1,764
Pima.....	Cu.....	61	28
Pinal.....	Cu.....	46	21,777
Santa Cruz.....	Cu-Pb-Zn.....	27	66
Yavapai.....	Cu-Au.....	94	677
Yuma.....	Au-Cu-Pb.....	52	55
Total.....		519	66,607
California:			
Amador.....	Au.....	34	6,422
Butte.....	Au.....	8	32
Calaveras.....	Au-Cu.....	40	3,634
El Dorado.....	Au.....	25	104
Imperial.....	Au.....	2	65
Inyo.....	Au.....	50	277
Kern.....	Au.....	49	1,318
Madera.....	Au.....	10	12
Mariposa.....	Au.....	29	305
Mono.....	Au.....	13	96
Nevada.....	Au.....	36	2,964
Placer.....	Au.....	13	153
Plumas.....	Cu-Au.....	15	1,160
San Bernardino.....	Au.....	54	42
Shasta.....	Au-Cu.....	53	567
Sierra.....	Au.....	26	534
Siskiyou.....	Au.....	39	35
Trinity.....	Au.....	24	169
Tuolumne.....	Au.....	55	1,851
Total.....		575	19,740
Colorado:			
Boulder.....	Au-Ag.....	60	110
Chaffee.....	Zn-Au-Pb.....	29	252
Clear Creek.....	Au-Ag-Zn-Pb.....	91	830
Custer.....	Au-Ag.....	23	18
Eagle.....	Zn.....	29	302
Gilpin.....	Au-Ag-Cu.....	90	398
Gunnison.....	Au-Zn-Pb-Ag.....	25	38
Lake.....	Zn-Pb.....	94	204

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 3. - Amount of mill tailings produced during the period 1910-19 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Colorado: - cont'd			
Mineral.....	Pb-Zn-Au-Ag....	13	183
Ouray.....	Au-Ag.....	52	750
Park.....	Ag-Pb-Au.....	21	21
Pitkin.....	Pb-Ag.....	13	567
San Juan.....	Au-Pb-Ag-Zn....	46	934
San Miguel.....	Au-Ag-Pb.....	28	4,191
Summit.....	Zn-Pb.....	41	178
Teller.....	Au.....	92	8,695
Total.....		747	17,671
Idaho:			
Blaine.....	Ag-Pb-Zn.....	33	59
Boise.....	Au.....	33	224
Bonner.....	Pb-Ag.....	7	10
Boundary.....	Pb-Ag.....	4	162
Elmore.....	Au.....	11	163
Fremont.....	Pb.....	1	34
Idaho.....	Au.....	56	50
Lemhi.....	Au.....	42	68
Owyhee.....	Au-Ag.....	18	144
Shoshone.....	Pb-Ag-Zn.....	66	16,192
Washington.....	Pb-Ag-Zn.....	1	4,049
Total.....		272	21,155
Illinois:			
Hardin.....	Pb.....	2	148
Jo Davies.....	Zn-Pb.....	9	2,463
Total.....		11	2,611
Kansas:			
Cherokee.....	Zn-Pb.....	60	8,286
Kentucky:			
Livington.....	Zn-Pb.....	8	51
Michigan:			
Houghton.....	Cu.....	16	68,339
Keweenaw.....	Cu.....	6	15,363
Ontonagon.....	Cu.....	5	3,486
Total.....		27	87,188

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 3. - Amount of mill tailings produced during the period 1910-19 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Missouri:			
Jasper.....	Zn-Pb.....	75	75,949
St. Francois...	Pb.....	21	44,454
Total.....		96	120,403
Montana:			
Beaverhead.....	Au-Ag.....	37	18
Broadwater.....	Au-Ag.....	5	161
Cascade.....	Pb-Ag.....	23	21
Chouteau.....	Au.....	2	139
Fergus.....	Au.....	13	564
Jefferson.....	Pb-Cu-Ag.....	76	204
Lewis & Clark..	Au.....	82	440
Montana:			
Lincoln.....	Pb-Zn-Ag.....	4	230
Madison.....	Au-Ag.....	97	132
Mineral.....	Cu-Ag-Pb-Zn....	6	136
Missoula.....	Au-Pb-Ag.....	7	32
Phillips.....	Au-Ag.....	3	896
Silver Bow.....	Cu-Zn-Ag.....	87	28,689
Total.....		442	31,662
Nevada:			
Churchill.....	Ag-Au.....	14	652
Clark.....	Zn-Pb-Ag-Au....	54	158
Elko.....	Au-Ag.....	80	213
Esmeralda.....	Au.....	70	3,545
Eureka.....	Ag-Pb.....	42	245
Humboldt.....	Au-Ag.....	96	320
Lander.....	Ag-Au.....	35	47
Lincoln.....	Zn-Ag-Pb-Au....	23	18
Lyon.....	Au-Cu-Ag.....	64	158
Mineral.....	Au-Ag.....	93	781
Nye.....	Ag-Au.....	99	5,249
Pershing.....	Ag-Au.....	40	224
Storey.....	Au-Ag.....	36	778
Washoe.....	Au-Ag-Pb.....	47	28
White Pine.....	Cu.....	50	27,869
Total.....		843	40,285
New Jersey:			
Sussex.....	Zn.....	1	1,129

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 3. - Amount of mill tailings produced during the period 1910-19 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
New Mexico:			
Colfax.....	Au.....	4	55
Grant.....	Cu.....	87	19,374
Lincoln.....	Au.....	6	48
Otero.....	Cu.....	18	25
Socorro.....	Zn-Ag-Au.....	27	1,159
Total.....		142	20,661
New York:			
St. Lawrence...	Zn.....	1	167
North Carolina:			
Catawba.....	Au.....	1	28
Montgomery.....	Au.....	4	75
Total.....		5	103
Oklahoma:			
Ottawa.....	Zn-Pb.....	42	19,766
Oregon:			
Baker.....	Au-Cu.....	22	908
Grant.....	Au-Ag.....	8	62
Jackson.....	Au.....	9	11
Lane.....	Au.....	5	16
Malheur.....	Au.....	3	34
Total.....		47	1,031
Pennsylvania:			
Lebanon.....	Cu.....	1	1,874
South Dakota:			
Lawrence.....	Au.....	24	17,813
Pennington.....	Au.....	6	11
Total.....		30	17,824
Tennessee:			
Jefferson.....	Zn.....	2	1,289
Knox.....	Zn.....	1	2,865
Union.....	Zn.....	1	24
Washington.....	Zn-Pb.....	2	160
Total.....		6	4,338

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 3. - Amount of mill tailings produced during the period
1910-19 from lode-mine operations - contiued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Texas:			
Presidio.....	Ag.....	2	318
Utah:			
Beaver.....	Cu-Pb-Zn.....	29	652
Juab.....	Au-Ag.....	56	157
Salt Lake.....	Cu.....	80	69,265
Summit.....	Pb-Ag-Zn.....	22	601
Toole.....	Pb-Au-Ag-Cu....	61	715
Utah.....	Pb-Ag.....	16	39
Wasatch.....	Pb-Ag-Zn.....	4	312
Total.....		268	71,741
Vermont:			
Orange.....		1	44
Virginia:			
Wythe.....	Zn-Pb.....	5	113
Washington:			
Ferry.....	Au-Ag.....	27	43
Pend Oreille...	Zn.....	6	32
Snohomish.....	Cu.....	5	24
Stevens.....	Cu-Ag.....	39	312
Whatcom.....		5	24
Total.....		82	435
Wisconsin:			
Grant.....	Zn.....	11	4,979
Iowa.....	Zn.....	44	4,496
Lafayette.....	Zn.....	27	7,679
Total.....		82	17,154
National Total.....		4,315	572,357

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

FIGURE 34. - Map showing the tailings produced between 1920 and 1929

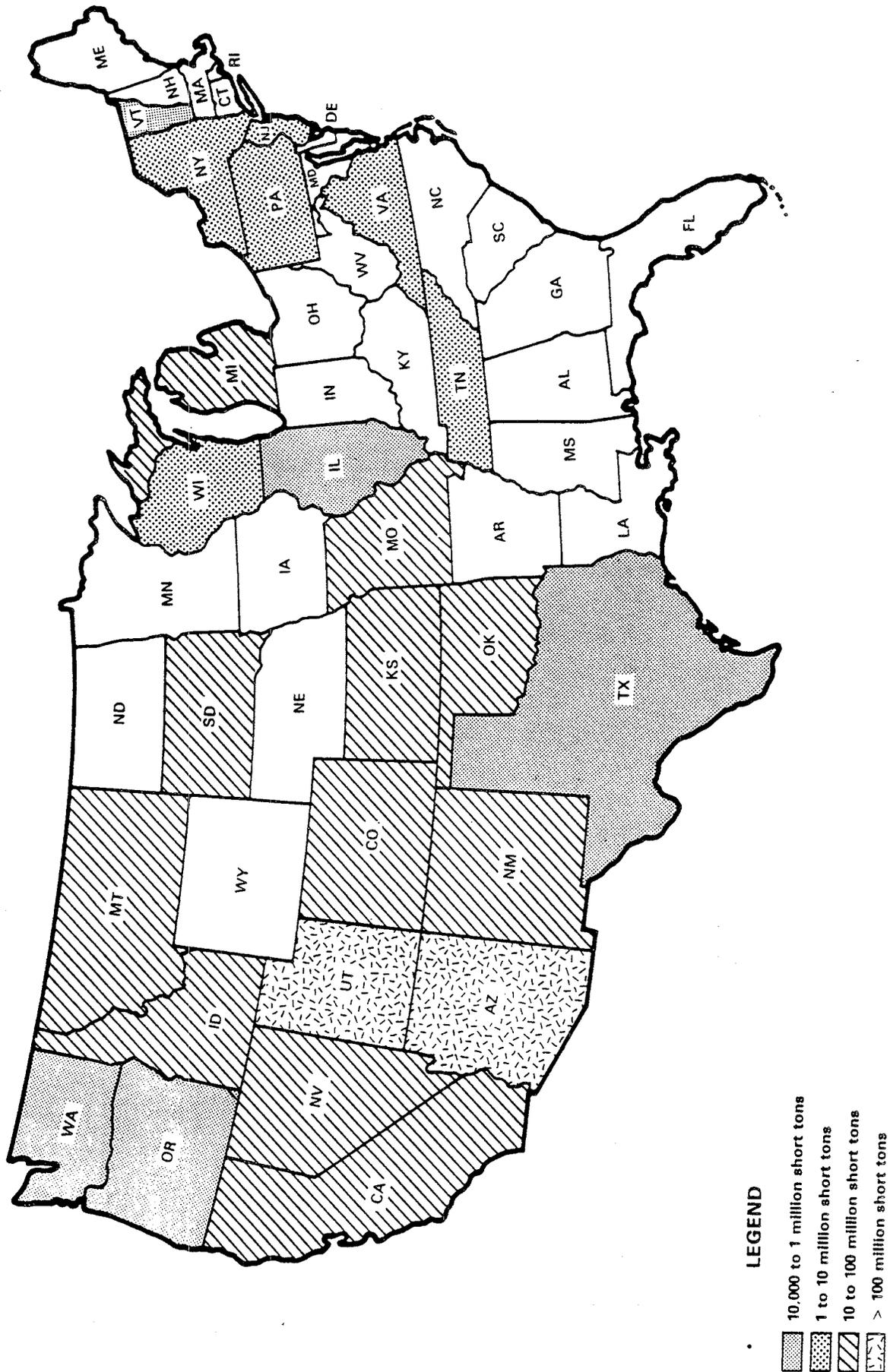


TABLE 4. - Amount of mill tailings produced during the period 1920-29 from lode-mine operations

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Arizona:			
Cochise.....	Cu.....	53	8,062
Gila.....	Cu.....	39	65,359
Graham.....	Pb.....	2	20
Greenlee.....	Cu.....	12	10,314
Maricopa.....	Pb-Au-Ag-Cu....	15	55
Mohave.....	Au.....	57	1,216
Pima.....	Cu.....	59	13,479
Pinal.....	Cu.....	46	23,252
Santa Cruz.....	Pb-Ag-Zn.....	38	66
Yavapai.....	Cu.....	62	1,693
Yuma.....	Cu-Au.....	22	120
Total.....		405	123,636
California:			
Amador.....	Au.....	23	2,055
Butte.....	Au.....	6	29
Calaveras.....	Au-Cu.....	36	1,287
El Dorado.....	Au.....	20	30
Inyo.....	Pb-Ag-Au.....	28	78
Kern.....	Au.....	30	181
Los Angeles....	Zn-Ag-Pb.....	1	25
Mariposa.....	Au.....	19	171
Mono.....	Au-Ag.....	10	11
Napa.....	Ag-Au.....	1	25
Nevada.....	Au.....	22	2,099
Placer.....	Au.....	9	36
Plumas.....	Cu.....	13	5,690
San Bernardino.	Ag-Au.....	38	483
Shasta.....	Zn-Cu.....	17	221
Sierra.....	Au.....	16	383
Siskiyou.....	Au.....	18	24
Trinity.....	Au.....	9	14
Tuolumne.....	Au.....	41	240
Total.....		357	13,082
Colorado:			
Boulder.....	Au-Ag.....	46	103
Clear Creek....	Ag-Au-Pb.....	59	288
Custer.....	Pb.....	8	255
Dolores.....	Zn-Pb-Ag.....	13	111
Eagle.....	Zn-Pb.....	8	179
Gilpin.....	Au-Ag.....	60	148
Gunnison.....	Zn-Pb-Au-Ag....	11	13
La Plata.....	Au-Ag.....	7	38
Lake.....	Zn-Pb.....	52	289
Ouray.....	Ag-Au-Pb.....	14	316

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 4. - Amount of mill tailings produced during the period 1920-29 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Colorado: - cont'd			
Pitkin.....	Pb-Ag.....	17	125
Saguache.....	Ag-Cu-Pb.....	12	487
San Juan.....	Zn-Pb-Ag.....	17	1,768
San Miguel.....	Au-Ag-Pb.....	19	3,157
Summit.....	Zn-Pb.....	27	249
Teller.....	Au.....	50	4,207
Total.....		420	11,733
Idaho:			
Blaine.....	Ag-Pb-Zn.....	20	155
Boise.....	Au.....	16	185
Bonner.....	Ag.....	10	134
Boundary.....	Pb-Ag.....	2	200
Butte.....	Pb-Ag.....	4	17
Custer.....	Ag-Cu-Pb.....	19	304
Idaho.....	Au.....	9	13
Lemhi.....	Au-Ag.....	23	147
Shoshone.....	Pb-Ag-Zn.....	49	12,823
Total.....		152	13,978
Illinois:			
Jo Davies.....	Zn-Pb.....	4	918
Kansas:			
Cherokee.....	Zn-Pb.....	70	33,501
Michigan:			
Houghton.....	Cu.....	11	62,387
Missouri:			
Iron.....	Pb.....	1	3,236
Jasper.....	Zn-Pb.....	70	4,983
Madison.....	Pb.....	3	15,836
St. Francois...	Pb.....	1	38,201
Total.....		75	62,256
Montana:			
Beaverhead.....	Ag-Pb-Cu-Au....	16	56
Broadwater.....	Au-Pb-Zn-Ag....	22	32
Cascade.....	Ag-Cu-Pb.....	17	1,133
Deer Lodge.....	Ag-Au.....	8	98
Fergus.....	Au-Ag.....	3	30
Granite.....	Ag-Zn.....	32	111
Jefferson.....	Ag-Au-Zn-Pb....	58	188
Judith Basin...	Pb-Ag-Zn.....	9	249

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 4. - Amount of mill tailings produced during the period 1920-29 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Montana: - cont'd			
Lewis & Clark..	Au-Ag.....	38	333
Lincoln.....	Pb-Zn-Ag.....	4	145
Madison.....	Au-Ag-Cu.....	66	181
Park.....	Au.....	2	217
Phillips.....	Au.....	2	188
Silver Bow.....	Cu-Ag-Zn.....	58	22,336
Total.....		335	25,297
Nevada:			
Clark.....	Zn-Pb-Au.....	35	27
Elko.....	Au-Ag.....	43	535
Esmeralda.....	Ag-Au.....	39	417
Eureka.....	Ag-Pb.....	15	222
Lander.....	Ag.....	25	297
Lincoln.....	Zn-Pb-Ag.....	17	138
Lyon.....	Cu.....	23	1,005
Mineral.....	Ag-Pb-Zn.....	41	357
Nye.....	Ag-Au.....	65	2,215
Pershing.....	Ag-Au.....	39	449
Storey.....	Au-Ag.....	23	2,407
Washoe.....	Ag-Pb.....	19	49
White Pine.....	Cu.....	37	32,457
Total.....		421	40,575
New Jersey:			
Sussex.....	Zn.....	1	2,109
New Mexico:			
Catron.....	Ag-Au.....	9	297
Colfax.....	Au.....	9	21
Grant.....	Cu.....	42	26,316
Hidalgo.....	Pb-Ag.....	18	20
San Miguel.....	Zn-Pb.....	1	489
Santa Fe.....	Zn-Pb-Ag.....	6	28
Socorro.....	Zn-Pb.....	11	35
Total.....		96	27,206
New York:			
St. Lawrence...	Zn.....	1	1,327
Oklahoma:			
Ottawa.....	Zn-Pb.....	85	76,766

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 4. - Amount of mill tailings produced during the period 1920-29 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Oregon:			
Baker.....	Au-Cu.....	22	229
Grant.....	Au-Ag.....	16	28
Total.....		38	257
Pennsylvania:			
Lebanon.....	Cu.....	1	8,695
South Dakota:			
Lawrence.....	Au.....	4	12,401
Pennington.....	Au.....	1	50
Total.....		5	12,451
Tennessee:			
Jefferson.....	Zn.....	1	2,706
Knox.....	Zn.....	1	2,618
Polk.....	Cu.....	3	3,544
Washington.....	Zn-Pb.....	1	84
Total.....		6	8,952
Texas:			
Presidio.....	Ag.....	2	584
Utah:			
Beaver.....	Pb-Zn-Ag.....	14	14
Box Elder.....	Ag.....	4	135
Juab.....	Pb-Ag.....	30	121
Piute.....	Au-Ag.....	4	26
Salt Lake.....	Cu-Pb.....	49	111,718
Summit.....	Pb-Ag-Zn.....	14	1,003
Toole.....	Pb-Ag-Zn.....	46	153
Utah.....	Pb-Ag.....	16	95
Wasatch.....	Pb-Ag-Zn.....	5	1,348
Total.....		182	114,613
Vermont:			
Orange.....	Cu-Ag.....	1	65
Virginia:			
Wythe.....	Zn-Pb.....	2	1,462

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 4. - Amount of mill tailings produced during the period 1920-29 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Washington:			
Okanagan.....	Ag.....	8	14
Pend Oreille...	Zn-Pb.....	4	147
Snobomish.....	Cu.....	2	182
Stevens.....	Zn-Pb-Ag.....	15	29
Whatcom.....	Au.....	2	52
Total.....		31	424
Wisconsin:			
Grant.....	Zn-Pb.....	3	706
Iowa.....	Zn-Pb.....	14	1,363
Lafayette.....	Zn-Pb.....	15	4,593
Total.....		31	6,662
National Total.....		2,732	648,936

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 5. - Amount of mill tailings produced during the period 1930-39 from lode-mine operations

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Arizona:			
Cochise.....	Cu.....	62	1,042
Gila.....	Cu.....	74	40,586
Greenlee.....	Cu.....	11	3,372
Maricopa.....	Au.....	59	222
Mohave.....	Au.....	90	2,102
Pima.....	Cu-Au.....	79	32,894
Pinal.....	Cu-Au.....	93	9,765
Santa Cruz.....	Ag-Pb-Zn-Ag....	67	779
Yavapai.....	Cu-Au-Ag.....	76	2,555
Yuma.....	Cu-Au.....	74	59
Total.....		685	93,376
California:			
Amador.....	Au.....	52	2,148
Butte.....	Au.....	29	100
Calaveras.....	Au.....	63	2,363
El Dorado.....	Au.....	62	1,032
Imperial.....	Au.....	66	132
Inyo.....	Au.....	85	201
Kern.....	Au-Ag.....	54	2,336
Los Angeles....	Au.....	12	98
Madera.....	Au.....	19	22
Mariposa.....	Au.....	92	380
Mono.....	Au-Ag.....	25	428
Napa.....	Ag-Au.....	1	75
Nevada.....	Au.....	42	5,273
Placer.....	Au.....	39	369
Plumas.....	Cu-Au.....	25	1,905
Riverside.....	Au-Pb.....	44	45
San Bernardino.	Au-Ag.....	41	173
Shasta.....	Au.....	39	1,873
Sierra.....	Au.....	21	420
Siskiyou.....	Au.....	63	508
Trinity.....	Au.....	29	42
Tuolumne.....	Au.....	79	159
Yuba.....	Au.....	11	67
Total.....		993	20,149
Colorado:			
Boulder.....	Au.....	85	494
Clear Creek....	Au.....	75	966
Dolores.....	Zn-Pb-Ag-Au....	8	67
Eagle.....	Zn.....	3	216
Gilpin.....	Au.....	69	1,342
Gunnison.....	Au.....	25	32

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 5. - Amount of mill tailings produced during the period 1930-39 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Colorado: - cont'd			
La Plata.....	Au-Ag.....	15	76
Lake.....	Au.....	82	369
Mineral.....	Ag.....	10	79
Ouray.....	Au-Ag.....	16	563
Park.....	Au.....	33	832
Pitkin.....	Ag-Pb.....	7	81
Rio Grande.....	Au.....	1	218
San Juan.....	Au-Ag-Pb.....	20	1,939
San Miguel.....	Au-Ag-Pb.....	28	727
Summit.....	Au-Zn-Pb-Ag....	29	30
Teller.....	Au.....	77	4,298
Total.....		583	12,329
Idaho:			
Blaine.....	Zn-Pb-Ag.....	30	190
Boise.....	Au.....	53	231
Bonner.....	Pb-Ag.....	11	145
Boundary.....	Pb-Ag.....	4	28
Custer.....	Pb-Ag.....	36	147
Elmore.....	Au.....	19	357
Idaho.....	Au.....	65	421
Lemhi.....	Au-Ag-Cu.....	52	3,237
Owyhee.....	Au-Ag.....	35	91
Shoshone.....	Pb-Ag-Zn.....	49	11,353
Valley.....	Au-Ag.....	9	391
Total.....		363	16,591
Kansas:			
Cherokee.....	Zn-Pb.....	50	29,502
Michigan:			
Houghton.....	Cu.....	4	28,271
Missouri:			
Iron.....	Pb.....	1	312
Jasper.....	Zn-Pb.....	86	4,448
Madison.....	Pb.....	1	2,386
St. Francois...	Pb.....	4	37,330
Washington.....	Pb.....	2	210
Total.....		94	44,686
Montana:			
Beaverhead.....	Au.....	49	228
Broadwater.....	Au.....	69	241
Cascade.....	Ag-Au.....	18	177
Deer Lodge.....	Au.....	25	140

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 5. - Amount of mill tailings produced during the period 1930-39 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Montana: - cont'd			
Fergus.....	Au.....	15	140
Granite.....	Au-Ag-Zn.....	68	577
Jefferson.....	Ag-Au-Pb-Zn....	96	619
Lewis & Clark..	Au.....	62	1,058
Lincoln.....	Au.....	10	72
Madison.....	Au.....	81	595
Park.....	Au.....	7	351
Phillips.....	Au.....	5	619
Powell.....	Au.....	25	31
Sanders.....	Pb-Zn.....	8	272
Silver Bow.....	Cu-Ag.....	55	16,158
Total.....		593	21,278
Nevada:			
Churchill.....	Au-Ag.....	32	21
Clark.....	Au-Ag.....	64	418
Elko.....	Cu-Au.....	64	630
Esmeralda.....	Au-Ag.....	42	1,673
Eureka.....	Au.....	30	68
Humbolt.....	Au.....	54	764
Lander.....	Au-Ag.....	65	77
Lincoln.....	Zn-Pb-Ag.....	68	968
Lyon.....	Au.....	58	474
Mineral.....	Au.....	73	52
Nye.....	Au-Ag-Pb-Zn....	90	856
Pershing.....	Au-Ag.....	69	138
Storey.....	Au-Ag.....	46	2,085
White Pine.....	Cu-Au.....	97	33,184
Total.....		852	41,408
New Jersey:			
Sussex.....	Zn.....	1	1,572
New Mexico:			
Catron.....	Au-Ag.....	12	434
Colfax.....	Au.....	8	67
Grant.....	Cu-Zn.....	81	23,893
Hidalgo.....	Cu-Au.....	35	339
San Miguel.....	Zn-Pb-Au.....	1	1,211
Socorro.....	Au.....	16	70
Total.....		153	26,014
New York:			
St. Lawrence...	Zn-Pb.....	2	2,700

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 5. - Amount of mill tailings produced during the period 1930-39 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Oklahoma:			
Ottawa.....	Zn-Pb.....	63	65,410
Oregon:			
Baker.....	Au.....	30	222
Grant.....	Au.....	17	39
Jackson.....	Au.....	33	64
Josephine.....	Au.....	23	64
Lane.....	Au.....	6	25
Total.....		109	414
Pennsylvania:			
Lebanon.....	Cu.....	1	8,917
South Carolina:			
Lancaster.....	Au.....	2	299
South Dakota:			
Lawrence.....	Au.....	10	15,038
Pennington.....	Au.....	8	68
Total.....		18	15,106
Tennessee:			
Jefferson.....	Zn.....	2	3,079
Knox.....	Zn.....	1	2,918
Polk.....	Cu-Zn.....	5	5,502
Washington.....	Zn-Pb.....	3	512
Total.....		11	12,011
Texas:			
Presidio.....	Ag.....	4	634
Utah:			
Juab.....	Zn-Pb-Ag.....	32	17
Piute.....	Au.....	11	69
Salt Lake.....	Cu-Au.....	31	120,257
Summit.....	Pb-Ag-Zn.....	7	779
Toole.....	Pb-Zn-Au-Ag....	49	1,635
Utah.....	Pb-Ag-Zn.....	25	90
Wasatch.....	Ag-Zn-Pb.....	7	537
Total.....		162	123,384
Virginia:			
Orange.....	Au.....	1	25
Wythe.....	Zn-Pb.....	2	4,152
Total.....		3	4,177

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 5. - Amount of mill tailings produced during the period 1930-39 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Washington:			
Chelan.....	Cu-Au.....	6	1,126
Ferry.....	Au.....	19	499
Okanagan.....	Au-Ag.....	26	77
Pend Oreille...	Zn-Pb.....	5	885
Stevens.....	Au-Ag.....	24	21
Whatcom.....	Au.....	5	68
Total.....		85	2,676
Wisconsin:			
Lafayette.....	Zn-Pb.....	50	2,329
National Total.....		4,881	573,233

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

FIGURE 36. - Map showing the tailings produced between 1940 and 1949

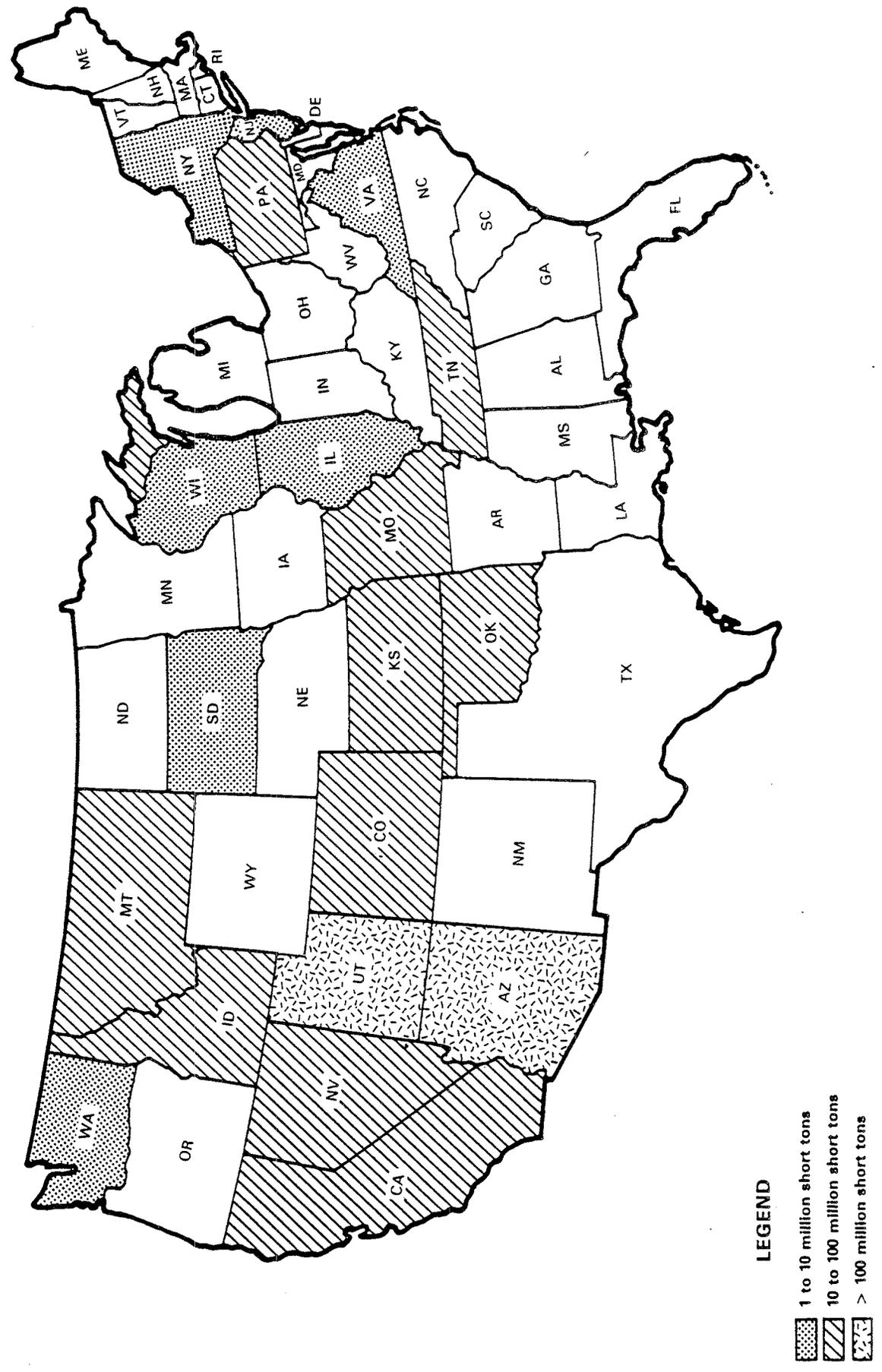


TABLE 6. - Amount of mill tailings produced during the period 1940-49 from lode-mine operations

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Arizona:			
Cochise.....	Zn-Pb.....	37	1,327
Gila.....	Cu.....	48	79,864
Graham.....	Pb-Zn.....	10	46
Greenlee.....	Cu.....	12	96,579
Maricopa.....	Au.....	49	172
Mohave.....	Au-Zn-Pb.....	93	877
Pima.....	Cu.....	56	72,653
Pinal.....	Cu.....	54	21,463
Santa Cruz.....	Zn-Pb-Ag.....	49	558
Yavapai.....	Cu-Zn.....	88	9,787
Yuma.....	Pb-Ag.....	63	95
Total.....		559	283,421
California:			
Amador.....	Au.....	23	1,710
Butte.....	Au-Zn.....	14	194
Calaveras.....	Au-Cu-Zn.....	43	2,150
El Dorado.....	Au.....	50	85
Inyo.....	Pb-Zn-Ag-Au....	71	282
Kern.....	Au-Ag.....	97	1,509
Mariposa.....	Au-Zn.....	53	393
Mono.....	Au-Ag.....	36	527
Nevada.....	Au.....	32	2,991
Placer.....	Au.....	24	232
Plumas.....	Cu-Au.....	25	766
San Bernardino.	Au-Ag.....	32	105
Shasta.....	Cu-Pb-Au.....	26	822
Sierra.....	Au.....	17	242
Siskiyou.....	Cu-Au.....	50	320
Tuolumne.....	Au.....	42	751
Total.....		635	13,079
Colorado:			
Boulder.....	Au-Ag.....	99	252
Clear Creek....	Au-Ag-Pb.....	77	495
Dolores.....	Zn-Pb.....	6	198
Eagle.....	Zn.....	5	1,061
Gilpin.....	Au-Pb.....	51	69
Gunnison.....	Zn-Pb.....	19	54
Lake.....	Zn-Pb-Au.....	45	1,771
Mineral.....	Ag-Pb.....	7	227
Ouray.....	Au-Pb-Zn-Ag....	19	300
Park.....	Au-Zn.....	21	349

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 6. - Amount of mill tailings produced during the period 1940-49 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Colorado: - cont'd			
Pitkin.....	Ag-Pb-Zn.....	5	71
Rio Grande.....	Au.....	1	73
San Juan.....	Pb-Au-Ag-Zn....	31	1,815
San Miguel.....	Au-Pb-Zn-Ag....	21	1,944
Summit.....	Zn-Pb.....	32	312
Teller.....	Au.....	99	2,381
Total.....		538	11,372
Idaho:			
Blaine.....	Zn-Pb-Ag.....	32	606
Bonner.....	Pb-Ag.....	10	71
Boundary.....	Pb-Ag.....	2	169
Custer.....	Pb-Ag-Zn.....	30	312
Elmore.....	Au-Ag.....	13	426
Idaho.....	Au.....	58	80
Lemhi.....	Au-Ag-Cu-Pb....	44	355
Owyhee.....	Zn-Ag-Au.....	15	201
Shoshone.....	Pb-Zn-Ag.....	61	21,577
Valley.....	Au-Ag.....	4	2,846
Total.....		269	26,643
Illinois:			
Hardin ^{2/}	Zn-Pb.....	23	1,317
Jo Davies.....	Zn-Pb.....	8	1,249
Total.....		31	2,566
Kansas:			
Cherokee.....	Zn-Pb.....	82	32,171
Kentucky:			
Crittenden.....	Zn-Pb.....	11	79
Livingston.....	Zn-Pb.....	10	87
Owen.....	Zn-Pb.....	4	80
Total.....		25	246
Michigan:			
Houghton.....	Cu.....	12	44,580
Missouri:			
Jasper ^{3/}	Zn-Pb.....	75	12,428
Jefferson.....	Pb-Zn.....	3	167
Lawrence.....	Zn-Pb.....	6	900

- ^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.
^{2/} Lead-Zinc are Recovered as byproducts of Fluorspar operations.
^{3/} Undistributed Tri-State tonnage assigned to Jasper Counties.

TABLE 6. - Amount of mill tailings produced during the period 1940-49 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Missouri: - cont'd			
Madison.....	Pb-Cu.....	5	4,245
Moniteau.....	Zn-Pb.....	4	95
Newton.....	Zn-Pb.....	5	669
St. Francois...	Pb.....	7	57,624
Washington.....	Pb.....	8	215
Total.....		113	76,343
Montana:			
Broadwater.....	Au-Zn.....	53	189
Cascade.....	Au-Zn-Pb.....	10	429
Fergus.....	Au.....	6	158
Granite.....	Zn-Pb-Ag.....	56	117
Jefferson.....	Zn-Pb-Ag-Au....	84	168
Lewis & Clark..	Pb-Zn-Ag-Au....	64	691
Lincoln.....	Zn-Pb-Au.....	7	123
Madison.....	Au-Zn-Pb.....	66	278
Mineral.....	Zn-Pb-Ag.....	4	58
Park.....	Au-Cu.....	7	592
Phillips.....	Au-Ag.....	2	410
Sanders.....	Pb-Zn.....	6	102
Silver Bow.....	Cu-Zn-Ag.....	50	32,619
Total.....		415	35,934
Nevada:			
Churchill.....	Ag-Au.....	28	110
Clark.....	Au-Ag.....	49	278
Elko.....	Cu.....	55	444
Esmeralda.....	Au-Ag.....	65	630
Eureka.....	Zn.....	8	57
Humboldt.....	Au.....	42	2,130
Lander.....	Au-Cu.....	43	1,331
Lincoln.....	Zn-Pb.....	36	1,440
Lyon.....	Au-Ag.....	47	94
Nye.....	Au-Ag.....	36	268
Pershing.....	Au-Ag.....	54	899
Storey.....	Au-Ag.....	46	1,557
White Pine.....	Cu-Au.....	97	56,921
Total.....		606	66,159
New Jersey:			
Sussex.....	Zn.....	2	1,206

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 6. - Amount of mill tailings produced during the period 1940-49 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
New Mexico:			
Catron.....	Ag-Au.....	9	123
Grant.....	Cu-Zn.....	68	67,859
Hidalgo.....	Cu.....	19	735
Santa Fe.....	Cu-Au.....	6	54
Socorro.....	Pb-Zn.....	11	406
Total.....		113	69,177
New York			
Lawrence.....	Zn-Pb.....	3	3,805
Oklahoma:			
Ottawa.....	Zn-Pb.....	22	96,505
Oregon:			
Baker.....	Au-Ag.....	22	65
Grant.....	Au-Ag.....	14	55
Josephine.....	Au.....	20	44
Total.....		56	164
Pennsylvania:			
Lebanon.....	Cu.....	1	18,226
South Carolina:			
Lancaster.....	Au.....	3	270
South Dakota:			
Lawrence.....	Au.....	6	8,728
Pennington.....	Au.....	4	68
Total.....		10	8,796
Texas:			
Persidio.....	Ag.....	2	280
Tennessee:			
Jefferson.....	Zn.....	6	6,615
Knox.....	Zn.....	3	4,206
Polk.....	Cu-Zn.....	6	8,720
Total.....		15	19,541
Utah:			
Beaver.....	Zn-Pb-Ag.....	16	40
Juab.....	Pb-Zn-Ag.....	27	471

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 6. - Amount of mill tailings produced during the period 1940-49 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Salt Lake.....	Cu-Au.....	27	269,001
San Juan.....	Cu.....	2	199
Summit.....	Pb-Zn-Ag.....	11	2,003
Tooele.....	Pb-Zn-Ag-Au....	44	833
Utah.....	Pb-Zn-Ag.....	21	23
Wasatch.....	Pb-Zn-Ag-Au....	4	504
Total.....		152	273,074
Vermont:			
Orange.....	Cu.....	1	791
Virginia:			
Wythe.....	Zn-Pb.....	2	4,354
Washington:			
Chelan.....	Cu-Au-Zn.....	5	5,576
Ferry.....	Au-Ag.....	11	591
Okanogan.....	Pb-Ag-Zn.....	12	111
Pend Oreille...	Zn-Pb.....	3	2,706
Stevens.....	Zn-Pb.....	16	341
Total.....		47	9,325
Wisconsin:			
Grant.....	Zn-Pb.....	10	186
Iowa.....	Zn-Pb.....	36	1,226
Lafayette.....	Zn-Pb.....	46	2,190
Total.....		92	3,602
National Total.....		3,806	1,101,630

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 7. - Amount of mill tailings produced during the period 1950-59 from lode-mine operations

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Arizona:			
Cochise.....	Cu.....	27	24,055
Gila.....	Cu.....	21	102,255
Graham.....	Zn-Pb.....	7	110
Greenlee.....	Cu.....	4	140,748
Mohave.....	Cu-Zn.....	20	82
Pima.....	Cu.....	32	120,515
Pinal.....	Cu.....	36	77,870
Santa Cruz.....	Zn-Pb.....	30	384
Yavapai.....	Cu-Zn.....	57	16,391
Total.....		234	482,410
California:			
Amador.....	Au-Cu.....	7	111
Calaveras.....	Zn-Cu.....	5	44
El Dorado.....	Au.....	9	91
Inyo.....	Pb-Zn-Ag.....	29	715
Kern.....	Au-Ag.....	18	47
Nevada.....	Au.....	8	876
Shasta.....	Zn-Cu-Pb-Ag....	10	27
Sierra.....	Au.....	12	232
Siskiyou.....	Au-Ag.....	8	354
Total.....		106	2,497
Colorado:			
Cleer Creek....	Pb-Zn-Au-Ag....	22	133
Dolores.....	Zn-Pb-Ag.....	4	193
Eagle.....	Zn-Pb.....	2	1,920
Gunnison.....	Zn-Pb-Ag-Cu....	5	168
Lake.....	Zn-Pb.....	13	628
Mineral.....	Pb-Zn-Ag.....	7	316
Ouray.....	Pb-Zn-Cu-Au-Ag.	17	264
San Juan.....	Pb-Zn-Ag-Au-Cu.	28	623
San Miguel.....	Zn-Pb-Cu-Ag-Au.	9	3,804
Summit.....	Pb-Zn.....	29	57
Teller.....	Au.....	13	1,146
Total.....		149	9,252
Idaho:			
Blaine.....	Pb-Zn-Ag.....	20	536
Bonner.....	Pb-Ag-Zn.....	8	51
Custer.....	Pb-Zn-Ag.....	22	358
Lemhi.....	Cu.....	14	1,904
Shoshone.....	Pb-Zn-Ag.....	67	15,089
Valley.....	Au-Ag.....	1	1,213
Total.....		132	19,151

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 7. - Amount of mill tailings produced during the period 1950-59 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Illinois:			
Hardin ^{2/}	Zn-Pb.....	17	3,143
Jo Davies.....	Zn-Pb.....	7	4,773
Total.....		24	7,916
Kansas:			
Cherokee.....	Zn-Pb.....	67	9,832
Kentucky:			
Crittenden.....	Zn-Pb.....	2	214
Livingston.....	Zn-Pb.....	4	201
Total.....		6	415
Michigan:			
Houghton.....	Cu.....	13	39,674
Ontonagon.....	Cu.....	1	22,014
Total.....		14	61,688
Missouri:			
Jasper.....	Zn-Pb.....	18	1,879
Madison.....	Pb-Cu.....	7	6,523
Newton.....	Zn.....	4	522
St. Francois...	Pb.....	1	63,205
Washington.....	Pb.....	9	2,193
Total.....		39	74,322
Montana:			
Granite.....	Zn-Ag-Pb.....	14	121
Lewis & Clark..	Pb-Zn.....	22	72
Madison.....	Cu-Au.....	26	33
Missoula.....	Pb.....	3	18
Park.....	Cu-Au.....	5	54
Sanders.....	Pb-Zn.....	4	75
Silver Bow.....	Cu-Zn.....	22	67,413
Total.....		96	67,786
Nevada:			
Clark.....	Au.....	15	53
Elko.....	Au.....	18	39
Esmeralda.....	Ag-Au.....	8	69
Humboldt.....	Au.....	8	103
Lander.....	Au.....	16	1,530
Lincoln.....	Zn-Pb.....	18	773

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.
^{2/} Lead-Zinc was recovered as byproducts of Fluorspar operations.

TABLE 7. - Amount of mill tailings produced during the period 1950-59 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Nevada: - cont'd			
Lyon.....	Cu.....	3	25,392
Mineral.....	Ag-Au.....	10	96
White Pine.....	Cu.....	50	61,365
Total.....		146	89,420
New Jersey:			
Sussex.....	Zn.....	1	312
New Mexico:			
Grant.....	Cu-Zn.....	28	69,538
Hidalgo.....	Cu.....	11	620
Socorro.....	Pb-Zn.....	15	425
Total.....		54	70,583
New York:			
St. Lawrence...	Zn.....	2	4,863
N. Carolina:			
Ashe.....	Cu.....	1	621
Oklahoma:			
Ottawa.....	Zn-Pb.....	74	18,449
Pennsylvania:			
Lebanon.....	Cu.....	1	15,882
Lehigh.....	Zn.....	1	592
Total.....		2	16,474
South Dakota:			
Lawrence.....	Au.....	3	15,736
Tennessee:			
Hancock.....	Zn.....	1	728
Jefferson.....	Zn.....	6	8,065
Knox.....	Zn.....	1	3,825
Polk.....	Cu-Zn.....	5	10,113
Total.....		13	22,731

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 7. - Amount of mill tailings produced during the period 1950-59 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Utah:			
Beaver.....	Cu-Ag-Pb-Zn....	4	38
Juab.....	Zn-Pb-Ag.....	15	297
Salt Lake.....	Cu.....	8	272,500
Summit.....	Zn-Pb-Ag.....	12	453
Tooele.....	Pb-Zn-Ag.....	19	233
Wasatch.....	Zn-Pb-Au.....	4	669
Total.....		62	274,190
Vermont:			
Orange.....	Cu.....	1	1,949
Virginia:			
Rockingham.....	Zn.....	1	553
Wythe.....	Zn-Pb.....	1	4,947
Total.....		2	5,500
Washington:			
Chelan.....	Cu-Au.....	5	2,969
Ferry.....	Au.....	2	452
Okanogan.....	Cu-Au.....	5	33
Pend Oreille...	Zn-Pb.....	6	7,175
Stevens.....	Zn-Pb.....	17	2,283
Total.....		35	12,912
Wisconsin:			
Grant.....	Zn-Pb.....	4	321
Iowa.....	Zn-Pb.....	4	266
Lafayette.....	Zn-Pb.....	17	4,801
Total.....		25	5,388
National Total.....		1,288	1,274,397

- ^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.
^{2/} Lead-Zinc was recovered as byproducts of Fluorspar operations.

FIGURE 38. - Map showing the tailings produced between 1960 and 1969

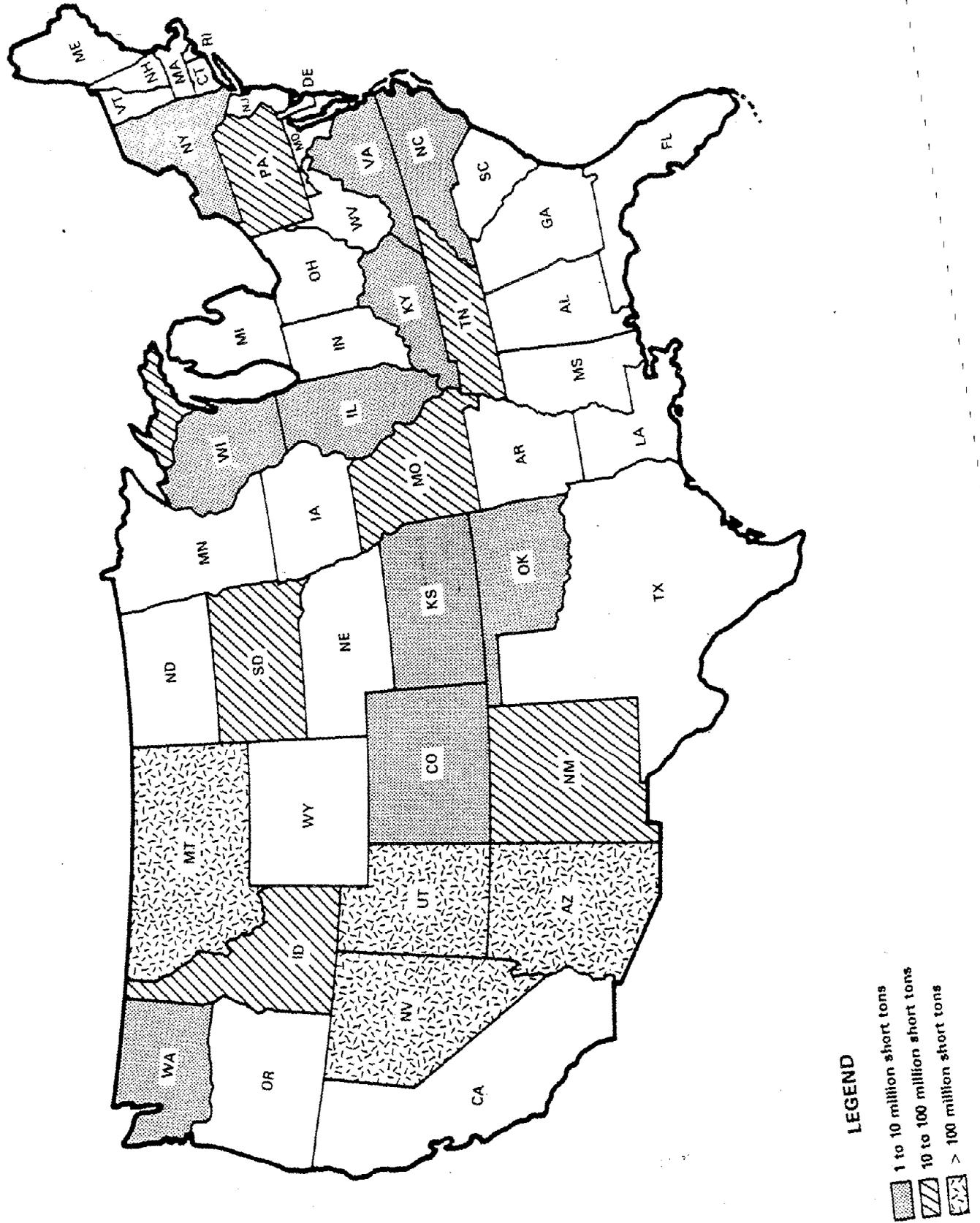


TABLE 8. - Amount of mill tailings produced during the period 1960-69 from lode-mine operations

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Arizona:			
Cochise.....	Cu.....	10	49,032
Coconino.....	Cu.....	3	737
Gila.....	Cu.....	16	110,598
Graham.....	Cu-Pb-Zn.....	4	291
Greenlee.....	Cu.....	3	161,667
Mohave.....	Cu.....	9	28,178
Pima.....	Cu.....	18	277,311
Pinal.....	Cu.....	19	198,809
Santa Cruz.....	Zn-Pb-Ag.....	8	83
Yavapai.....	Cu-Zn.....	27	25,990
Yuma.....	Cu.....	7	982
Total.....		124	853,678
California:			
Humboldt.....	Cu-Zn-Ag-Pb....	2	30
Inyo.....	Au.....	10	140
Nevada.....	Au.....	6	31
Sierra.....	Au-Ag.....	7	85
Siskiyou.....	Cu-Au-Zn.....	6	89
Total.....		31	375
Colorado:			
Clear Creek....	Ag-Pb-Zn.....	10	37
Dolores.....	Zn-Pb-Ag.....	2	185
Eagle.....	Zn-Pb.....	1	1,967
Gunnison.....	Zn-Pb-Ag-Cu....	6	310
Mineral.....	Zn-Pb-Ag.....	3	391
Ouray.....	Zn-Pb-Cu-Ag-Au.	7	1,075
Pitkin.....	Ag-Pb.....	2	329
San Juan.....	Pb-Zn.....	13	1,245
San Miguel.....	Zn-Pb-Cu-Ag-Au.	4	2,875
Teller.....	Au.....	12	93
Total.....		60	8,508
Idaho:			
Blaine.....	Pb-Ag-Zn.....	7	210
Custer.....	Ag-Pb-Zn.....	13	520
Lemhi.....	Cu.....	16	364
Shoshone.....	Ag-Pb-Zn.....	26	11,475
Total.....		62	12,569

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 8. - Amount of mill tailings produced during the period 1960-69 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Illinois:			
Hardin ^{2/}	Zn-Pb.....	12	2,409
Jo Davies.....	Zn.....	4	1,087
Total.....		16	3,496
Kansas:			
Cherokee.....	Zn-Pb.....	12	1,560
Kentucky:			
Crittenden.....	Zn.....	1	16
Livingston.....	Zn-Pb.....	2	1,110
Total.....		3	1,126
Maine:			
Hancock.....	Zn-Cu.....	1	259
Michigan:			
Houghton.....	Cu.....	8	20,482
Keewanaw.....	Cu.....	4	6,088
Ontonagon.....	Cu.....	2	52,188
Total.....		14	78,758
Missouri:			
Crawford.....	Pb.....	1	4,676
Iron.....	Pb.....	3	5,290
Madison.....	Pb-Cu.....	1	272
Reynolds.....	Pb-Zn.....	2	3,326
St. Francois...	Pb.....	1	28,942
Washington.....	Pb.....	3	7,919
Total.....		11	50,425
Montana:			
Granite.....	Zn-Ag.....	22	131
Mineral.....	Pb-Cu-Ag-Zn....	4	44
Silver Bow.....	Cu.....	11	124,841
Total.....		37	125,016

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.
^{2/} Lead-Zinc was recovered as byproducts of Fluorspar operations.

TABLE 8. - Amount of mill tailings produced during the period 1960-69 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Nevada:			
Elko.....	Cu-Pb-Ag.....	7	101
Eureka.....	Au.....	4	3,694
Humboldt.....	Au.....	7	1,950
Lander.....	Cu-Au.....	6	4,585
Lincoln.....	Zn-Pb-Ag.....	4	764
Lyon.....	Cu.....	4	60,289
White Pine.....	Cu.....	17	65,926
Total.....		49	137,309
New Mexico:			
Grant.....	Cu.....	27	75,998
Hidalgo.....	Cu.....	8	612
Socorro.....	Zn-Pb.....	9	129
Total.....		44	76,739
New York:			
St. Lawrence...	Zn.....	2	5,918
North Carolina:			
Ashe.....	Cu.....	1	752
Vance.....	Ag-Pb-Cu.....	1	628
Total.....		2	1,380
Oklahoma:			
Jackson.....	Cu.....	1	731
Ottawa.....	Zn-Pb.....	78	3,188
Total.....		79	3,919
Pennsylvania:			
Lebanon.....	Cu.....	1	6,312
Leigh.....	Zn.....	1	4,829
Total.....		2	11,141
South Dakota:			
Lawrence.....	Au.....	2	19,145
Tennessee:			
Hancock.....	Zn.....	1	3,023
Jefferson.....	Zn.....	7	21,263
Knox.....	Zn.....	2	5,604
Polk.....	Cu-Zn.....	5	14,190
Total.....		15	44,080

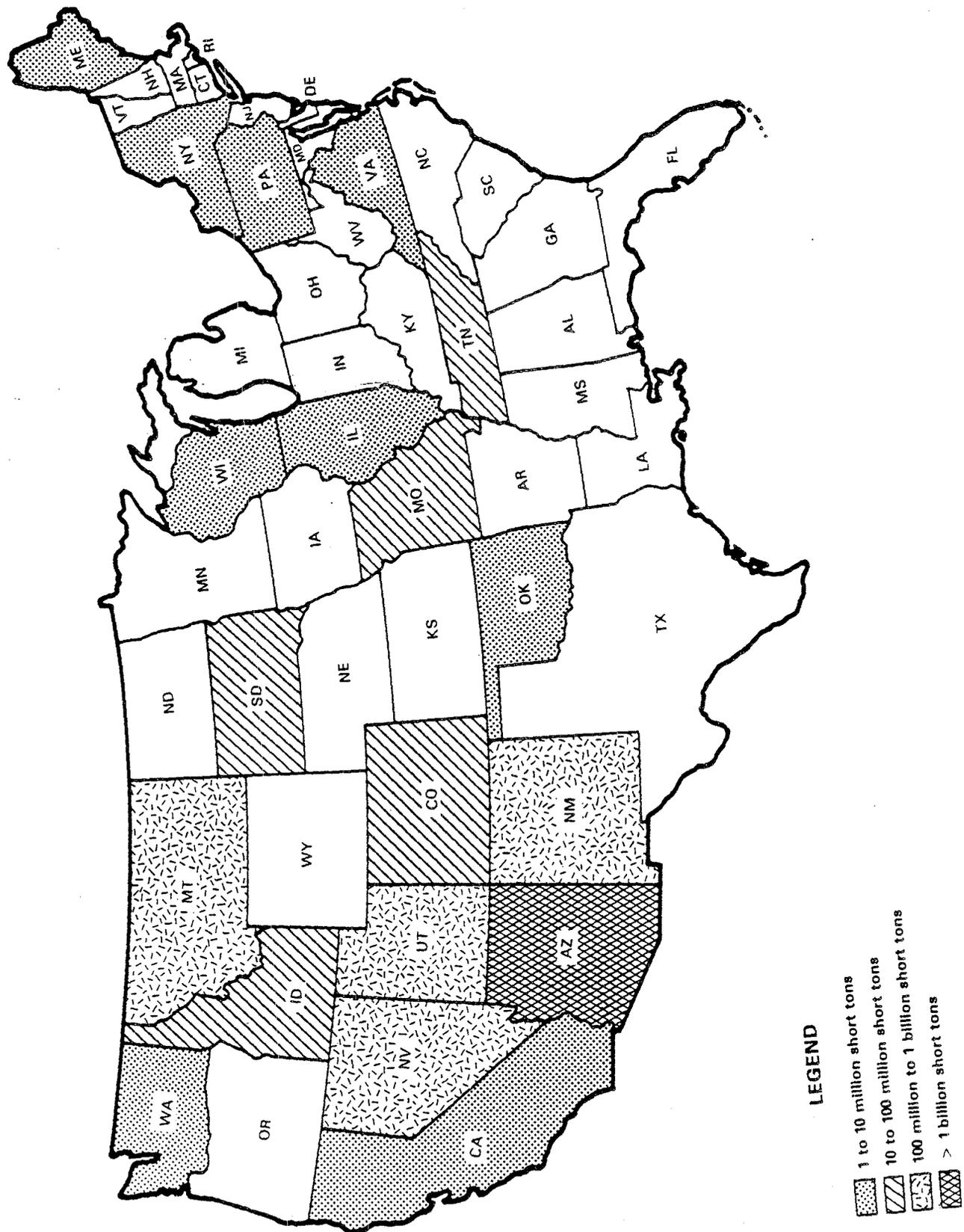
^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 8. - Amount of mill tailings produced during the period 1960-69 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Utah:			
Beaver.....	Cu.....	6	584
Salt Lake City.	Cu.....	9	280,091
San Juan.....	Cu.....	5	367
Summit.....	Zn-Pb-Ag.....	5	634
Tooele.....	Pb-Zn-Ag.....	7	182
Utah.....	Zn-Pb-Ag.....	3	114
Wasatch.....	Pb-Au-Zn-Ag-Cu.	2	844
Total.....		37	282,816
Virginia:			
Rockingham.....	Zn.....	1	681
Wythe.....	Zn-Pb.....	2	5,969
Total.....		3	6,650
Washington:			
Chelan.....	Au.....	2	387
Ferry.....	Au-Ag.....	3	709
Pend Oreille...	Zn-Pb.....	5	5,996
Stevens.....	Zn-Pb.....	5	2,253
Total.....		15	9,345
Wisconsin:			
Grant.....	Zn-Pb.....	4	804
Iowa.....	Zn-Pb.....	4	309
Lafayette.....	Zn-Pb.....	11	4,095
Total.....		19	5,208
National Total.....		640	1,739,420

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

FIGURE 39. - Map showing the tailings produced between 1970 and 1981



LEGEND

- 1 to 10 million short tons
- 10 to 100 million short tons
- 100 million to 1 billion short tons
- > 1 billion short tons

TABLE 9. - Amount of mill tailings produced during the period 1970-1981 from lode-mine operations

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Arizona:			
Cochise.....	Cu.....	4	21,864
Gila.....	Cu.....	11	245,143
Greenlee.....	Cu.....	5	267,709
Mohave.....	Cu.....	7	72,226
Pima.....	Cu.....	11	909,198
Pinal.....	Cu.....	14	361,752
Yavapai.....	Cu.....	11	79,257
Total.....		63	1,957,149
California:			
Alpin.....	Au-Ag.....	1	22
Calaveras.....	Au-Ag.....	2	30
Inyo.....	Cu.....	2	4,213
Total.....		5	4,265
Colorado:			
Boulder.....	Au-Ag.....	3	26
Clear Creek....	Cu-Ag-Au.....	6	23
Conejos.....	Ag-Au.....	1	35
Dolores.....	Ag-Zn-Pb-Cu....	2	145
Eagle.....	Zn.....	1	1,383
Gilpin.....	Au-Ag.....	5	12
Gunnison.....	Zn-Ag-Pb.....	2	23
Lake.....	Zn-Ag-Pb-Au....	2	2,407
Mineral.....	Ag.....	3	1,406
Ouray.....	Zn-Pb-Cu-Ag....	2	1,053
San Juan.....	Au-Zn-Ag-Pb....	7	2,031
San Miguel.....	Zn-Pb-Cu-Ag-Au.	1	2,396
Summit.....	Ag-Zn-Pb-Au....	2	16
Teller.....	Au.....	3	87
Total.....		40	11,043
Idaho:			
Adams.....	Cu-Ag.....	1	856
Custer.....	Ag-Zn-Pb.....	8	1,038
Owyhee.....	Ag-Au.....	1	3,275
Shoshone.....	Ag-Zn-Pb.....	23	16,483
Total.....		33	21,652
Illinois:			
Hardin ^{2/}	Zn-Pb.....	3	3,283
Jo Davies.....	Zn-Pb.....	4	729
Total.....		7	4,012

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.
^{2/} Lead-Zinc was recovered as byproducts of Fluorspar operations.

TABLE 9. - Amount of mill tailings produced during the period 1970-1981 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Kansas:			
Cherokee.....	Zn-Pb.....	2	60
Kentucky:			
Livingston.....	Zn.....	2	225
Maine:			
Hancock.....	Zn-Cu.....	2	1,309
Michigan:			
Houghton.....	Cu.....	1	233
Ontonogan.....	Cu.....	4	65,373
Total.....		5	65,606
Missouri:			
Crawford.....	Pb-Cu-Zn.....	1	3,465
Iron.....	Pb-Zn.....	3	35,264
Reynolds.....	Pb-Zn.....	3	36,048
St. Francois...	Pb.....	1	4,896
Washington.....	Pb-Zn-Cu.....	5	15,302
Total.....		13	94,975
Montana:			
Lincoln.....	Ag-Cu.....	1	567
Madison.....	Au-Ag-Cu.....	9	26
Mineral.....	Ag.....	2	51
Silver Bow.....	Cu-Ag.....	12	198,225
Total.....		24	198,869
Nevada:			
Elko.....	Au-Cu.....	6	1,995
Eureka.....	Au.....	7	9,554
Humboldt.....	Au.....	4	392
Lander.....	Au-Cu.....	6	21,786
Lincoln.....	Au-Ag-Zn.....	3	1,740
Lyon.....	Cu.....	1	56,225
Nye.....	Au.....	4	355
Pershing.....	Cu.....	4	314
Storey.....	Ag-Au.....	1	35
White Pine.....	Au-Ag.....	5	47,278
Total.....		41	139,674

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 9. - Amount of mill tailings produced during the period 1970-1981 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
New Mexico:			
Grant.....	Cu.....	11	266,060
Hidalgo.....	Cu.....	1	350
Sandoval.....	Cu.....	1	3,525
Santa Fe.....	Au-Cu.....	3	155
Socorro.....	Zn-Pb-Ag-Au....	1	10
Total.....		17	270,100
New York:			
St. Lawrence...	Zn.....	4	8,638
Oklahoma:			
Jackson.....	Cu.....	1	945
Ottawa.....	Zn-Pb.....	2	57
Total.....		3	1,002
Pennsylvania:			
Lebanon.....	Cu.....	1	2,043
Leigh.....	Zn.....	1	5,624
Total.....		2	7,667
South Dakota:			
Lawrence.....	Au.....	1	19,719
Tennessee:			
Grainger.....	Zn.....	1	1,203
Hancock.....	Zn.....	1	982
Jefferson.....	Zn.....	5	29,400
Knox.....	Zn.....	2	7,153
Polk.....	Cu-Zn.....	5	19,746
Smith.....	Zn.....	2	3,815
Total.....		16	62,299
Utah:			
Beaver.....	Cu.....	1	1,018
Grand.....	Cu.....	1	76
Salt Lake.....	Cu-Au.....	3	409,602
San Juan.....	Cu.....	2	938
Summit.....	Zn-Ag-Pb.....	1	447
Tooele.....	Cu-Au-Ag.....	2	2,061
Utah.....	Zn-Pb-Ag.....	4	1,102
Wasatch.....	Au-Cu-Pb-Ag-Zn.	1	296
Total.....		15	415,540

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

TABLE 9. - Amount of mill tailings produced during the period 1970-1981 from lode-mine operations - continued

State and county	Major Commodity	Number ^{1/} of mines	Mill tailings, 10 ³ tons
Virginia:			
Wythe.....	Zn-Pb.....	1	6,409
Washington:			
Ferry.....	Au-Ag.....	3	838
Pend Oreille...	Zn-Pb.....	3	1,843
Stevens.....	Zn-Pb.....	1	352
Total.....		7	3,033
Wisconsin:			
Grant.....	Zn.....	2	281
Iowa.....	Zn.....	1	99
Lafayette.....	Zn.....	2	3,780
Total.....		5	4,160
National Total.....		308	3,297,406

^{1/} Approximate number of mines contributing to the Mill Tailings Tonnages.

Type of Mill Tailings

The general type of mill tailings created was determined based on the gross value of the primary commodity(s) primarily produced in that particular county. An attempt was made to assign one major commodity type to each county, however, in many instances this was not possible. Where ore production in some counties included production of different commodities from separate mining operations or revenues from co- and by-products accounted for a significant amount of the recovered metal, more than one commodity was assigned to these counties. Furthermore, over the course of time as ore bodies have been exhausted and others developed the type of minerals produced in a county often shift (for example, from a gold production to a copper or lead-zinc production).

The type of tailings, based on gross value of the commodities, were further aggregated to fall within three broad categories of tailings types. The three types of tailings are: 1) copper; 2) zinc-lead-silver; and 3) gold-silver.

Copper tailings, for the purpose of this report, are defined as tailings produced from primary copper operations that account for the majority of the counties' total mineral production. In some instances, judgment was required in designating a county as primarily producing copper tailings when revenue credits from gold, silver, lead and zinc were significant. In certain instances these commodities were considered to be byproducts from copper operations and a copper tailings designation was assigned for the county.

Zinc-lead-silver tailings are a broad category encompassing a variety of ore types. Examples are zinc ore from Tennessee, lead ores from Missouri, lead-zinc ores from the 'Tri-State' region (Kansas, Missouri, and Oklahoma), and lead-zinc-silver from Idaho. Grouping each type of ore into a broad category enabled the quantification of lead-zinc tailings where silver was in some instances a co-product and then assigned this tailing type to that particular country.

Gold-silver tailings are defined as those tailings from mining done primarily for their precious metal content (gold and silver). Although a major portion of the production of these metals are as a byproduct of copper operations (as is the case of gold from the Bingham Canyon operation in Utah) designation of this type of tailings to other countries were made where the main production was from gold and silver operations.

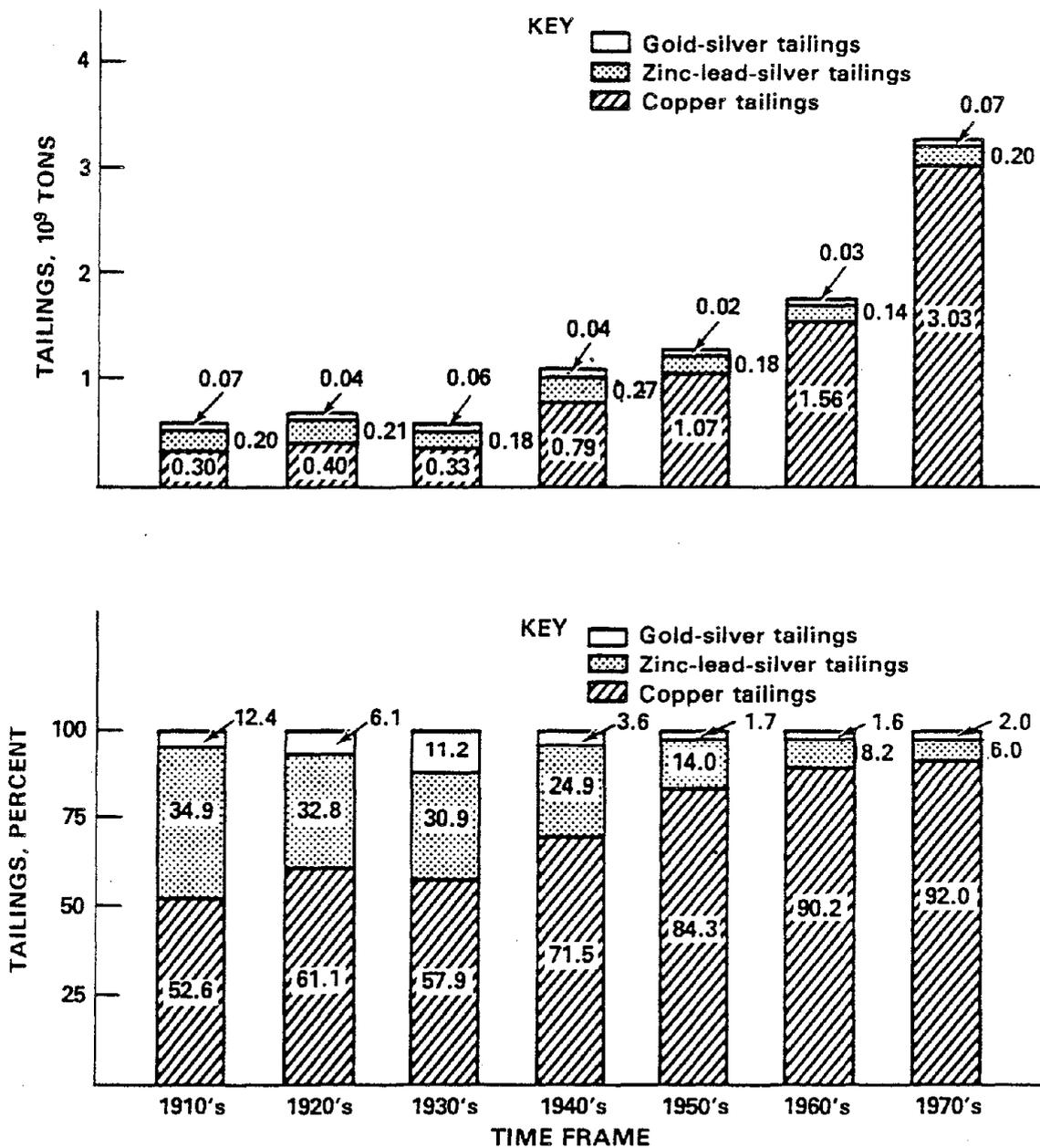
Based on these definitions, tonnages from each county were incorporated into one of the three categories of tailings type and summed over a decade.

Table 10 and Figure 40 illustrate the types of tailings produced.

TABLE 10. - Summary of mill tailings by commodity type

Period	Cu		Zn-Pb-Ag		Au-Ag	
	Tons	Pct	Tons	Pct	Tons	Pct
1910-19....	301,211	52.6	199,969	35.0	71,177	12.4
1920-29....	396,676	61.1	213,017	32.8	39,243	6.1
1930-39....	331,902	57.9	177,104	30.9	64,227	11.2
1940-49....	787,980	71.5	274,509	24.9	39,141	3.6
1950-59....	1,074,317	84.3	177,932	14.0	22,148	1.7
1960-69....	1,568,957	90.2	142,632	8.2	27,831	1.6
1970-81....	3,033,614	92.0	197,844	6.0	65,948	2.0
Total...	7,494,657	81.4	1,383,007	15.0	329,715	3.6

FIGURE 40. - Type of mill tailings created during 10-year periods expressed as a percentage and in billions of tons



The increase in the amount of tailings produced over time has been primarily caused by copper production which accounts for over 81 percent (nearly 7.5 billion tons) of tailings produced over the past 72 years. The main reason for this is the mining of lower grade material in conjunction with the increased demand for copper, thereby producing increasingly larger tonnages of mill tailings. The tailings produced from copper operations have increased 10 fold during the study period, from 300 million in the 1910's to 3 billion tons in the 1970's.

Tailings produced from zinc-lead-silver mines have, for the most part, remained rather constant over time with the exception of an increase during the war years of the 1940's. The amount of tailings produced during the first decade of this study and that produced between 1970 and 1981 are approximately the same. A little less than 200 million tons of tailings was generated in each of these period.

Fluctuations in the amount of gold-silver tailings can be correlated with to the rise in the selling prices of these precious metals. Most notable was the rise in the price of gold from \$20 to \$35 per ounce in the 1930's and its recent price increase of the late 1970's. In the early 1970's the price of gold was deregulated and allowed to fluctuate and the ban on ownership of gold was removed. This coupled with inflation caused the unprecedented rise in the gold price. Comparison of Table 10 with the annual production graph shown in Figure 3 also indicates that the grades of ores for gold and silver were also decreasing over this time frame 1930's to 1970's. Proportionally less tailings were produced per unit of production in the early years of this study as compared to the same ratio in recent years.

Mine-Mill Waste Material Analysis

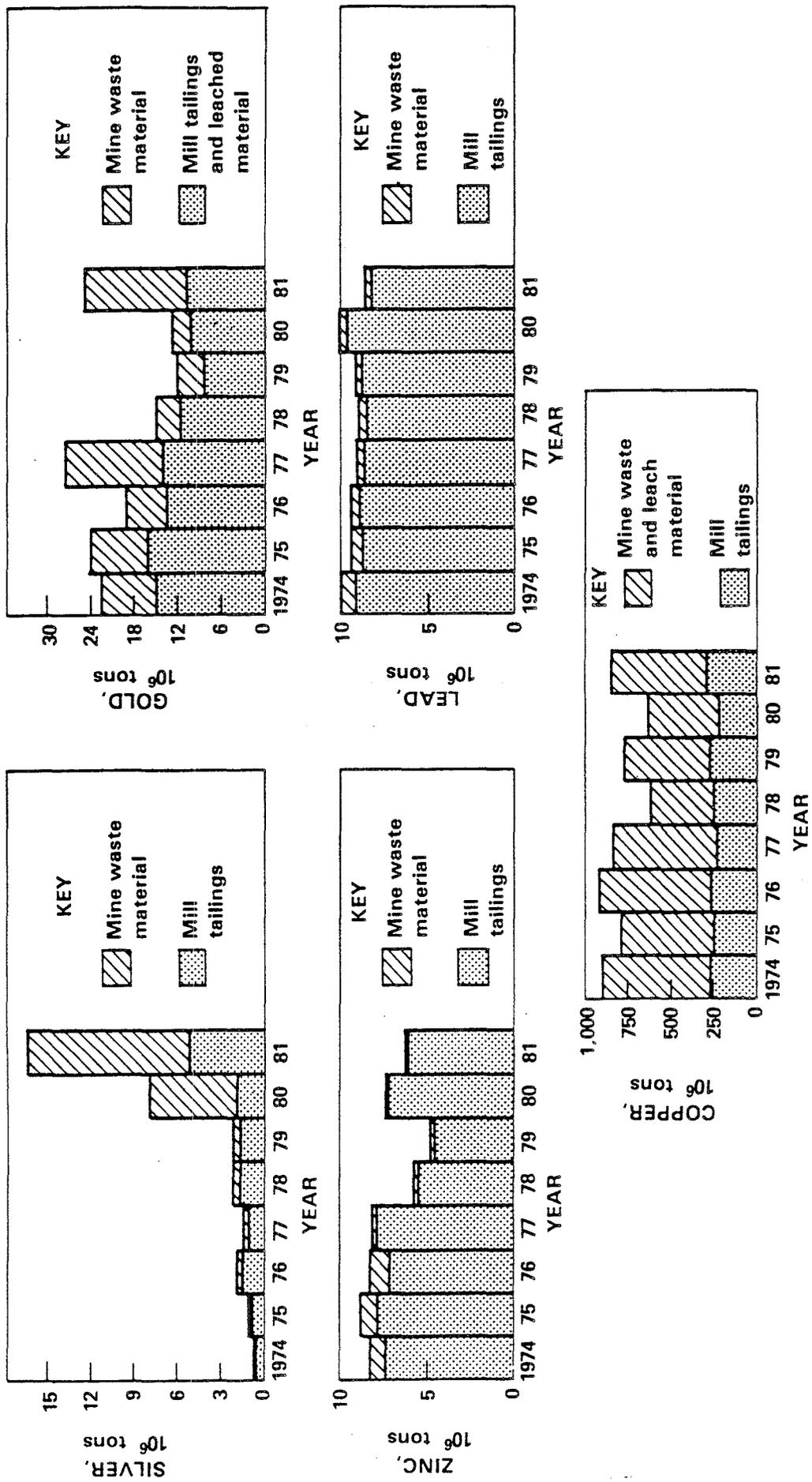
Mill tailings account for only a portion of the waste material produced from a mining operation. Waste material produced in the development of the mine site, and waste rock removed during production may substantially increase the total waste material produced from a mining venture. In the case of open-pit copper operations the mine waste material is quite significant.

Due to the lack of specific data for the years prior to 1974, summary of the pre-1974 mine waste material is not included in this report. For the time frame 1974 through 1981 data was available and is present in the following graphs. Figure 41 illustrates the relationship between mill tailings to mine waste material on a commodity basis over this 8 year period.

Copper is predominately mined by large open pit operations and consequently involves the removal of large volumes of waste rock. The mine waste to mill tailings ratio for copper over this period is approximately 3:1.

Fluctuation in the amount of waste material moved over time is influenced by economic conditions, as well as the development of new mining operations.

FIGURE 41. - Mine waste to mill tailings relationship for lode mine operations for the period of 1974 to 1981



Lead and zinc ores are taken from underground mines where a small amount of waste rock is removed along with the ore. The percentage of mine waste material to total material moved in lead mines and zinc mines accounts for only 3.1 and 6.1 percent respectively.

Gold and silver ores are mined by both surface and underground methods hence, producing varying quantities of mine waste material. The average ratio of mine waste to mill tailings for the time frame shown, 1974 to 1981, is 2.2 to 1 for silver and 1.8 to 1 for gold. There are wide variations in this ratio, that can be attributed to new mining operations resulting from sharp increases in the market price of these metals. This was the apparent case in 1980 when the average price of gold and silver increased to \$613/oz and \$21/oz respectively and resulting in a corresponding increase in mine waste. The large amount of mine waste in silver operations in 1980-81 is due to the preproduction development of recently opened silver open-pit mines.

Tailings Projections

In addition to the amount of mill tailings generated from a historic perspective, the continued production of the lode-mine commodities will continue to increase the amount of tailings. The majority of the tailings have been produced since the 1950's and indications are that this production trend will continue. A projection of the amount of tailings to be produced over the next 20 years was made. The assumptions used in this projection are that production levels will be maintained throughout the life of the operations based on current production and known ore reserves. It should be realized that the likelihood of new operations coming on line or the development of greater ore reserves at an operating property is very high; hence the following projection of potential tailings being created is a conservative estimation. On the other hand recent set backs in the market price, particularly for copper, may tend to restrict production hence tailings produced.

This projection was made using the annual production and demonstrated reserves as contained in the Bureau of Mines Mineral Availability System. Based on this data, the annual production was continued over the life of the operation by the currently know ore reserves at the active operation. The lode-mine commodities were broken down into three categories copper, lead-zinc and silver, and gold-silver, similar to the breakdown in the section on type of tailings. The commodity categories were summed on a state and county basis over the next 20 years, beginning in 1982.

It is estimated that an additional 5 billion tons of mill tailings will be produced from copper mine operations over the next two decades. For the lead-zinc and gold-silver mining operations an additional 300 and 470 million tons of tailings will be created respectively for each of these commodity types. Summaries of these projections are given in Tables 11-13.

TABLE 11. - Twenty year projection of mill tailings produced from copper ores

State and county	Tailings 106 tons
Arizona:	
Greenlee.....	565,136
Pima.....	938,703
Pinal.....	1,010,132
Ontonagon.....	176,802
Yavapia.....	234,574
Total.....	<u>3,308,443</u>
Michigan:	
Gila.....	<u>559,898</u>
Montana:	
Silver Bow.....	<u>370,706</u>
New Mexico:	
Grant.....	396,939
Sierra.....	62,081
Total.....	<u>459,020</u>
Tennessee:	
Polk.....	<u>13,632</u>
Utah:	
Salt Lake.....	<u>738,966</u>
National total.....	<u>5,117,071</u>

TABLE 12. - Twenty year projection of mill tailings produced from lead-zinc ores

State and county	Tailings 106 tons
Colorado:	
Lake.....	1,056
Mineral	850
San Juan.....	<u>1,711</u>
Total	<u><u>3,617</u></u>
Idaho:	
Shoshone.....	<u>6,038</u>
Illinois:	
Hardin.....	<u>1,704</u>
Missouri:	
Iron.....	94,943
Reynolds.....	87,888
Washington.....	<u>2,428</u>
Total	<u><u>185,259</u></u>
New York:	
St. Lawrence.....	<u>5,505</u>
Pennsylvania:	
Lehigh.....	<u>9,435</u>
Tennessee:	
Grainger.....	2,266
Jefferson.....	27,951
Polk.....	22,247
Smith.....	<u>33,947</u>
Total	<u><u>86,411</u></u>
National total.....	<u><u>297,970</u></u>

TABLE 13. - Twenty year projection of mill tailings produced from gold-silver ores

State and county	Tailings 106 tons
California:	
Calaveras.....	<u>6,985</u>
Idaho:	
Owyhee.....	14,626
Phillips.....	4,202
Valley.....	<u>4,049</u>
Total.....	<u>22,877</u>
Montana:	
Lincoln.....	49,503
Phillips.....	42,998
Granite.....	<u>2,205</u>
Total.....	<u>94,706</u>
Nevada:	
Elko.....	12,404
Esmeralda.....	1,202
Eureka.....	29,988
Humboldt.....	9,823
Lander.....	20,727
Mineral.....	17,199
Nye.....	211,325
White Pine.....	<u>9,592</u>
Total.....	<u>312,259</u>
South Dakota:	
Lawrence.....	<u>22,050</u>
Utah:	
Tooele.....	10,496
Utah.....	<u>154</u>
Total.....	<u>10,650</u>
Washington:	
Ferry.....	<u>212</u>
 National total.....	 <u>469,740</u>

Mine Openings Analysis

There are potential environmental problems that can be caused by the voids left from mining. Ground water may react with sulfide minerals to create acid mine water; underground mine subsidence may disturb the terrain directly above the workings; and large surface areas may be disturbed by disposed waste from open pit mines. The potential effect on the environment is greatly dependent on the mineral type, geology, hydrology, and rain fall. Proximity to population centers increases the nuisance value of these possible environmental damages. This section quantifies voids left by the mining of the lode-mine minerals since 1910 upon which further analyses can be based. It should not be assumed that all mine activities covered in this report have in the past or will in the future pose environmental problems.

Estimation of the voids left by mining on a county basis is illustrated in Table 14. This was accomplished by using the historical production data to calculate an estimate of the volume of mine openings left by mining. The estimation of mine voids is complicated by the fact that some mining areas began as underground operations and later were reworked by surface mines when the recovery of lower grade ores became economic. Some mining areas, such as the Coeur d'Alene district in Idaho and the Franklin-Sterling mine area of New Jersey, have employed cut-and-fill mining techniques where mill tailings or waste rock has been deposited back into the mine openings. In others where a block cave mining method was used the void has been filled by the induced collapse of strata above the workings.

The specific gravity of in situ ore was estimated and applied to the amount of ore metallurgically processed. The volume associated with each county relates only to the ore mined and excludes any waste rock moved in the process. For underground mining this volume is quite reasonable; however, for estimations of surface mines a waste to ore ratio would be required to estimate the total void. The relationship between mine waste and mill tailings for the period 1974-81 is shown in Figure 41. In addition to the volume of mine workings, an estimation of the volume of mill tailings potentially residing in that county is also included. This data was then compiled on a county basis and summed for each state in Table 14.

The type of mining method prevalent in the county (either surface or underground) has been designated and is based on information from the Bureau of Mines Minerals Availability System (MAS) data base. By searching the MAS data base on a commodity basis, the predominant mining method employed in that particular county was assigned for the study period. If production came from a combination of mining methods the county was designated as surface-underground.

The results of this analysis show that more than 4.3 billion cubic yards of ore were removed over the last 72 years. Mill tailings volume in excess of 6.9 billion cubic yards were created over the same period.

TABLE 14. - Cumulative mill tailings produced and mine openings created from lode-mine operations over the period 1910-81

State and county	Mining ^{1/} method	Volume, 10 ³ yd ³	
		Mill tailings	Mine openings
Arizona:			
Cochise.....	S-U	80,110	51,918
Coconino.....	S-U	545	327
Gila.....	S	497,874	301,023
Graham.....	S-U	367	238
Greenlee.....	S	572,507	314,258
Maricopa.....	U	438	272
Mohave.....	S	79,229	47,857
Pima.....	S	1,061,412	642,466
Pinal.....	S-U	529,587	326,176
Santa Cruz....	U	1,440	1,024
Yavapai.....	S-U	101,035	63,110
Yuma.....	U	968	595
Total....		2,925,512	1,749,264
California:			
Alpine.....	U	17	12
Amador.....	U	9,522	5,756
Butte.....	U	262	158
Calaveras....	U	7,317	4,483
El Dorado....	U	1,018	632
Humboldt.....	U	29	21
Imperial.....	U	177	106
Inyo.....	S-U	4,398	2,756
Kern.....	U	4,002	2,372
Los Angeles...	U	142	86
Madera.....	U	36	25
Mariposa.....	U	970	592
Mono.....	U	800	476
Napa.....	S-U	82	50
Nevada.....	U	10,943	6,550
Placer.....	U	596	360
Plumas.....	U	7,463	4,717
Riverside.....	U	38	22
San Bernardino	S-U	623	380
Shasta.....	U	2,604	1,632
Sierra.....	U	1,443	858
Siskiyou.....	U	984	615
Trinity.....	U	172	104
Tuolumne.....	U	2,298	1,418
Yuba.....	U	103	60
Total....		56,039	34,241

^{1/} S = Surface Mine
U = Underground Mine

TABLE 14. - Cumulative mill tailings produced and mine openings created from lode-mine operations over the period 1910-81 - continued

State and county	Mining method ^{1/}	Volume, 10 ³ yd ³	
		Mill tailings	Mine openings
Colorado:			
Boulder.....	U	788	488
Chaffee.....	U	188	132
Clear Creek...	U	3,854	6,336
Conejos.....	U	26	17
Custer.....	U	219	136
Dolores.....	U	716	559
Eagle.....	U	5,563	4,359
Gilpin.....	S-U	1,495	958
Gunnison.....	U	484	352
Lake.....	U	5,023	3,338
Mineral.....	U	1,985	1,304
Ouray.....	U	3,255	2,146
Park.....	S-U	958	621
Pitkin.....	U	910	656
Rio Grande....	U	237	145
Saguache.....	U	418	305
San Juan.....	U	8,241	5,376
San Miguel....	U	14,675	9,529
Summit.....	U	755	632
Teller.....	U	15,682	9,344
Total....		63,005	41,745
Idaho:			
Adams.....	U	641	391
Blaine.....	U	1,335	1,005
Boise.....	U	528	326
Bonner.....	U	310	200
Boundary.....	U	456	290
Butte.....	U	44	31
Custer.....	U	1,991	1,263
Elmore.....	U	734	446
Fremont.....	U	26	22
Idaho.....	U	418	249
Lemhi.....	U	2,293	1,443
Owyhee.....	S-U	2,755	1,643
Shoshone.....	U	79,753	54,614
Valley.....	U	3,302	2,046
Washington....	U	3,000	2,150
Total....		97,586	66,119
Illinois:			
Hardin.....	S-U	7,523	4,091
Jo Daviess....	S-U	8,312	5,250
Total....		15,835	9,341

^{1/} S = Surface Mine
U = Underground Mine

TABLE 14. - Cumulative mill tailings produced and mine openings created from lode-mine operations over the period 1910-81 - continued

State and county	Mining ^{1/} method	Volume, 10 ³ yd ³	
		Mill tailings	Mine openings
Kansas:			
Cherokee.....	U	85,155	52,870
Kentucky:			
Crittenden....	S-U	273	165
Livingston....	S-U	1,213	776
Owen.....	S-U	58	36
Total....		1,544	977
Maine:			
Hancock.....	U	1,179	808
Michigan:			
Houghton.....	U	195,483	117,768
Keweenaw.....	U	17,653	10,617
Ontonagon.....	U	108,582	66,637
Total....		321,718	255,022
Missouri:			
Crawford.....	S	6,030	3,752
Iron.....	U	32,682	21,950
Jasper.....	U	93,246	57,030
Jefferson.....	S-U	124	78
Lawrence.....	U	668	410
Madison.....	S-U	21,531	13,323
Moniteau.....	S-U	70	46
Newton.....	U	880	552
Reynolds.....	U	29,177	19,030
St. Francois..	U	197,482	121,615
Washington....	S	19,151	12,043
Total....		401,041	249,829
Montana:			
Beaverhead....	S-U	311	190
Broadwater....	U	365	247
Cascade.....	S-U	1,320	834
Chouteau.....	U	102	62
Deer Lodge....	U	171	102
Fergus.....	S-U	678	406
Granite.....	S-U	802	558
Jefferson.....	S-U	878	601
Judity Basin..	U	252	182
Lewis & Clark.	U	1,984	1,283

^{1/} S = Surface Mine
U = Underground Mine

TABLE 14. - Cumulative mill tailings produced and mine openings created from lode-mine operations over the period 1910-81 - continued

State and county	Mining ^{1/} method	Volume, 10 ³ yd ³	
		Mill tailings	Mine openings
Montana: - cont'd			
Lincoln.....	U	891	557
Madison.....	S-U	918	579
Mineral.....	S-U	239	157
Missoula.....	U	52	32
Park.....	S-U	932	580
Phillips.....	U	1,572	932
Powell.....	U	22	15
Sanders.....	U	336	233
Silver Bow....	S-U	366,518	238,771
Total....		378,643	246,321
Nevada:			
Churchill.....	S-U	598	356
Clark.....	U	722	510
Elko.....	S-U	3,014	1,958
Esmeralda.....	S-U	4,751	2,847
Eureka.....	S-U	10,255	6,101
Humboldt.....	U	4,190	2,501
Lander.....	S-U	21,970	13,262
Lincoln.....	U	4,330	3,000
Lyon.....	S-U	106,495	63,884
Mineral.....	S-U	1,015	612
Nye.....	U	7,271	4,368
Pershing.....	U	1,614	958
Storey.....	U	5,160	3,071
Washoe.....	U	83	56
White Pine....	S-U	244,108	152,327
Total....		415,576	55,811
New Jersey:			
Sussex.....	U	4,936	13,141

^{1/} S = Surface Mine
U = Underground Mine

TABLE 14. - Cumulative mill tailings produced and mine openings created from lode-mine operations over the period 1910-81 - continued

State and county	Mining ^{1/} method	Volume, 10 ³ yd ³	
		Mill tailings	Mine openings
New Mexico:			
Catron.....	U	634	378
Colfax.....	U	116	68
Grant.....	S	409,476	252,928
Hidalgo.....	U	1,984	1,305
Lincoln.....	U	34	22
Otero.....	U	18	12
San Miguel....	U	1,260	1,060
Sandoval.....	S-U	2,641	1,589
Santa Fe.....	U	208	137
Socorro.....	U	1,724	1,112
Total....		418,095	258,611
New York:			
St. Lawrence..	U	20,369	14,296
North Carolina:			
Ashe.....	U	1,018	651
Catawba.....	U	20	12
Montgomery....	U	68	40
Vance.....	U	465	277
Total		1,511	980
Oklahoma:			
Jackson.....	S	1,240	764
Ottawa.....	U	207,300	128,976
Total....		208,540	129,740
Oregon:			
Baker.....	U	1,180	740
Grant.....	U	136	92
Jackson.....	U	56	34
Josephine.....	U	84	54
Lane.....	U	34	22
Malheur.....	U	26	14
Total....		1,516	956

^{1/} S = Surface Mine
U = Underground Mine

TABLE 14. - Cumulative mill tailings produced and mine openings created from lode-mine operations over the period 1910-81 - continued

State and county	Mining method	Volume, 10 ³ yd ³	
		Mill tailings	Mine openings
Pennsylvania:			
Lebanon.....	U	46,932	28,213
Lehigh.....	U	5,411	3,553
Total....		52,343	31,766
South Carolina:			
Lancaster.....	U	434	258
South Dakota:			
Lawrence.....	U	82,469	48,962
Pennington....	S-U	146	86
Total....		82,615	49,048
Tennessee:			
Grainger.....	U	892	558
Hancock.....	U	3,507	2,182
Jefferson.....	U	54,355	33,986
Knox.....	S-U	22,171	13,579
Polk.....	S-U	45,802	28,816
Smith.....	U	2,827	1,778
Union.....	U	20	14
Washington....	S-U	648	484
Total....		130,222	81,397
Texas:			
Presidio.....	U	1,430	852
Utah:			
Beaver.....	S-U	1,738	1,094
Box Elder.....	U	100	64
Grand.....	U	56	34
Juab.....	U	788	607
Piute.....	U	108	73

1/ S = Surface Mine
 U = Underground Mine

TABLE 14. - Cumulative mill tailings produced and mine openings created from lode-mine operations over the period 1910-81 - continued

State and county	Mining method	Volume, 10 ³ yd ³	
		Mill tailings	Mine openings
Utah: - cont'd			
Salt Lake.....	S	1,135,536	695,483
San Juan.....	S-U	1,125	675
Summit.....	U	4,387	3,287
Tooele.....	U	4,304	3,092
Utah.....	U	1,081	881
Wasatch.....	U	3,352	2,689
Total....		1,152,575	707,979
Vermont:			
Orange.....	S-U	2,114	1,344
Virginia:			
Orange.....	U	18	12
Rockingham....	U	917	578
Wythe.....	U	20,315	12,992
Total....		21,250	13,582
Washington:			
Chelan.....	U	7,449	4,642
Ferry.....	S-U	2,321	1,493
Okanogan.....	S-U	182	110
Pend Oreille..	S-U	13,919	8,791
Snohomish.....	U	208	138
Stevens.....	S-U	4,120	2,625
Whatcom.....	U	104	66
Total....		28,303	17,865
Wisconsin:			
Grant.....	U	11,161	7,204
Iowa.....	U	3,618	2,299
Lafayette.....	S-U	18,198	11,592
Total....		32,977	21,095
National Total.....		6,922,063	4,304,506

1/ S = Surface Mine
U = Underground Mine

MINING AND MILLING PRACTICES USED
IN THE RECOVERY OF LODE-MINE

The following sections describe the technologies used in the recovery of the five lode-mine commodities. This includes a description of the mining and waste disposal techniques employed, the metallurgical techniques and historical technological advances, and a brief description of the materials that constitute the tailings.

The variety of minerals processed in recovering copper, lead, zinc, silver, and gold, coupled with the changes in tailings impoundment over time, make it virtually impossible to estimate the amount of potentially hazardous material deposited in specific cases. However, a general overview of the tailings produced has been provided. This coupled with the estimates on the quantities of tailings that potentially exist across the country will provide an improved basis for future analysis.

Mine Waste and Mill Tailings Disposal Practices

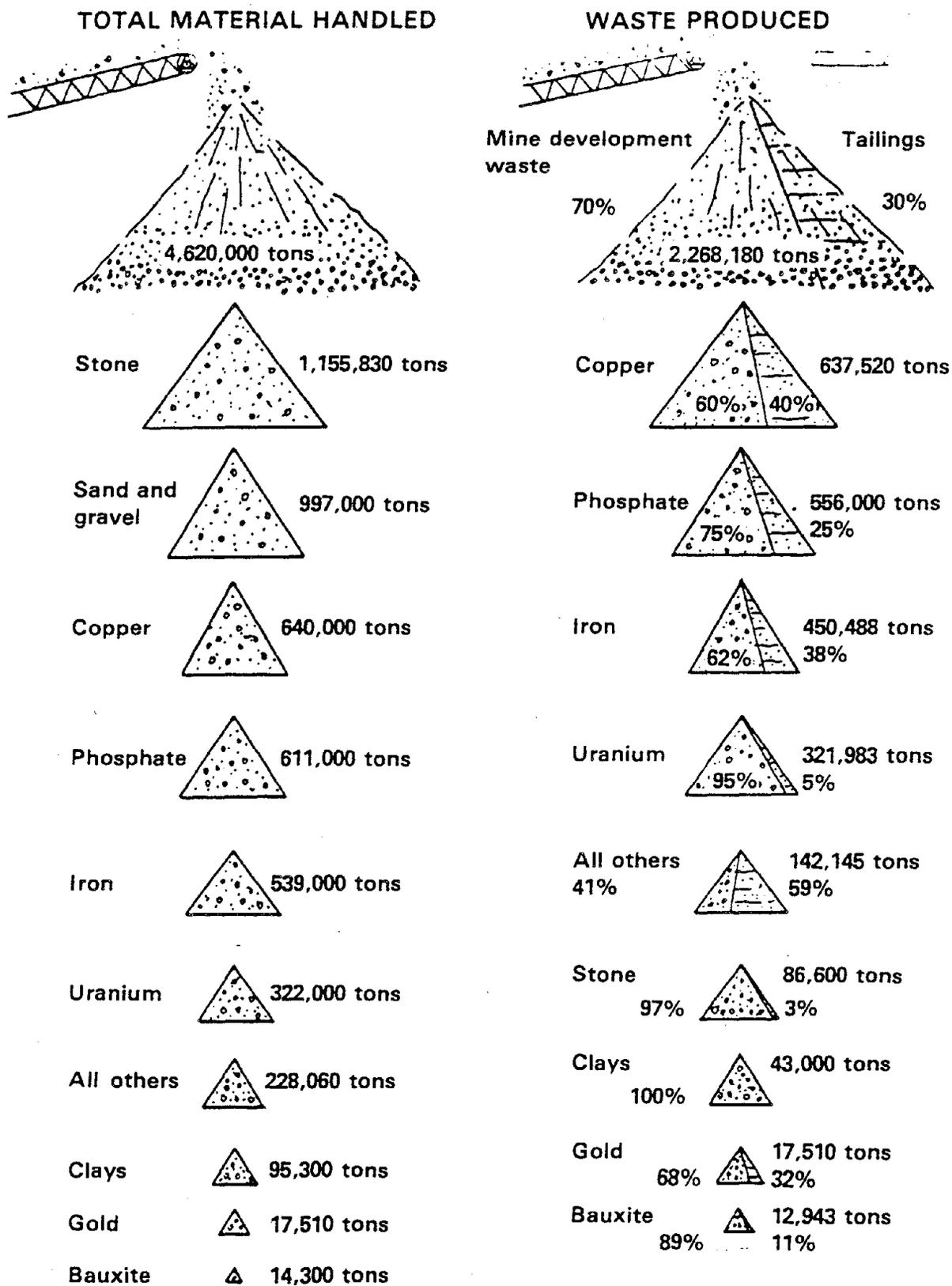
Evidence of metal mining activities dates back to the Bronze Age (4000 B.C.). Primitive mining utilized basic man power and fabricated hand tools to extract the minerals. With the introduction of black powder for blasting, the invention of the steam engine, and the dawn of the Industrial Revolution, the mining industry began to grow at a more rapid pace. However, prior to the 1900's, mining was still labor intensive and few mines produced more than 10 to 20 tons of ore per day. These mines were typically in high grade deposits and produced relatively little waste since the miners hand picked the ore. In the early 1900's advances in mining technology, ore beneficiation, and refining made possible the mining of large low grade ore deposits.

Today, low grade large open pit ore mines handle hundreds of thousands of tons of ore and waste rock per day. The high volumes mined and processed intensified the waste disposal problem. Early milling processes, utilizing gravity separators, produced mill waste with a large portion consisting of a relatively coarse, freer draining material than today's processes. In the early days and as late as the 1930's, the finer slimes and waste water were dumped into streams, rivers, or lakes. Mine waste disposal facility construction techniques utilized hand labor to raise the embankment heights and tailings were delivered to the disposal site by launders. These embankments typically were built by the upstream construction method and rose to heights of 200 feet or more.

The development of flotation processes, about 1916, for processing ore created a need for much finer mill grind, with grinds as fine as 60 percent passing minus 200 mesh. These new processes made possible the mining of much lower grade deposits and subsequently produced larger volumes of finer tailings for disposal. Many of the developments in mining and milling technology have occurred during the life of existing large mines. The consequences of new technology and the increased demand for minerals have created several problems for the mining industry: previously uneconomical ore deposits became economically feasible and larger daily volumes of tailings had to be handled; previously poorly arranged and haphazardly constructed waste disposal facilities had to be expanded to accommodate increasingly finer waste; and more recent environmental awareness required closed circuit disposal systems that could impound large quantities of water in addition to tailings.

In the last 25 years, public awareness of the environmental impacts of disposal of large volumes of mine waste has steadily increased. Within the last 10 years, much legislation, at both the federal and state level, has affected the mining industry's waste disposal practice. Public awareness of the land areas permanently committed to waste disposal and increased competition for the use of land has created land use conflicts for the miner. These conflicts have in part restricted the expansion of waste facilities and are requiring the disposal of larger volumes of waste in more confined areas forcing embankment heights up to 500 feet. Some current plans for tailings impoundments will require embankments approaching 700 feet in height.

FIGURE 42. - Total material handled by the United States mining industry during 1978



The total materials handled by the mining industry was 4.62 billion tons in 1978 (figure 42). Of the total material handled, 1.59 billion tons was mine waste. The remaining 3.03 billion tons was crude ore, which, after processing, generated approximately 700 million tons of tailings.

Approximately 13,000 mines produced construction materials such as sand, gravel, stone, clay and gypsum and although these mines handle approximately 50% of the total material mined and represent 92% of the mines in this country, they only produce 3% of the mine waste. In contrast, approximately 400 mines producing copper, iron, titanium, uranium, and phosphate represent only 3% of the mines, but they handle nearly 50% of the total material handled and produce 87% of the mine waste (Figure 42).

Disposal Practices of Mine Waste

Mine development waste makes up the bulk of the coarse waste handled at a mining operation. This material is dumped in large piles for either permanent disposal or heap leaching. Environmental concerns are generally not significant in the permanent waste dumps since the rock is in an unaltered state. Stability can be a problem if the material is subject to natural degradation due to time and weather, resulting in a loss of shear strength. Coarse waste is primarily transported by the following methods:

Truck - Although excavated material is often moved short distances by dozer tractors, trucks of many types and sizes are the primary vehicles used to transport coarse mine waste to a disposal pile or to leaching dumps. The

material transported by truck is usually deposited at the angle of repose by end dumping at the edge of a pile. End dumping usually produces steep slopes and some segregation of particle sizes with the largest sizes relegated to the bottom of coarse material resulting in a lower water table (phreatic surface).

Conveyor - Conveyors are used to transport coarse mine waste to a hopper to be trucked or to free discharge at the disposal site where it may be spread by dozers. Waste piles constructed in this manner have steep outer slopes and may have compacted layers from equipment travel with the possible result of perched water tables on the compact layers.

Train - Transport of coarse waste by rail is not common, but is used at several mining operations.

Leach Dumps

Most leach dumps consist of waste and low-grade ore that has accumulated from underground mines and open pits over a period of years (up to 50 years or more). This material can be leached at a profit by spraying or injecting water or dilute acid onto the surface and into the pile and collecting the pregnant solution for metal recovery by precipitation. The gradation of the dump material ranges from large boulders to fine clay with a continuing change in physical properties as the material changes with time and chemical action. Stability analyses of these old waste piles are very difficult because of the heterogeneous mixture and changing nature of the materials. Today, at a single large mining operation, as much as 70,000 tons per day of waste and low grade ore are being transported to leaching beds where the dumped material is

spread by bulldozers. Equipment travel on the leach dump provides some random compaction of the top lift of the material, so before the leaching process is started the top layer is scarified to facilitate infiltration of the leach solution. The leaching process is stopped when excessive channeling develops, when surface infiltration decreases or ceases due to accumulation of clay and precipitates, whereupon the surface is rescarified and the leaching process resumed.

In order to eliminate or substantially decrease the potential for the leachate to contaminate the groundwater, the leaching area may be prepared by constructing a soil-cement or asphalt base upon which the low grade ore is placed. The impervious character of the base reduces infiltration into the groundwater and the leachate can flow directly into a water tight pond.

Mill Waste Disposal

The mining and processing of low grade metallic ores results in large quantities of waste which leave the plant as a slurry generally containing as much as 30 to 95 percent of material of minus 200 mesh size. This slurry is retained in the tailings pond(s) allowing the solids to settle out. The decant water may be recycled or discharged into a watercourse. Mining operations handling 30,000 to 100,000 tons of ore per day are not uncommon with over 95 percent being waste. The amount of waste produced has increased significantly in the last 50 years; for example, in 1938, 1 ton of ore produced 27 pounds of copper; in 1947--18 pounds; in 1960--14.4 pounds; and in 1971--11 pounds. This indicates that in 1971 nearly 2.5 tons of ore was processed to obtain the same amount of copper that was produced from 1 ton in 1938. This trend will probably continue, but at a reduced rate.

Early-day milling required only coarse crushing for gravity separation on tables or in jigs. The resulting tailings were disposed of in the most convenient manner available, often dumped into nearby streams. This type of disposal is no longer acceptable, and active tailings ponds now cover areas from as little as 1 acre to as many as 5,000 acres. Tonnages of tailings produced annually approach 700 million tons (30 percent of total waste) as shown in figure 42. Copper, iron, and phosphate account for about 75 percent of this total.

Tailings Disposal Practices

Most mills use a wet process to separate the valuable minerals from the fine ore producing a waste slurry. The waste slurry is transported to the tailings disposal area by open ditch, flume, or by pipeline. Because the silt and finer fractions are not suitable for embankment construction, separation of particle size is necessary to obtain a coarse fraction with adequate shear strength if the tailings are to be used for construction. The most frequently used separation methods are spigotting and hydrocycloning when there is the presence of a coarse sand fraction in the tailings. A starter dam must be constructed first if this coarse sand fraction is to be used in the construction of the containment embankment.

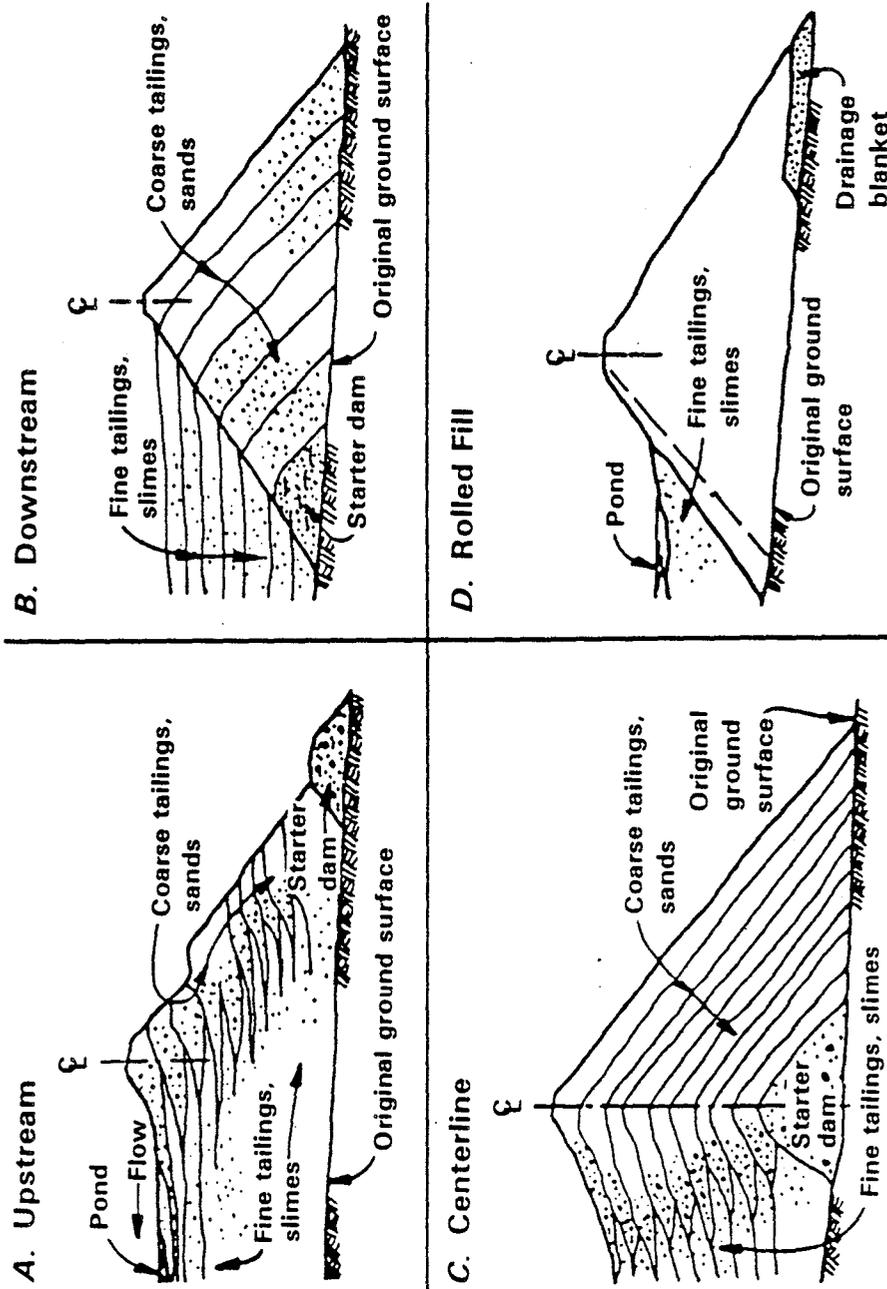
Spigotting - The hydraulically transported tailings are discharged from one or several points along the crest of the embankment. As the tailings slurry meanders in a random manner, gravity separation occurs. A gently sloping beach is formed by the coarsest fraction settling out near the discharge point

while the finer fractions are deposited progressively toward the pond. The coarse materials may possibly be used to increase the height of the containing dike. Spigotting of tailings on the upstream face of an embankment of borrow pit material or mine waste rock will produce a moderately impervious seal on the embankment.

Hydrocycloning - Hydrocyclones (cyclones) are sizing devices used to separate the tailings sands from the slimes. Cyclones can be used with finer grind tailings to recover a larger percentage of the sand fraction for embankment construction. The cyclones can be placed along the crest as in spigotting, several can be mounted in a group on a mobile vehicle which travels parallel to the axis of the embankment, or they can be mounted on an abutment. The underflow of coarse sands can either be dropped directly onto the embankment or, by repulping, can be transported through ditches or launders onto the embankment. The overflow of fines can be piped an adequate distance upstream so that the fines will not be under the containing embankment as it is raised in height.

Embankments to contain the tailings are constructed using one of four methods: upstream, downstream, centerline, or rolled fill as shown in figure 2. In the upstream method the embankment is constructed from the starter dam in lifts which are placed successively on the previous lift in the upstream direction.

FIGURE 43 - Four methods of constructing tailings dams



The centerline of the embankment crest moves in the upstream direction. In the downstream method the embankment building material is added successively to the downstream side of the previously placed embankment. The centerline of the crest moves in a downstream direction. In the centerline method the embankment is raised in steps with the centerline of the crest remaining above the starter dam. In rolled fill construction the embankment is constructed of compacted borrow pit material or mine development waste. Zoning of the embankment and drainage blanket depends on the relative permeability and grain size of the tailings and embankment material.

Copper in the United States

Over the past century copper production has increased from 50,000 tons in 1896 to nearly 1.3 million tons in 1981 -- an increase of 26 fold. This increase has been due in large part to the greater demand for copper in the electronics and manufacturing industries and has been accomplished by the technological advances in the mining and processing of low-grade ore bodies. As is evident in the sections estimating the amount of tailings across the nation, copper processing waste materials pose difficulties simply from the volumes that have accumulated over time. However, the majority of the copper operations are located in semi-arid to arid climates, and the problems encountered due to groundwater and surfacewater runoff pollution have been minimal.

This section will identify the historical changes and improvements in technology that have on one hand allowed for the supply of relatively inexpensive copper, while on the other hand produced large tonnages of solid waste material. In addition, an attempt will be made to describe the content of mill tailings that are currently being produced.

Historical Sketch

In 1869, the Calumet and Hecla Company, in Michigan, became the largest individual copper producer in the world although its annual production was less than 6,200 tons of copper. By 1877, the mines of Rio Tinto (Spain) took a leading position with an annual output of slightly more than 27,000 tons and maintained this leadership until it was displaced by the Anaconda Copper Company (Montana) in 1892 with an annual output of 37,500 tons. The first mine in the U.S. to produce more than 50,000 tons a year was Anaconda in 1896, and, with the exception of only a few years it maintained its position as the world's largest copper mine until 1920.

The potential of the massive low-grade porphyry copper deposits of the southwestern U.S. was first realized when D.C. Jackling developed improved concentration methods to process ore for the open-pit mine at Bingham Canyon, Utah. Introduction of flotation for beneficiation of sulfide ores during the 1920's improved metal recovery and permitted the exploitation of the low-grade porphyry deposits of the southwest United States. As a result of the development of the major porphyry copper deposits, the U.S. has been a major source of copper in the world during this century.

Processing of Copper Ores

Porphyry copper deposits have become the chief source of the world's copper. The term porphyry copper deposits is generally applied to a type of disseminated ore which is igneous in origin and is characterized by a large proportion of the minerals being rather uniformly distributed throughout thin fractures. The porphyry deposits typically are low in copper content, usually one percent or less; however, the massive horizontal development renders them amenable to large-scale production methods. The major porphyry deposits in the United States are located in the southwest. Other types of important copper-ore bodies found in the United States are the complex systems of vein deposits of Butte, Montana, and the predominantly native copper of the Michigan copper district on the Keweenaw Peninsula.

The beginning of open-pit mining in 1907 permitted profitable exploitation of huge bodies of low-grade disseminated copper resources in the southwest that previously had been considered uneconomical. Advancements in mining technology effecting development of better mining methods, mining and transportation equipment, explosives and engineering control contributed to increased output by open-pit mining. This in turn required adjustments and improvements to be made in copper concentrating processes.

The concentrating phase of the copper production cycle is necessitated by the low grade of the ore available from mass production mining. The principal methods of concentration are froth flotation for sulfide ores and hydrometallurgy for oxide ores.

Flotation is a process of wet concentration in which air bubbles are used to float one kind of particle from a mixture of two or more kinds of finely divided materials suspended in water. Certain minerals may be preferentially wetted by organic reagents in the presence of water so that the bubbles will adhere to mineral and float them to the surface. Gangue (waste) minerals are unaffected and remain suspended in the water.

Prior to 1916 and the introduction of the flotation process, the standard concentrating practice was to use gravity methods to concentrate the ore. The recovery of copper contained in the feed as shown in Table 15, ranged from 75.5 to 79.9 percent (11, p. 9). The loss of copper in the tailings consisted of unliberated copper minerals attached to or enclosed within gangue particles and finely divided copper minerals free from gangue but too finely divided to be saved by the standard concentrating machines.

Commercial development of the flotation process for use in copper concentration occurred about 1916. A comparison of gravity separation with flotation recoveries, pre-1915 versus post-1920, respectively, shown in Table 15, indicates flotation improved the recovery of copper from finely ground ores by approximately 21 percent. Since the introduction of flotation, recoveries of sulfide copper steadily improved, and although the first marked improvement was due to the treatment of slimes by flotation, the later improvements due to finer grinding and more efficient classification, also affected concentration recoveries. In terms of the amounts of concentrates and tailings produced due to the adoption of flotation by industry, the immediate net effect was negligible.

TABLE 15. - Trends in copper concentrating

Year	Ore	Cu wt pct		Recovery pct	Distribution, pct	
		Concentrate	Tailing		Concentrate	Tailing
1900	3.4	61.1	0.783	77.9	4.4	95.6
1905	3.2	62.0	.667	79.9	4.1	95.9
1910	2.0	56.8	.450	75.5	2.7	97.3
1915	2.0	58.5	.463	76.7	2.6	97.4
1920 ¹	2.0	56.0	.179	91.0	3.3	96.7
1925	2.2	63.2	.143	93.8	3.3	96.7
1926	2.3	62.2	.129	94.5	3.5	96.5
1927	2.2	60.2	.117	94.8	3.7	96.3
1928	2.3	61.3	.114	95.1	3.8	96.2
1929	2.2	61.3	.124	94.6	3.6	96.4

¹ Exemplifies results achieved from the initial use of flotation by industry.

About 1921, the discovery that certain flotation reagents could be used to affect separation of metallic sulfides from each other made additional tonnage of copper and other minerals in selective mixed ores available. Selective flotation made effective separation of these minerals possible if the minerals themselves were not so intimately intergrown as to require excessive comminution to liberate them as discrete particles.

With the introduction of flotation at several concentrators, recoveries between 1914 and 1930 increased. These trends are indicated in Table 16 (11, p. 11), in terms of improved concentration recoveries of copper at typical plants. For example, at the Utah Copper Co. mill after 1914, when flotation was incorporated in the system, recovery was increased from 66 percent in that year to more than 89 percent by 1930, despite a general decline in the grade of ore treated. At the Calumet & Hecla mill, flotation was applied only to slime removal, and the indicated improvement in recovery was from 75.9 percent in 1914 to 95.7 percent in 1930.

TABLE 16. - Trends in copper recoveries at typical concentrators
(Cu recovery, pct)

Year	Utah Copper Copper Co.	Miami Copper Copper Co.	Nevada Consolidated Copper Co., Hayden concentrator	Calumet & Hecla Consolidated Copper Co., conglom-concentrator
1914	66.04	69.93	67.88	75.90
1915	64.13	75.17	64.11	76.72
1916	62.34	73.88	70.20	76.60
1917	61.10	69.25	74.53	75.91
1918	65.11	71.15	74.92	80.75
1919	78.46	82.38	79.45	85.75
1920	81.38	82.48	81.98	91.01
1921	83.87	85.37	77.82	91.59
1922	80.00	86.36	76.66	93.30
1923	80.96	83.98	74.87	93.49
1924	85.94	80.17	78.27	93.00
1925	86.96	72.60	84.25	93.83
1926	87.01	76.77	N/A	94.49
1927	89.12	77.64	N/A	94.81
1928	85.56	68.41	87.06	95.12
1929	85.67	72.80	N/A	94.62
1930	89.00	78.88	N/A	95.70

NA = Not available.

From 1930 to 1960, innovations continued to be introduced not only to improve recovery, but to reduce processing costs from low-grade ores and mixed sulfide and oxide ores. Other important occurrences of this period saw the gradual development and advancement in methods and equipment, which increased the efficiency of crushing, grinding, classifying, flotation, and dewatering operations.

Throughout the next twenty years (1960-1980) as ore grades continued to decrease further, technological improvements were made in the mining and the milling of the ores to continue decreasing the processing cost for copper. The trend in mining continued towards large open-pit mines where the problems associated with maintaining desired production levels from ore of declining grade was met by using very large capacity equipment such as 500-900 ft³ shovels and 100-250-ton haulage trucks, and railroad hopper cars to increase their output (31, p. 827).

To accommodate the increase in the mine output, significant changes occurred in the comminution operations with the use of autogenous and semiautogenous grinding equipment (9, p. 17). In this type of grinding all or part of the ball charge in the ball mills is replaced by ore, so that the ore grinds itself. The mills are larger in diameter than conventional ball mills and perform part of the crushing operation in addition to grinding.

As mine and comminution outputs increased, a corresponding change was necessary for concentrating. Equipment size was increased as daily throughputs increased to compensate for the steady decline in ore grades. Presently, the newest flotation cells each have capacities of 7,400 gallons or more whereas capacities in 1950's rarely exceeded 800 gallons (31, p. 832). As a result, the improvement in processing capacity has resulted in an increase in the amount of concentration waste generated. Figure 44 illustrates a general flowchart of mining, milling and refining of copper ores.

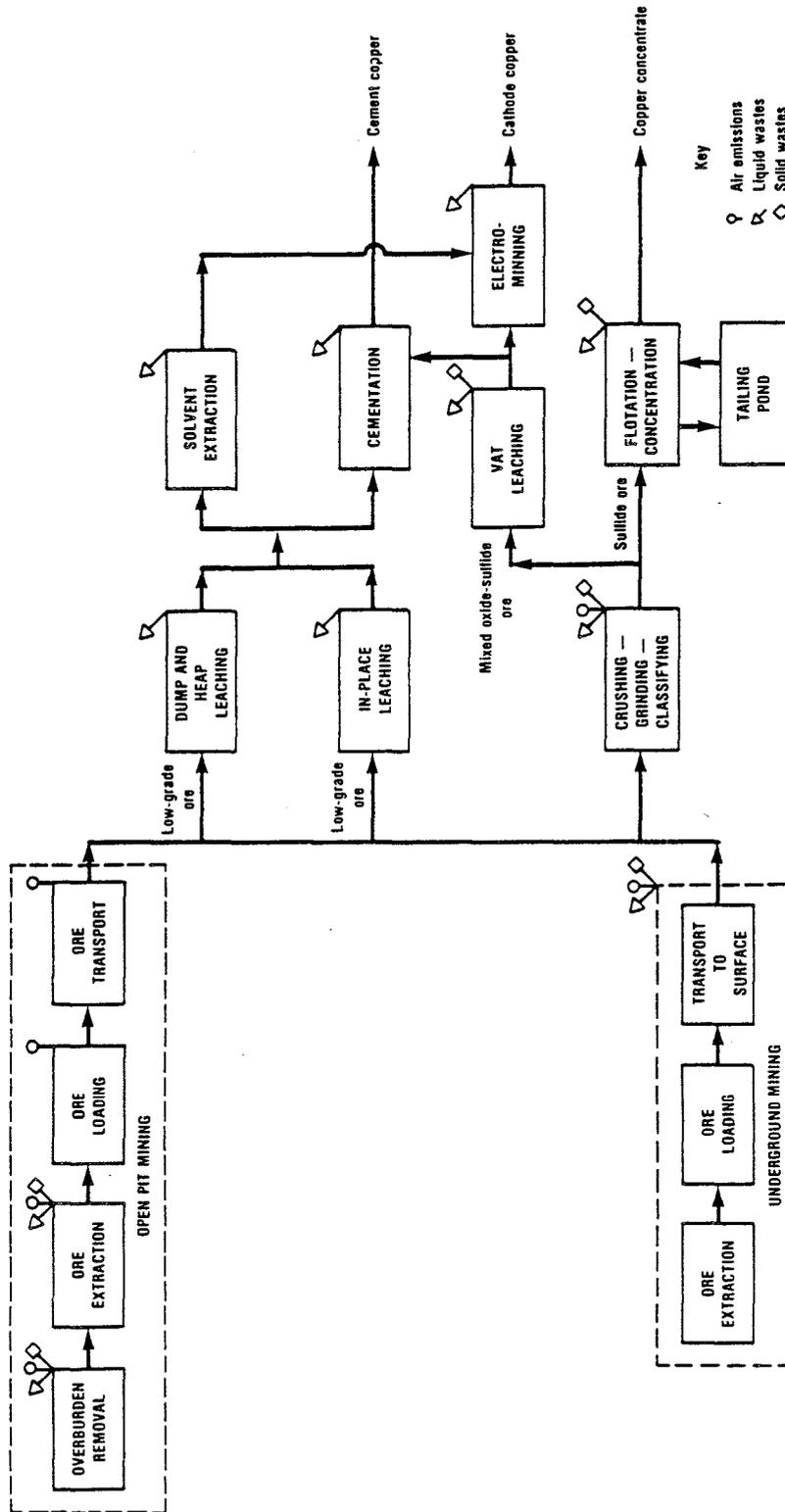


Figure 44 - Flow chart of the mining and milling of copper ores (21, p. 119)

A typical mass flow only for the concentrating of copper flotation is shown in table 17 (6, p. 50).

TABLE 17. - Representative mass flows (dry basis)

Item	Tons/Day	Copper pct
Feed.....	50,000	0.75
Concentrate.....	1,500	24.00
Tailings.....	48,500	0.05
Scavenger middlings....	1,000	3.00
Cleaner middlings.....	1,000	12.00

Waste Material From Copper Ores

The waste material from copper ores consists of both liquid and solid waste. This waste can be further categorized as wastewater from the mine or the milling operation and solid waste in the form of mine waste rock (overburden, etc.) or solid tailings from the milling operation.

Liquid Waste

Mine wastewater can result from several sources including groundwater, hydraulic backfilling, and to a lesser extent surface water. Problems can potentially be encountered when mine wastewater reacts with heavy metals placing these metals into solution. This is a function of geological and hydrological conditions restricted to the presence of such acid-forming sulfide minerals as pyrite in a heavily fractured or fissured geologic environment, in the absence of neutralizing carbonate minerals such as limestone. Table 18, illustrates the analysis raw waste water pumped from selected copper mine operations.

Tailings from the copper flotation mills are the other major source of liquid waste. The waste material consisting of between 25 and 50 percent solids (gangue material from milling, unrecovered heavy metal minerals, and reagents used in flotation) are transported hydraulically to tailings ponds where in most instances the solids are allowed to settle out and the water is then either recycled to the milling operation, evaporated, or discharged. Because the majority of the copper production comes from areas with arid to semi-arid climates, the hazards posed by surface water runoff are negligible.

TABLE 18. - Raw waste water pumped from selected copper mines

Parameter	Underground mine		Open-pit mine	
	Conc., mg/l	Raw waste load per unit ore mined, kg/t	Conc., mg/L	Raw waste load per unit ore mined, kg/t
Total dissolved solids (TDS).....	29,250	5.05	1,350	.101
Total suspended solids (TSS).....	69	.012	2	.0002
Oil and grease.....	1.0	.00017	7	.0005
Total oxygen content (TOC).....	4.5	.00078	10	.00075
Chemical oxygen demand (COD).....	819	.142	4	.0003
B.....	2.19	.00038	.07	.000005
Cu.....	.87	.00015	1.05	.00008
Co.....	.04	.000007	.06	.000005
Se.....	.077	.000013	.096	.000007
Te.....	.60	.00010	.2	.00002
As.....	.07	.00001	.01	.0000008
Zn.....	2.8	.00048	.1	.000008
Sb.....	.5	.000086	.5	.00004
Fe.....	.1	.000017	.1	.000008
Mn.....	2.22	.00038	.9	.00007
Cd.....	.02	.000003	.03	.000002
Ni.....	.05	.000009	.05	.000004
Mo.....	.5	.000086	.2	.00002
Sr.....	119	.0206	.8	.00006
Hg.....	.0001	.00000002	.0001	.000000008
Pb.....	.1	.000017	.5	.00004
Flow, m ³ /d.....	3,815.3	.017	409	.075
pH ^{1/}	7.37	7.37	6.96	6.96

^{1/} Value in pH units.

Source: Greber (21, p. 164.)

Solid Waste

As shown previously in figure 40, solid waste from a mining operation consists of two major sources: mine waste rock and tailings solids produced from the milling of mineral ore. The mine waste rock from a surface mining operation is removed to provide access to the ore body and is deposited in a predesignated location where reclamation of these waste piles is instituted. For the copper ores, where the majority is extracted by surface mining operations, the ratio of mine waste rock to mill tailing is quite high. Over the last decade the ratio of mine waste (overburden, waste rock, etc.) to ore mined was approximately 3:1. Although the leaching of sulfide minerals is a possibility this material will remain inert under normal conditions.

The solids in the concentrator tailings are composed primarily of the common rock-forming minerals, but they also contain approximately 15 percent of the heavy metals (Table 19) originally found in the ore and much of the pyrite (21, p. 167). The tailings may also contain one or more of the various reagents (Table 20) added during the concentration operation (21, p. 165). Since the minerals in concentrator solid waste have been pulverized and intimately mixed, they are subject to weathering much more rapidly than natural rock masses of similar composition. The material that they form is usually acidic, has no plant nutrients, and is phytotoxic.

TABLE 19. - Partial analysis of solids in tailings discharged from a copper concentrator

Element	Concentration, ppm	
	Concentrator	Background
Sb	462	-
Cd	1,172	1,500
Cd	1.4	-
Cu	2,179	21
Fe	264,667	11,800
Pb	1,349	51
Mg	6,051	3,700
Mn	19,129	490
K	115	1,800
Na	75	151
Zn	868	150

Source: Greber (21, p. 166)

TABLE 20. - Chemical reagents that may be used in copper flotation

Mineral	Precipitation agent	pH regulation	Dispersant	Depressant	Activator	Collector	Frother
Bornite	none	Lime	Sodium silicate	Sodium cyanide	none	Xanthate aerofloats	Pine oil
Chalcocite	do	do	do	do	do	do	do
Chalcopyrite	do	do	do	do	do	do	do
Native Cu	do	do	do	do	do	do	do
Azurite	Sodium monosulfide	Sodium carbonate	do	Quebracho	Polysulfide	Xanthate, aerofloats, fatty acids	Pine oil, vapor oil, cresylic acid
Cuprite	do	do	do	do	do	Fatty acids aerofloats, xanthates.	do
Malachite	do	do	do	Tannic acid	do	do	do

Source: Greber (21, p.165)

Extraction Procedure Toxicity

A recent study for the U.S. Environmental Protection Agency (EPA) entitled "Evaluation of Management Practices for Mine Solid Waste Storage, Disposal, and Treatment", (42) attempts to define the characteristic of mining industry waste.

One form of analysis used in the above study was the Extraction Procedure Toxicity (EP toxicity) test. By definition a material exhibits the characteristic of EP toxicity if any of the EP toxicity contaminants leach from a representative sample of the raw material in a concentrate equal to or greater than the maximum concentration established by the EPA (Fed. Reg. Vol. 45, No. 98, pp. 33122). These concentrations are defined as 100 times the Primary Drinking Water Standard (PDWS). In the study leaching agents, acetic acid and deionized water, were used on the solid and slurry samples only. None of the samples subjected to the deionized water test were found to exceed EP toxicity standards.

Analysis for EP toxicity was performed on copper, lead/zinc, and gold/silver operations from both solid and liquid mine and mill waste sources. Reaction to the results of this study by outside observers has been mixed. Some contend that only a small number of samples proved to have high or elevated EP toxicity levels and only when a slightly acidic leaching agent was used and argue is that when deionized water is used no analysis exceeds the EP toxicity criteria. On the other hand, concern must be given to the levels of lead, mercury, and cadmium found through the analysis using acetic acid agent in waste streams of certain lode-mine operations. Conclusive studies of a site specific nature will be required before these questions can be resolved.

Lead-Zinc in the United States

Lead and zinc minerals, particularly those that are sulfides, frequently occur in ore deposits throughout the United States. A considerable portion of these ores has been treated by the same process to obtain concentrates of each mineral type from the mined ore. In fact, it would be difficult to consider the milling of lead or zinc ores as separate processes. In addition, silver and other metals are common and economically important byproducts recovered from these ores. Their recovery does not introduce any serious complication in the milling practice.

Production of lead-zinc metals over the past 70 years has remained rather constant with fluctuations in production tied to economic conditions. This fact is illustrated in figure 3, which shows the annual production from lode-mine operations over the period 1910-1981. Peak production of lead occurred in 1917 with about 860,000 tons being produced and then declined. Not until recent years has production approximated that tonnage. Zinc production has remain constant for most of the time but in recent years has decreased slightly. It should be noted that these figures are for primary lode-mine operations and do not take into consideration secondary supply, such as the recycling of batteries for lead and scrap automobiles for zinc. Although production rates remained relatively constant, the amount of solid waste has increased over the same time due to the processing of lower grade ores.

This section will describe the historic technological changes and improvements used in the mining of lead-zinc ores. In addition, a brief discussion is included on the types of material that constitute the waste material from these ores.

Historical Sketch

Early mining, in Southeastern Missouri, was confined to surface pits and excavations above the water table. In 1867, new discoveries at depths of over 100 feet were exploited by the St. Joseph Lead Company which eventually expanded into the most productive lead-mining enterprise in the world. Mine production of lead increased from 20,000 tons in 1871 to more than 200,000 tons in 1897. This trend continued through the first World War, reaching 684,000 tons in 1925 or about half the total world production for that year.

Since that time, lead production has remained relatively constant with most of the production coming from the Tri-state District and southeastern Missouri. Idaho and Tennessee have contributed additional tonnages.

Mine production of zinc in the United States reportedly began in southwestern Missouri in 1872. However there are references to shipments of zincite to England as early as 1774. The Valle mines of Jefferson county, Missouri were opened in 1824, and the Franklin mine in New Jersey stated production in the 1850's.

In the early part of this century New Jersey and Missouri were the major zinc producing states, with Colorado and Montana adding significant tonnages. Throughout the period of 1920 to 1970 the Tri-state mining district was the major producer of zinc in the United States.

Many advances to improve mining and milling of lead and zinc ores were introduced and put into practice during the period 1880-1925. Centrifugal pumps developed in the late 1800's permitted the mining of ore at greater depths. The rather intimate association of lead with zinc in many mining districts posed difficult problems before the development of flotation, separation and concentration technology. Following the first World War, the simple lead ores were thought to be nearing depletion, and smelter penalties for zinc content often offset payments for the lead and silver values. At that time selective froth flotation was introduced as a new technology for treating these ores and permitted effective concentration of these individual minerals into smelter feedstock. Many of the deposits considered submarginal at the time then became profitable.

Processing of Lead-Zinc Ores

Lead-zinc ores can be classified into two categories; those that are strata-bound carbonate deposits common to the Missouri lead belt and Tri-State districts (Mississippi Valley type deposits) and the second, those that are not sedimentary in origin such as the vein type deposits of the Coeur d'Alene district of Idaho (non-Mississippi Valley type deposits). However, in each case lead and zinc are associated minerals and may contain other desirable metals and minerals. In addition, economic considerations sometimes dictated production of several concentrates of the same mineral, each differing in metal content and in associated mineral species.

Mining of the lead-zinc deposits is most commonly done using underground mining methods. For the strata-bound deposits, large tabular-shaped deposits varying in thickness which are normally flat lying or slightly dipping, a room-and-pillar method is used. The room-and-pillar mining method utilizing large drilling machinery, blasting the ore with explosives, and removing the ore with Load-Haul-and-Dump vehicles and conveyor systems then hoisted to the surface. In contrast, the vein type deposits utilize more selective mining methods such as a cut-and-fill method, common in the Idaho mining district. Stopes are drilled using small jackleg type drills then blasted and the ore removed using mucking machinery. The ore is then transported to the hoisting area by rail. In the mines that employ the cut-and-fill mining method it is common to use mill tailings as the back filling agent.

Concentration processes in mills start with reduction in size of the ore fragments to such a degree that the valuable minerals are liberated (to an economic extent) from the interlocking gangue. This is done by crushing and grinding the ore. During the early part of the century this was performed mainly by jaw crushers and roll mills; however, these were replaced by gyratory crushers and conical ball mills during the 1920's. Later (1970's) the ball mills were replaced by autogenous grinding in some concentrators.

In many mills, wet cyclones were installed in closed circuit with grinding mills to classify the fines prior to the flotation cycle and return the over-sized material for further grinding. This also marked an increase in operational efficiency over the mechanical classifiers.

Prior to 1916, the method used for concentrating the lead and zinc minerals from the ore was gravity concentration. Among the methods relevant to lead and zinc ore milling were jigging, heavy-medium separation, and tabling. The advent of flotation, at that time, allowed for the recovery of the lead and zinc from the slimes, the most finely ground particles previously unrecoverable by gravity concentration. Gravity and flotation concentration were then used in combination. Eventually, with the introduction of reagents that allowed for more selective recovery of different minerals as well as advances in the grinding of the ores, the flotation system replaced the gravity method almost entirely.

Once the lead and/or zinc concentrates have been produced the tailings are transported (usually hydraulically) to a tailings pond where the solids settle out and the water is discharged or recycled to the mill circuit.

A general flow diagram of the mining and processing of lead-zinc ores is illustrated in figure 45.

Over the years that lead and zinc ores have been mined and milled, many technological changes and innovations have taken place. Many of these have been small improvements and would probably have little influence on the makeup or characteristics of mill tailings. However, there have been some major changes in the basic flowsheets for treating lead and zinc ore which would result in both physical and chemical differences in mill tailings.

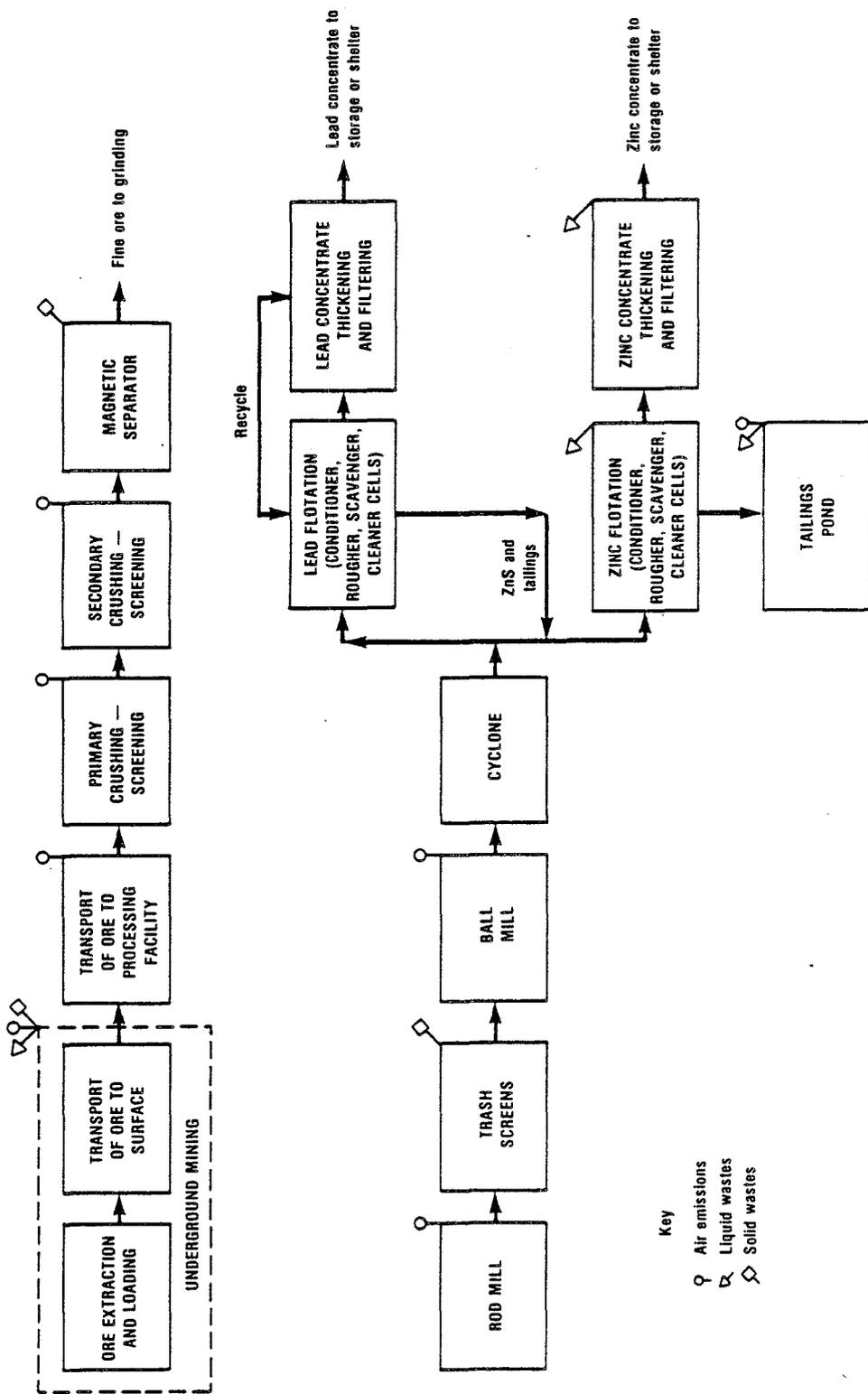


Figure 45 - Flow chart of the mining and milling of lead-zinc ores (21, p. 188)

The introduction of new, or at least different technology, into the milling practice does not happen on a wide scale in short periods of time, and may in fact only be found practical for certain types of ores. In this respect the following table has been constructed:

Technological Changes in Milling Lead and Zinc Ores

Early	Stamp mills, handsorting, screens, jigs, and tables
1910's	Jaw crushers, grinding, jigs, tables, and flotation for slimes
1920's	Jigs and flotation
1930's	Jigs, flotation, magnetic, and heavy media
1950's	Heavy media and flotation
1960's	Flotation

In 1969, of 51 operating U.S. lead and zinc mills it was reported that 41 used flotation as the principal milling method, 2 used gravity separation methods, 5 used both gravity and flotation, 1 used heavy media and flotation, 1 used a chemical method and flotation, and 1 mill circuit included a combination of flotation, gravity and chemical treatment. This trend is consistent through the present day where the vast majority of the operations apply the flotation method of beneficiation.

Waste Material From Lead-Zinc Ores

The waste material from lead and zinc ores consists mainly of liquid and solid waste. These wastes can be further categorized as wastewater from the mine or the milling operation and solid waste in the form of mine waste rock (overburden, etc.) or solid tailings from the milling operation.

Liquid Waste

Mine wastewater can result from several sources including groundwater, hydraulic backfilling, and to a lesser extent surface water. Potential problems can be encountered when mine wastewater reacts with heavy metals placing these metals into solution. This is a function of geological and hydrological conditions restricted to the presence of such acid-forming sulfide minerals as pyrite in a heavily fractured or fissured geologic environment and in the absence of neutralizing carbonate minerals such as limestone. Tables 21 and 22, show the chemical characteristics of waste water from several mines with high solubility potential and several from low solubility potential, respectively.

TABLE 21 - Chemical characteristics of raw mine waters
from four operations indicating high solubilization potential

Parameter	Concentration in raw mine water, mg/L	
Alkalinity.....	14.6	- 167
Hardness.....	178	- 967
Total suspended solids (TSS).....	2	- 58
Total dissolved solids (TDS).....	260	- 1,722
Chemical oxygen demand (COD).....	15.9	- 95.3
Total oxygen content (TOC).....	1	- 11
Oil and Grease.....	0	- 3
P.....	0.020	- 0.075
Ammonia.....	0.05	- 4.0
Hg.....	0.0001	- 0.0013
	0.0001	- 0.0001
Pb.....	0.1	- 0.3
Zn.....	1.38	- 38.0
Cu.....	0.02	- 0.04
Cd.....	0.016	- 0.055
Cr.....	0.17	- 0.42
Mg.....	0.02	- 57.2
Fe.....	0.12	- 2.5
Sulfate.....	48	- 775
Chloride.....	0.01	- 220
Fluoride.....	0.06	- 0.80
pH <u>1/</u>	3.0	- 8.0

1/ Value in pH units.

Source: Greber (21, p. 194.)

Table 22 - Chemical characteristics of sampled raw mine waters from three lead-zinc operations showing low solubilization

Parameter	Concentration in raw mine water, mg/l		
Alkalinity.....	180	-	196
Hardness.....	200	-	330
Total suspended solids (TSS).....	2	-	138
Total dissolved solids (TDS).....	326	-	510
Chemical oxygen demand (COD).....	10	-	631
Total oxygen content (TOC).....	1	-	4
Oil and Grease.....	3	-	29
P.....	0.03	-	0.15
NH ₃	0.05	-	1.0
Hg.....	0.0001	-	0.0001
Pb ^{1/}	0.2	-	4.9
Zn.....	0.03	-	0.69
Cu.....	0.02	-	
Cd.....	0.002	-	0.015
Cr.....	0.02	-	
Mg.....	0.02	-	0.06
Fe.....	0.02	-	0.90
Sulfate.....	37	-	63
Chloride.....	3	-	57
Fluoride.....	0.03	-	1.2
pH ^{2/}	7.4	-	8.1

^{1/} Data may reflect influence of acid stabilization on sediment.

^{2/} Value in pH units.

Source: Greber (21, p. 195.)

Tailings water from the lead-zinc flotation mills is the other major source of liquid waste. The waste material consisting of between 25 and 50 percent solids (gangue material from milling, unrecovered lead-zinc and other minerals, and reagents used in flotation) are transported hydraulically to tailings ponds where in most instances the solids are allowed to settle out and the water then either recycled to the milling operation or discharged. Table 23 shows the characteristics of the waste water and raw and treated waste loads from five flotation mills. This data illustrates the wide variations in tailing wastewater due to different ore mineralogy, reagents, and grinding practices.

Solid Waste

As shown previously in Figure 40, solid waste from a mining operation consists of two major sources: mine waste rock and tailings solids produced from the milling of mineral ore. For the lead-zinc ores where the majority is extracted by underground mining operations the ratio of mine waste rock to mill tailing is quite low. The solid material from the mill tailing is allowed to settle with the waste water eventually recycled or discharged. The content of these tailings consists mainly of inert silicious material, however, as indicated in Table 23, some heavy metals and reagents used in the mill operation are discharged into the tailings ponds and could pose potential problems depending on climatic, hydrological, and operational conditions.

TABLE 23. - Range of constituents of wastewater and raw waste loads from five selected mines

Parameter	Range of raw waste load					
	Range of concentration in, wastewater, mg/L		Per unit ore milled, g/t		Per unit concentrate produced, g/t	
	lower limit	upper limit	lower limit	upper limit	lower limit	upper limit
Alkalinity.....	26	609	410	1,600	1,450	10,200
Hardness.....	310	1,760	460	4,700	2,290	32,500
Total suspended solids (TSS)..	2	108	7	285	30	2,000
Total dissolved solids (TDS)...	670	2,834	940	8,500	4,800	50,900
Chemical oxygen demand (COD)...	71.4	1,535	6	4,800	30	50,000
Total oxygen content (TOC)....	11	35	6.35	130	30	580
Oil and grease.....	0	8	5	21	30	130
MBAS surfacants.....	.18	3.7	.236	13	2.05	60.7
P.....	.42	.150	.108	.876	.54	2.54
Ammonia.....	.05	14	.064	26.4	.32	185
Hg.....	.0001	.1	.00013	.0026	.00168	.130
Pb.....	.1	1.9	.127	6.9	.900	32.2
Zn.....	.12	.46	.089	17.2	.62	86.0
Cu.....	.02	.36	.026	.158	.18	1.96
Cd.....	.005	.011	.008	.018	.18	8.85
Cr.....	.02	.67	.026	1.77	.18	1.36
Mg.....	.02	.08	.026	.290	.45	10.0
Fe.....	.05	.53	.064	1.16	.012	.198
Cyanide.....	.01	.03	.013	.109	.091	.509
Sulfate.....	295	1,825	130	4,800	1,260	33,700
Chloride.....	21	395	20	870	210	4,070
Fluoride.....	.13	.26	.370	.944	230	5.45
pH ^{1/}	7.9	8.8	-	-	-	-

^{1/} Value in pH units.

Source: Greber (21, p. 197)

Gold in the United States

Commercial gold mining in the United States began about 1800 in North Carolina. An important early gold discovery was that at Sutter's Mill in California in 1848. Later discoveries followed in many other Western States and Territories.

Early mining was largely by placer methods with a multitude of miners working stream deposits (placers) by various hydraulic techniques. The gold was recovered by gravity separation or by amalgamation with mercury. In the 1860's, the more difficult underground mining of lode deposits, the sources of the placers, became important. Cyanidation, a chemical process for gold extraction, was introduced about 1890. The flotation process allowed the concentration of finely ground ores by selective adherence of mineral particles to rising bubbles. It was first used for gold ores around 1900 and came into general use about 30 years later.

In 1981, 71 percent of domestic production came from precious metals ores, and 27 percent was produced as a byproduct of copper and other base metal production. Placer gold production has declined to about 2 percent of the total in recent years. Changes in ore type, and associated changes in processing techniques over time, can be seen through examination of past industry data (Tables 24 and 25).

TABLE 24. - Gold recovered from various ore types, percent

Year	Dry siliceous ores	Base metal ores	Placers
1917.....	62	12	26
1926.....	58	21	21
1935.....	67	9	24
1947.....	39	29	32
1957.....	43	38	19
1967.....	69	27	4
1977.....	60	38	2
1981.....	71	27	2

Source: U.S. Bureau of Mines Minerals Yearbook, 1917, 1926, 1936, 1947, 1957, 1967, 1977, 1981.

TABLE 25. - Gold recovered from all sources by different processes, pct

Year	Amalgamation	Cyanidation	Smelting	Placers
1917.....	21	30	24	25
1926.....	31	20	29	20
1935.....	29	17	30	24
1947.....	18	13	37	32
1957.....	24	14	43	19
1967.....	25	39	32	4
1977.....	2	55	41	2
1981.....	1	66	31	2

Source: U.S. Bureau of Mines Minerals Yearbook, 1917, 1926, 1936, 1947, 1957, 1967, 1977, 1981.

Gold is recovered by cyanidation, amalgamation, flotation, and gravity concentration, or by a combination of these processes. Normal mill recovery rates range from 92 to 96 percent. When gold is associated with copper ores, it travels with the base metal through concentration and smelting to the refining stage. It is eventually separated from the anode slimes that accumulate in electrolytic refining cells, and is recovered as gold bullion in the precious metals refineries.

Tailings disposal can be a significant cost item. To avoid water pollution by cyanide wastes, tailings effluents and ground water cyanide levels must be monitored. The problem dissipates with time, however, because of natural oxidation of cyanide to harmless compounds. In an emergency, the breakdown can be induced quickly with chlorine gas.

Because of the danger of pollution and advances in extractive metallurgical technology, the use of mercury amalgamation in large gold operations is now virtually nonexistent. Mercury and arsenic can be natural contaminants of gold ores, requiring troublesome or costly extraction processes. Other potential pollutants or byproducts from gold mining include tellurium, bismuth, antimony, and thallium. Two iron sulfides, pyrite and pyrrhotite, commonly occur in gold deposits and can be a source of stream pollution as they oxidize to sulfates and other soluble compounds. Waste dumps, mill tailings, and excavations are increasingly subject to public scrutiny, and control costs must be taken into account along with other operating factors.

Processing of Gold Ores

Gold ores are processed by four different techniques depending on the mineralogical characteristics of the ore, and the economics of the process. Figure 46 schematically displays each of these techniques (gravity separation, amalgamation, cyanidation, and flotation), and indicates the processing step responsible for air emissions and liquid and solid wastes. Each of these four techniques is discussed briefly in the following sections of the paper with an emphasis on identifying waste streams and milling waste disposal practices. Table 26 shows analysis of liquid wastes from typical gold ores beneficiation.

Historically, lode gold mining utilized gravity separation and amalgamation. These techniques gave way to flotation and cyanidation as the composition of the ore changed and the health hazards of mercury were recognized. Today, the majority of gold ores are processed by one of several cyanidation techniques. The chemistry of cyanide dissolution of gold is common to each of these techniques. Therefore, a separate section on cyanide chemistry, control migration, and environmental persistence is included.

Gravity concentration using jigs or plane tables is an important process in the recovery of gold too coarse to dissolve during leaching treatment or to float in the froth flotation method. Furthermore, gravity methods are usually used in placer operations. As an example of the extent of gravity process application, at the Homestake Mining Company, Lead, South Dakota, about 28 to 30 percent of the gold in the ore is recovered in gravity traps.

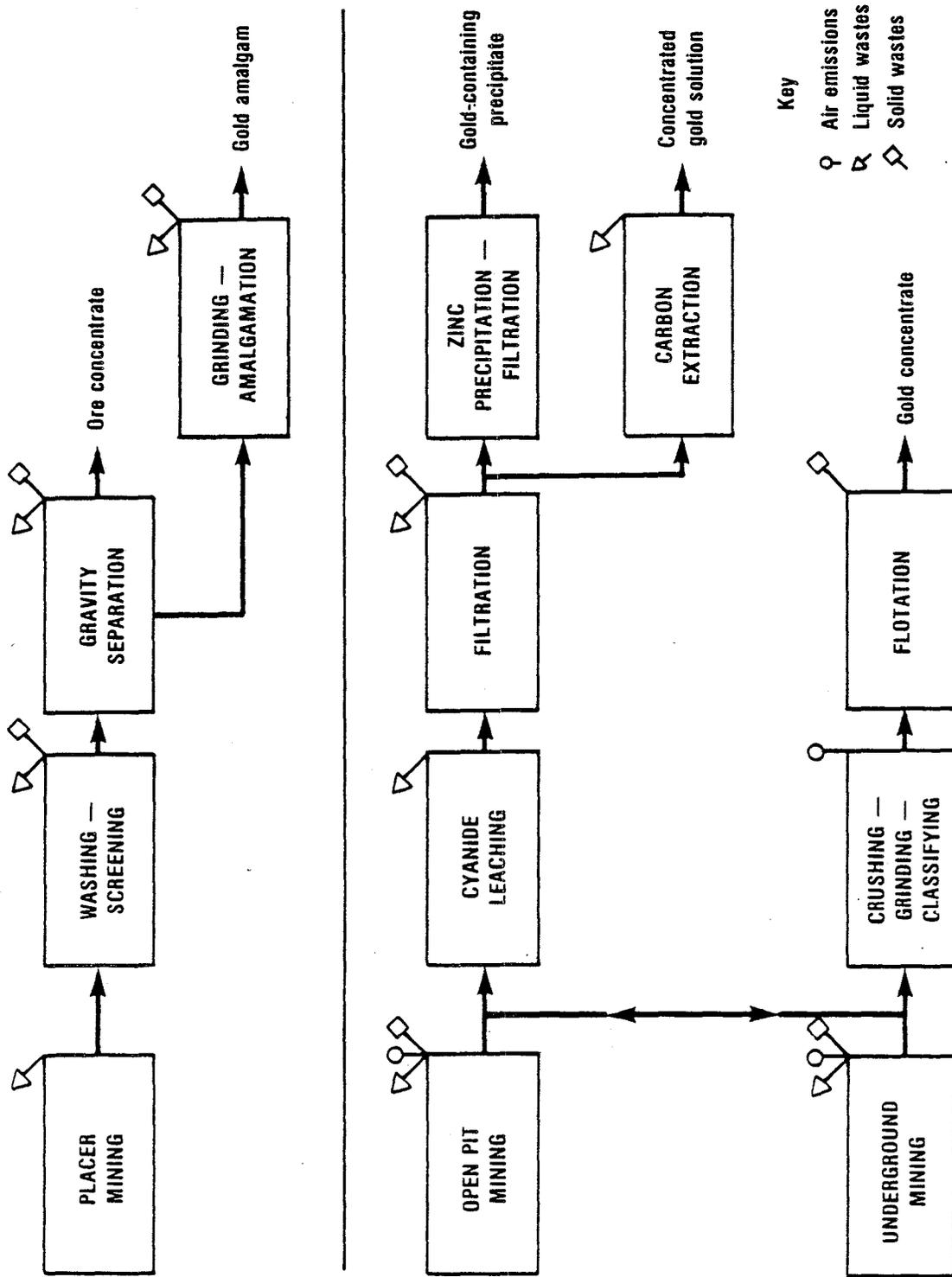


Figure 46 - Flow chart of the mining and milling of gold ores (21, p. 176)

TABLE 26. - Summary of liquid wastes from beneficiation of gold ores

Source and pollutant	Liquid Discharge Mg/L
Grinding/amalgamation:	
Total suspended solids.....	2,871
Total dissolved solids.....	.930
Total organic carbon.....	.199
Chemical oxygen demand.....	.066
Cu.....	.0002
As.....	.0004
Fe.....	.0087
Zn.....	.0075
Pb.....	.0006
Cd.....	.0001
Hg.....	.0000064
Cyanide.....	.00006
S.....	.0029
Cyanide leaching:	
Total suspended solids.....	545,000
Total dissolved solids.....	4,536
Chemical oxygen demand.....	43
Cyanide.....	5.06
As.....	.05
Cd.....	.10
Cr.....	.06
Cu.....	.17
Fe.....	.5
Pb.....	.1
Mg.....	.02
Zn.....	3.1

Source: Battelle Columbus Laboratories. (4)

The amalgamation process, which has been widely used in a variety of forms from earliest times, depends upon the wetting and alloying of metallic gold with mercury. Because of its high specific gravity and tendency to be collected by larger masses of liquid mercury or mercury-coated surfaces, this alloy, or amalgam, is readily separated from the lighter constituents of the ore pulp.

Mill water from amalgamation is discharged to a tailings pond. Decant from this pond may be discharged into a stream, or may flow into a smaller settling pond prior to discharge into a stream. Data from one mill indicate that the use of two settling ponds achieves 99.9 percent total suspended solids removal. Even so, the potential hazards related to the liberation of mercury in the environment has restricted the use of amalgamation in the United States.

Gold that is finely disseminated in pyrites and some low grade ores is recovered by flotation. The ore is crushed, wet ground in a ball mill, and classified. After conditioning, the pulp flows to a flotation tank. Reagents for gold flotation are usually soda ash, a xanthate, and a frother. The gold-containing minerals that float to the top are collected and sent to a disk filter for dewatering. The resulting gold concentrate is further processed at a smelter.

The froth flotation and smelting processes provided 31 percent of the 1981 U.S. gold production as a by- or co-product from base metal ores. Flotation also may be used to treat flotation tailings after the cyanide consuming copper sulfides have been recovered.

The principal method used in the milling of gold is cyanidation. The basic principle of the cyanidation process is that cyanide solutions have a preferential dissolving action for the precious metals contained in an ore.

The gold dissolution rate is dependent on the concentration of sodium cyanide and the alkalinity of the solution, the optimum pH being from 10 to 11. For efficient leaching, the gold should occur as free, fine-size, clean particles in an ore that contains no cyanicids or impurities that might destroy cyanide or otherwise inhibit the dissolution reaction. After the gold-bearing solution is either filtered from the ground pulp, or from separated crushed ore from the heap leach, the precious metals are recovered by precipitation with zinc dust or by absorption of the precious metal cyanide complex on activated charcoal.

The resulting "gold-free" barren solution contains free cyanide and metal-cyanide complexes of copper, iron, nickel, and zinc, as well as other impurities. These other impurities include reaction products of sulfur and cyanide and other compounds soluble in alkaline solutions such as arsenic, antimony, and silica, which dissolve simultaneously with the gold. Much of the barren solution is recycled for its remaining leaching potential but a

portion must be treated to reduce the cyanide content and discharged from the mill to avoid the deleterious build-up of these metal impurities which would subsequently interfere with the dissolution and precipitation of gold. Zinc is also present as a result of its addition as a precipitant for gold. Barren solution is used for washing the filter cakes to displace and recover residual gold-bearing solution in the filter cake. In some mills the filter cake is given an additional water wash to reduce the cyanide in the water with the solids before they are pumped to the tailing impoundment area.

Consequently, two principal cyanide containing waste streams are discharged from the conventional gold mill - waste barren solution and leached tailings slurry.

Waste Material From Gold Ores

The waste material from gold ores consist of both liquid and solid waste. This waste can be further categorized as wastewater from the mine or the milling operation and solid waste in the form of mine waste rock (overburden, etc.) or solid tailings from the milling operation.

Liquid Waste

Mine wastewater can result from several sources including groundwater, hydraulic backfilling, and to a lesser extent surface water runoff. Problems can potentially be encountered when mine wastewater dissolves with heavy metals placing these metals into solution and forming mine acid water.

Tailings from the gold mills are the other major source of liquid waste. The waste material consisting of between 25 and 50 percent solids (gangue material from milling, unrecovered heavy metal minerals, and reagents including cyanide compounds) are transported hydraulically to tailings ponds where in most instances the solids are allowed to settle out and the clear water is then either recycled to the milling operation or discharged..

Solid Waste

Solid waste from a mining operation consists of two major sources, mine waste rock and tailings solids produced from the milling of ore. This was illustrated in figure 40. The mine waste rock from a surface mining operation is removed to provide access to the ore body and is deposited in a predesignated location. Large amounts of mine waste rock can be produced from open pit operations; however, in underground mines this is not a critical problem. Solid tailings however are of great concern due to the large volumes of ore that must be processed to recover only a small amount of gold and the reagents, such as sodium cyanide, which are in the waste streams.

Cyanide in Mill Tailings Waste

A variety of cyanide compounds are present in the barren solution and waste effluents resulting from cyanidation of gold-bearing ores. In general, the stronger the cyanide complex, the less free cyanide ion required to maintain it in solution and the less readily it dissociates to yield cyanide ions. In some cases, a metal forms several complexes with successively higher cyanide content.

Cyanide and metal-cyanide complexes are present in process streams from different mills, but both the relative and total concentrations vary considerably. The principal constituents of barren process streams are simply cyanides of sodium or calcium, and the cyanide complexes of copper, iron (less frequently), nickel, zinc, thiocyanates and, at some mines, arsenic.

The analyses of waste barren solutions discharged from a number of Canadian gold mills and the final decants are shown in Table 27.

The data show that in these Canadian tailings impoundments, the concentration of pollutants is reduced considerably. Cyanide concentrations can be decreased through physical and chemical action, dilution, vaporization, and precipitation. Many U.S. operations are quite different from Canadian practice and experience. Differences include ore types, leaching practices, recovery methods, and climate. In some areas of the U.S., ground water contamination may be a much more serious problem than in Canada.

Migration of Cyanide

The migration of high concentrations of free cyanides from land disposal of liquid cyanide wastes has been observed at several sites. However, because the toxicity of cyanide is well known, treatment of wastes is a standard practice. Little information is available on movement of either free or complex cyanides at low concentration through soils or tailings.

TABLE 27.- Chemical analyses of Canadian gold mill barren solutions and tailings pond effluents ^{1/}

Solution	Volume (IMPD) ^{2/}	Fe	Ni	Zn	Cu	Cyanide	Suspended solids	SCN
Plant A:								
Barren.....	N/A	35.7	2.9	17.9	73	220	N/A	180
Effluent...	200,000	.6	.4	.82	2.4	13	17	N/A
Plant B:								
Barren.....	N/A	21.4	10.0	62.5	6.7	300	N/A	54
Effluent...	516,000	8.2	.7	.70	1.1	3.3	37	N/A
Plant C:								
Barren.....	N/A	.4	1.7	84.1	11	610	N/A	400
Effluent...	1,500,000	.3	.1	.20	2.3	6.8	24	N/A
Plant D:								
Barren.....	N/A	.1	.3	13.9	6.1	86	N/A	42
Effluent...	7,200,000	NA	.4	.19	.3	.3	10	N/A
Plant E:								
Barren.....	N/A	.1	9	31.0	29	74	N/A	50
Effluent...	1,678,000	NA	.2	.13	.5	1.2	19	N/A
Plant F:								
Barren.....	N/A	.8	3.1	12.0	300	310	N/A	NA
Effluent...	915,000	NA	1.8	.60	16.0	26.5	53	N/A

NA - Not available

N/A - Not applicable

^{1/} These analyses are from grab samples taken in 1978. Arsenic was found in the Waste Barren solution from Canadian ores in the range of 0.01 to 0.03 mg/L. The range reported in the final tailings effluent was 0.01 to 21.4 mg/L.

^{2/} Imperial gallons per day.

Adapted from Harrison 1979 (23)

A 1976 EPA laboratory study (57) of cyanide movement in different soils showed that some cyanides are quite immobile while others may be more mobile. Ferric ammonium hexacyanoferrate was apparently very immobile. Cyanide as hexacyanoferrate ions and cyanide ions in water were found to be very mobile in soils. Cyanide as potassium cyanide in natural landfill leachate was found to be less mobile. Soil properties such as low pH, percent free-iron oxide, and kaoline, chlorite, and gibbsite type clay tend to increase attenuation of cyanide in the three forms tested. High pH, presence of free calcium carbonate, low clay content and the presence of montmorillonite clay tend to increase the mobility of the cyanide forms. The cyanide salts of most cations are soluble but move only a short distance through soil before being biologically converted under aerobic conditions to nitrates or fixed by trace metals through complex formation. Under anaerobic conditions, cyanides denitrify to gaseous nitrogen compounds which enter the atmosphere. The movement of cyanide in soil is usually quite limited because it is either complexed by trace metals or metabolized by various microorganisms. If a high concentration of cyanide is found in the soil, it usually can be attributed to improper industrial waste management procedures.

Environmental Persistence of Cyanide

Free cyanide occurs only rarely in nature because of the high reactivity of the molecule. In the environment cyanides are either connected to other compounds or are fixed by trace metals, with which they form strong complexes. High concentrations of cyanide in soil and water nearly always are the result of improper waste disposal. In small concentrations, the

free cyanide will (1) react with various forms of sulfur from pyrites and other mineral constituents to form thiocyanate, (2) complex with trace metallic ions present, (3) be released to the atmosphere and dispersed, (4) be metabolized by microorganisms, (5) oxidize to cyanate and degrade chemically to carbon dioxide and ammonia, (6) react with organic matter, and/or (7) hydrolyze to ammonia and formate.

In soils, free cyanide ions are not strongly adsorbed or retained. As noted earlier the cyanide salts of most cations are soluble but move only a short distance through soil before being biologically converted under aerobic conditions to nitrates, or fixed by trace metals through complex formation. Under anaerobic conditions, cyanides denitrify to gaseous nitrogen compounds which enter the atmosphere. The carbon and nitrogen of cyanide are converted to carbonate and ammonia, respectively, in nonsterile soils.

Silver in the United States

Present-day extractive metallurgy of silver was developed over a period of more than 100 years. Initially, silver as the major ore product, was recovered from rich, yet simply structured oxidized ores by relatively crude methods. As the ores became more complex and leaner, a more complicated extractive technology was developed. Today, silver production is predominantly a co-product or byproduct geared to the production of lead, zinc, and copper via the processing of complex sulfide ores by froth flotation and smelting. Simple silver and gold-silver ores processed by amalgamation and/or cyanidation now contribute only a small fraction of the world production of silver. Changes in ore type, and associated changes in processing techniques over time, can be seen through examination of past industry data.

Due to the fact that silver production is tied to the production of copper, lead, zinc, and gold, this section describes the methodology for the recovery of silver as either a coproduct or byproduct of these other lode-mine minerals. Also, a brief description of typical process waste, liquid or solid, is included in this section. Additional information on potential pollutants can be found in combination with gold ores in the section on Gold in the United States.

Processing of Silver Ores

Historically, many of the mining districts were first exploited for their precious metals of silver and gold content from the high-grade easily recoverable portions of the deposit. These high grade ore bodies were soon depleted. With technological advances these same deposits were later found to be profitable when mined for their lead, zinc and copper content with recovery of the silver as a byproduct. This is illustrated to some extent in Table 28. The recent shift back to silver production from siliceous ores is mainly due to increased market prices of both gold and silver and hence the return to the gold-silver ores. It is interesting to note that many of the technological advances in the area of froth flotation that enabled the processing of lower grade copper and lead-zinc deposits also provided for the recovery of silver at appreciably lower grades.

Three basic methods of milling were used in the recovery of silver either as the primary, coproduct or byproduct. These three processes are amalgamation, cyanidation, and flotation. As is illustrated in Table 29 the majority of the silver recovery has been realized from the smelting of concentrates (mainly from flotation mills), while recovery by cyanidation has been dependent on the type of ores prevalently being mined at that time (Table 28). Silver recovered by amalgamation constituted only a small percentage of the total and has declined to the point that this process is almost non-existent.

TABLE 28. - Silver recovered from various ore types, pct

Year	Dry siliceous ores	Base metal ores	Placers
1917.....	30	70	.2
1926.....	21	79	.1
1935.....	40	60	.2
1947.....	26	74	.2
1957.....	32	68	.1
1967.....	40	60	.02
1977.....	43	57	.01
1981.....	54	46	.01

Source: U.S. Bureau of Mines Minerals Yearbook, 1917, 1926, 1936, 1947, 1957, 1967, 1977, 1981.

TABLE 29. - Silver recovered from all sources by different processes, pct

Year	Amalgamation	Cyanidation	Smelting	Placers
1917.....	.4	16.0	83.4	.2
1926.....	.3	8.0	91.6	.1
1935.....	.9	3.5	98.8	.2
1947.....	.2	0.8	98.8	.2
1957.....	.2	0.7	99.0	.1
1967.....	.3	0.2	99.5	.02
1977.....	.04	3.4	96.5	.01
1981	.005	11.0	88.9	.1

Source: U.S. Bureau of Mines Minerals Yearbook, 1917, 1926, 1936, 1947, 1957, 1967, 1977, 1981.

Between the early years of the 16th century and the last decade of the 19th century, amalgamation methods were the most important silver-recovery processes. These now obsolete processes reached their maximum use in the rich silver camps of Nevada, Colorado, and Montana. Currently amalgamation is applied to a limited extent only on placer and lode-type gold ores, wherein silver is a metal alloyed with the gold. This trend away from amalgamation was influenced by the recognition of the potential health hazards of mercury in the 1960's.

A few decades after its patent date in 1837, cyanidation had almost completely superseded all previously used silver amalgamation, brine, and hyposulfite leach processes. The current utilization of cyanidation as a silver production method is attributable to the near exhaustion of amenable types of silver ores. Although some silver ores and tailings are still processed in Mexico and Peru by cyanidation, the method finds its greatest use for recovery of gold-silver from simple lode-type ores.

The cyanide process is comparatively simple and applicable to many types of gold-silver ores, but efficient low-cost dissolution and recovery of the gold and silver is possible only by careful process control of the many unit operations involved. Effective cyanidation depends on maintaining and achieving the following conditions: (1) The gold and silver must be adequately liberated from the encasing gangue minerals by grinding and, if necessary, roasting and preliminary acid leaching. (2) The concentration of "free" cyanide and dissolved oxygen in the leaching solution must be kept at a level that will enable reasonably fast dissolution of the gold and silver. (3) The "protective" alkalinity of the leach solution must be maintained at a level that will minimize consumption of cyanide by the dissolution of other metal-bearing minerals. (4) The leach residues must be thoroughly washed without serious dilution to reduce losses of dissolved values and cyanide to acceptable limits. (5) The pregnant solution must be clarified and deaerated for effective precipitation of the gold and silver values. Discussion of cyanide emission problems can be found in the section on gold ores.

Since the advent of the flotation process, silver has increasingly been recovered from the flotation of low-grade and complex primary sulfide ores. Only about one-third of the new silver produced is derived from complex ores wherein silver is the principal metal value; the remainder is byproduct silver, chiefly from the processing of base-metal ores. This is due in part that these ores are less abundant economically and physically, than the sulfide ore type deposits.

Argentiferous tetrahedrite and galena, argentite, pyrargyrite, and proustite are the usual silver-bearing minerals in the ores. The lead and zinc are invariably present as galena and sphalerite, whereas the copper occurs chiefly as chalcopyrite, bornite, chalcocite, covellite, and native copper. Practically all the ores presently milled require fine grinding to liberate the sulfide minerals from one another and from the gangue minerals.

Although the ores are notably different in mineral complexity and grade, ore processing is remarkably similar. The ores are concentrated by selective froth flotation to produce individual lead, copper, zinc, and infrequently, silver concentrates. The copper and lead concentrates are smelted to produce lead and copper bullions from which the silver is recovered by fire and/or electrolytic refining. The silver-bearing zinc concentrates are commonly processed by leaching and electrolytic methods, but retorting methods also are used. Silver is ultimately recovered as a byproduct from the zinc-plant residues.

The froth flotation process, as developed from its first domestic application in 1911, has changed large tonnages of worthless sulfide-bearing rock into the exploitable mineral deposits that are the source of nearly all our domestic primary silver, copper, lead, and zinc. The advances in the practice of froth flotation during its application to sulfide ores have chiefly been in the development of reagent combinations and conditions enabling selective recovery of many different sulfide minerals in separate concentrates of high quality. Selective froth flotation processing can effectively and efficiently beneficiate almost any type and grade of sulfide ore.

Waste Material from Silver Ores

Both liquid and solid wastes from silver ores are generated in several steps of the processing cycle. Figure 46 is a composite flow diagram of the common silver ore processing steps from mining to refining which include ore types where silver is a coproduct or byproduct. Processing steps that produce wastes for disposal are identified.

Liquid Waste

The silver mining and milling industry, as in the other mining systems discussed in this paper, have two basic sources of liquid waste, that produced from the interesection of aquifers in the course of mining and the liquid waste produced in the beneficiation process. Many of the same problems of mine waste water described in the previous sections on copper, lead-zinc, and gold apply to that found in the silver mines; and because silver is in general a byproduct of these other base metals the effluents presented previously are representative of those found in conjunction with silver.

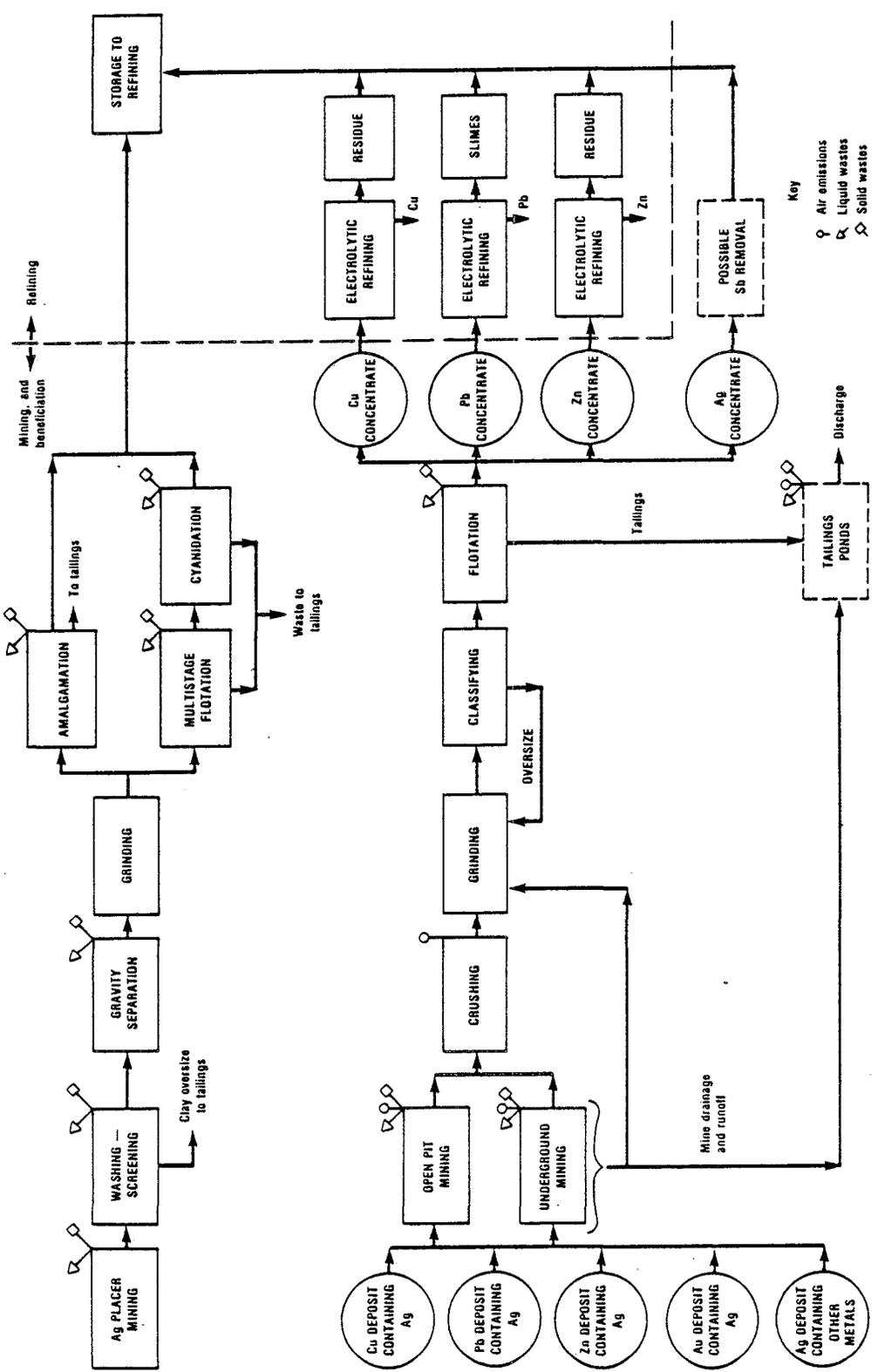


Figure 47 - Flow chart of the mining and milling of ores containing silver (21, p. 221)

Typical silver mining operations have little effluent treatment or control other than allowing the solids to settle out in ponds. Estimated control efficiencies for treating an average silver mine effluent by sedimentation are as follows: total suspended solids, 20 percent; copper, 10 percent; lead, 5 percent; zinc, 14 percent; mercury, 25 percent. When lime precipitation is used in conjunction with the settling, control efficiencies are increased by the following additional percentages: copper, 45 percent; zinc, 17 percent; and mercury, 33 percent. When sulfide precipitation and close control are practiced in addition, both lead and mercury levels are reduced an additional 40 percent.

Table 30 presents wastewater discharge rates for a hypothetical silver mine. The figures are based on an arithmetic average of five large silver mines.

TABLE 30. - Summary of wastes from processing of silver ores

Source and pollutant	Liquid Discharge kg/t	
Flotation:		
Total Suspended Solids.....	1.859	
Cyanide.....	.00019	
Cd.....	.00038	
Cu.....	.0016	
Hg.....	.00063	
Pb.....	.0027	
Zn.....	.0024	
Cu.....	.00034	
Tailings:		
Total Suspended Solids.....	.069	
Cu.....	.00031	- .00017
Pb.....	.00065	- .00034
Zn.....	.0021	- .0017
Hg.....	.000010	- .0000034

Source: Battelle Columbus Laboratories (4).

Froth flotation is the most common process now used in beneficiation. The volumes of the waste streams discharging from mills processing silver ore range from 400,000 to 840,000 gallons per day. The amount of solids contained in these waste streams vary from 300 to 1,700 tons per day.

Because most silver is mined in conjunction with several other minerals, separation is accomplished by a series of flotation cells, and many reagents are accumulated in the final wastewater. This multiplicity of reagents makes the recycling of flotation water difficult, if not completely impractical.

Effluent from grinding and amalgamation is high in suspended solids. Mercury is the prominent agent used in this process; therefore, the effluent is potentially toxic. Cyanide leaching results in high levels of soluble metals in which both the cyanide and heavy metals are potentially toxic.

Solid Waste

Because more than 300 U.S. mines produce silver from a wide variety of ores, it is difficult to quantify the solid waste from a silver mine. Silver has such a high value, that ore bodies containing even small concentrations of silver are mined. The silver is almost completely extracted, but this leaves large quantities of overburden, gangue, and tailings to be disposed.

Large volumes of mine waste rock and ore are moved in silver operations that employ open pit operations, while in others that employ underground mining operations the amount of mine waste rock is insignificant in comparison to the ore, and hence the mill tailings produced. In some of these mines waste rock may be used as backfill such as in the vein type mining operations of Idaho. Yet in others utilizing the room-and-pillar method most of the waste rock must be disposed of at the surface.

Solid waste generated by washing, gravity separation, cyanidation, amalgamation, and flotation is generally sent to a tailings pond, where most of the solids settle out. Because all these solid wastes use water as the separation and transport medium, the ultimate disposal method is tied to whatever control is used on the liquid waste. Liquid waste control involves the ultimate burial and revegetation of the tailings.

SUMMARY

Over the last 72 years of the mining of lode-mine commodities copper, lead/zinc, gold, and silver it is estimated that approximately 9.4 billion tons of mill tailings have been created. This waste material has been deposited either directly into the nearby creeks, rivers, or lakes, or, in the case of arid regions, in tailings piles. This was common practice prior to enforcement of environmental laws. In more recent years, the standard practice of impounding mill waste in tailing ponds has been employed. The solid material is allowed to settle and the water is then discharged to the environment.

It is estimated that approximately 81 percent of the waste material, from lode-mine operations, is a product of copper operations. This equates to approximately 7.5 billion tons. The majority of this potential tonnage is found in the states of Arizona, Utah, Michigan, and Montana. For primary lead/zinc operations it is estimated that 1.4 billion tons (15 percent of the total) of mill tailings have been produced over the past 72 years, mostly from Missouri, Idaho, Tennessee, and Oklahoma. Gold-silver operations accounted for the remainder of the waste material estimated at about 330 million tons (3.6 percent) and distributed throughout the western states, mostly in the states of South Dakota and Nevada.

Based on the content of these tailings, possible effects on the environment should not be stated or examined in generalities. Many factors would influence the classification of particular tailings as hazardous material. Such factors might include changes in operational and technological treatment of the ore over time, local surface and ground water, characteristics, permeability of the tailings, as well as, the mineral and chemical content of the tailings. In addition, factors such as secondary utilization of the tailings as land fill, road surfacing or the possible nuisance value of the tailings because of their proximity to population centers may be involved in classification of specific tailings. To evaluate the impact mine-mill waste material might have on the environment a site specific analysis should be performed and might require drill sampling and ground water monitoring.

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