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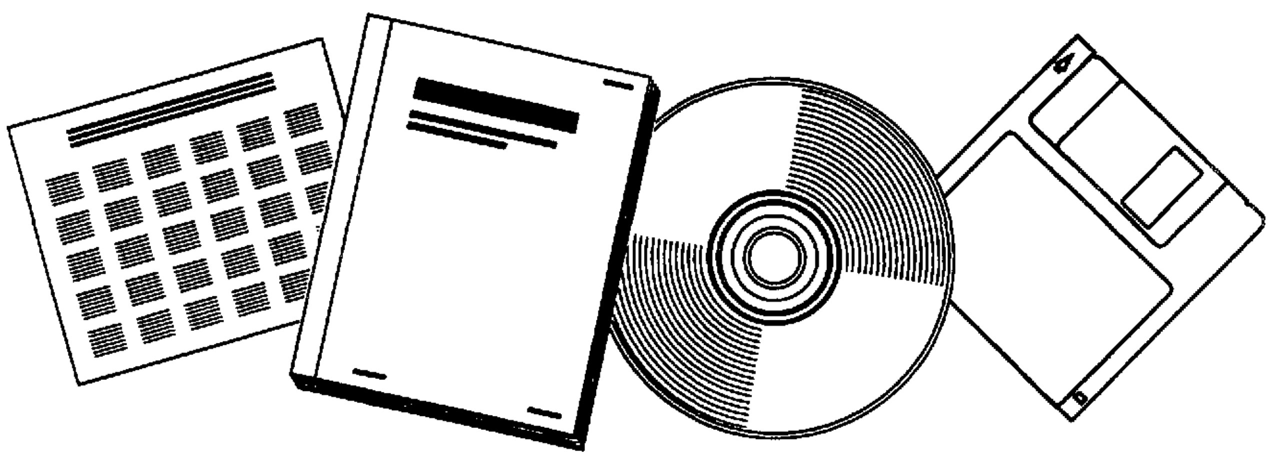
AVAILABILITY OF MINING WASTES AND THEIR POTENTIAL FOR USE AS HIGHWAY MATERIAL -- VOLUME II: LOCATION OF MINING AND METALLURGICAL WASTES AND MINING INDUSTRY TRENDS - FINAL REPORT

VALLEY FORGE LABORATORIES, INC.
DEVON, PA

MAY 76



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AVAILABILITY OF MINING WASTES AND THEIR POTENTIAL FOR USE AS HIGHWAY MATERIAL

Vol. II. Location of Mining and Metallurgical Wastes and Mining Industry Trends

May 1976

Final Report

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16. Abstract
Over 1.6 billion tons of mining and metallurgical wastes are produced each year in the United States. Many of these materials possess properties which make them potentially useful for construction purposes. Although some of these materials have been successfully used in certain phases of highway construction, most are avoided in favor of conventional materials. More information is needed regarding the types, locations, quantities, and nature of these wastes.

This study was performed to determine the availability of mining and metallurgical wastes and to assess their potential for use in highway construction. A large number of information sources were used to develop an inventory and classification system for these wastes. Information presented in Volume II was obtained mainly from knowledgeable personnel in the mining industry and government agencies, supplemented by key reports and industry periodicals. Maps and tabulations of mineral wastes from 35 principal mining states are presented in this volume.

This is the second of three volumes, Volume I, published as FHWA-RD-76-106, is subtitled "Classification and Technical and Environmental Analysis"; Volume III, published as FHWA-RD-76-108, is subtitled "Annotated Bibliography."

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PREFACE

This is the second phase of a three-volume report. This report presents the findings of an investigation funded by the Department of Transportation, Federal Highway Administration (FHWA), under Contract Number DOT-FH-11-8784. The Contract Manager was Dr. W. Clayton Ormsby, Materials Division, FHWA.

The work was conducted during the period July, 1975 through June, 1976 by Valley Forge Laboratories, Inc. This volume of the report was prepared by Mr. Robert J. Collins, who was the Principal Investigator for the study.

Research on mining waste accumulations and predominant rock types associated with such accumulations was performed by Dr. William B. Fergusson, who also assisted in developing quantity estimates for specific mining waste locations. Dr. Karl Dean, formerly of the U. S. Bureau of Mines, reviewed the tabulations of mining wastes and the plotting of waste locations on state maps.

Much of the information used to locate and quantify specific waste accumulations or production areas was provided by personnel from the coal, steel, and mining industries. This information was mapped and tabulated on an individual state basis with the assistance of Messrs. George T. Kraus and Marc J. Steinbring. The state maps presented in this volume of the report were prepared by Mr. Jeff Amerine.

Typing of the draft was performed by Miss Venise Leamy, Mrs. Mildred Staley, and Mrs. Vicki Thompson. Final typing of the report was under the direction of Mr. Kevin Leahy.

Evaluation of waste samples was performed by Drs. Stanley K. Ciesielski, William B. Gergusson, and Edward M. Wallo and Messrs. Robert J. Collins, Richard Hollinger, and Richard H. Miller. T total of eighty-five different mining and metallurgical waste samples were provided by companies in the coal, steel, and mining industries. The samples proved to be extremely valuable in performing a technical evaluation of these waste materials.

A great deal of useful information was supplied by personnel from Industry, State and national government, State highway or transportation departments, and universities. This information supplemented the findings of a literature review of mining and metallurgical wastes.

Photographs in this volume of the report were prepared by Miss Jessica Garnett. Typing of the draft was performed by Miss Venise Leamy, Mrs. Mildred Staley, and Mrs. Vicki Thompson. Final typing of the report was under the direction of Mr. Kevin Leahy.

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1. LOCATIONS OF MINING AND METALLURGICAL WASTES BY STATE

The information presented in Volume II is designed to assist potential users of mining and metallurgical wastes in locating and evaluating sources of these materials. This Volume contains individual state maps which show the locations of mining and metallurgical waste sources in each state. These locations are plotted on the maps using symbols which correspond to the waste classification described in Chapter 4 of Volume I of this report.

Figure 1 is a legend which shows the appropriate symbols for each type of waste classification. These symbols are used consistently on all state maps. Mining and metallurgical waste locations are referenced by number on each state map and these numbers are cross-referenced to a table for each state. Asterisks indicate those locations with very large waste quantities. The tables present information on the type of waste; town and county of location; company producing the waste; estimated quantity; and mineralogical composition (if available).

The information presented in this Volume was derived from the following sources:

1972 Minerals Yearbook

Engineering and Mining Journal 1975 Directory of Mining and Mineral Processing Operations

1974 Directory of Iron and Steel Works of the United States and Canada

Correspondence from personnel in the mining and mineral processing industries

When using the tables in Volume II, it must be kept in mind that 1 short ton equals 0.9072 metric tons.

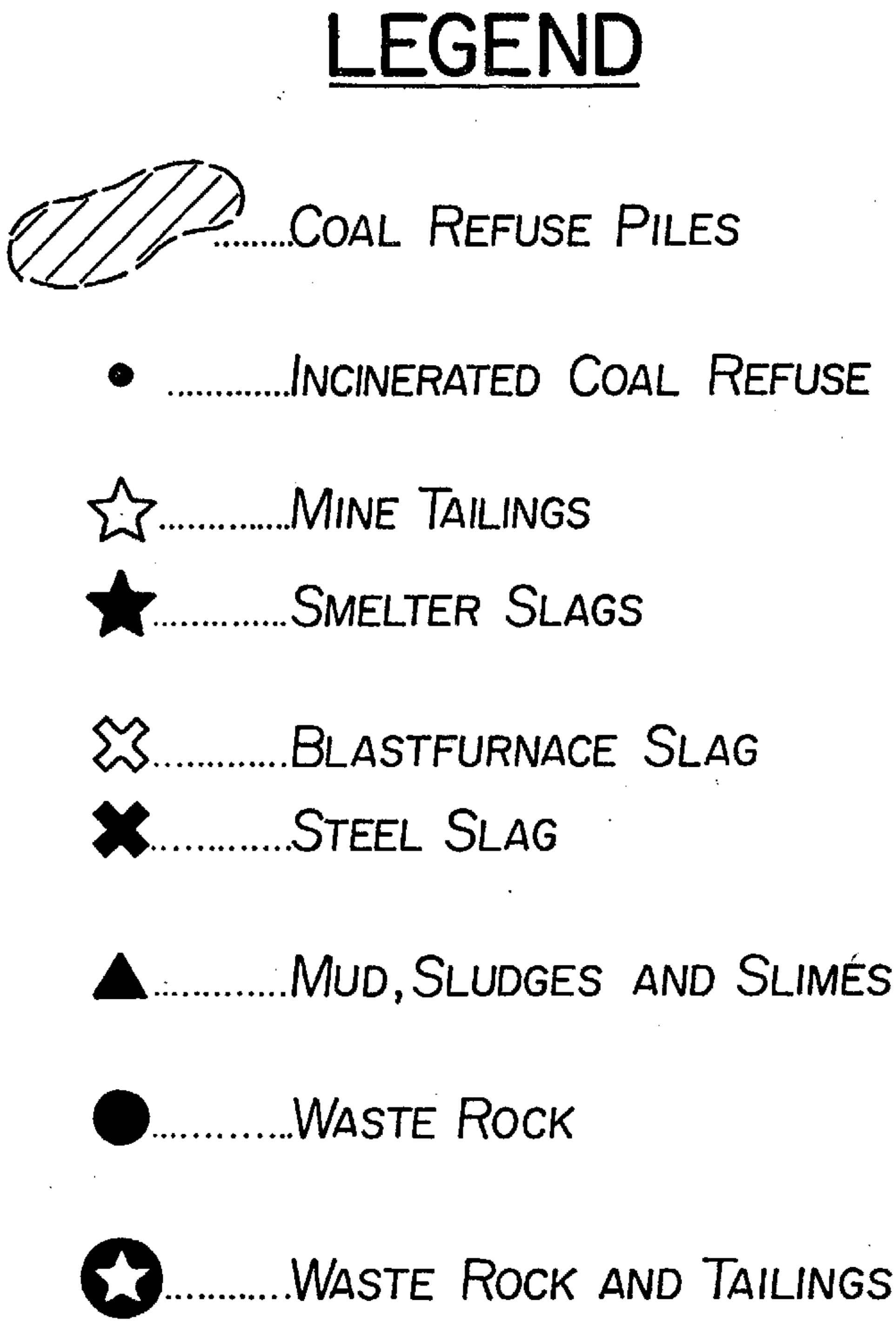

Figure 1. Legend for state maps showing mineral waste locations

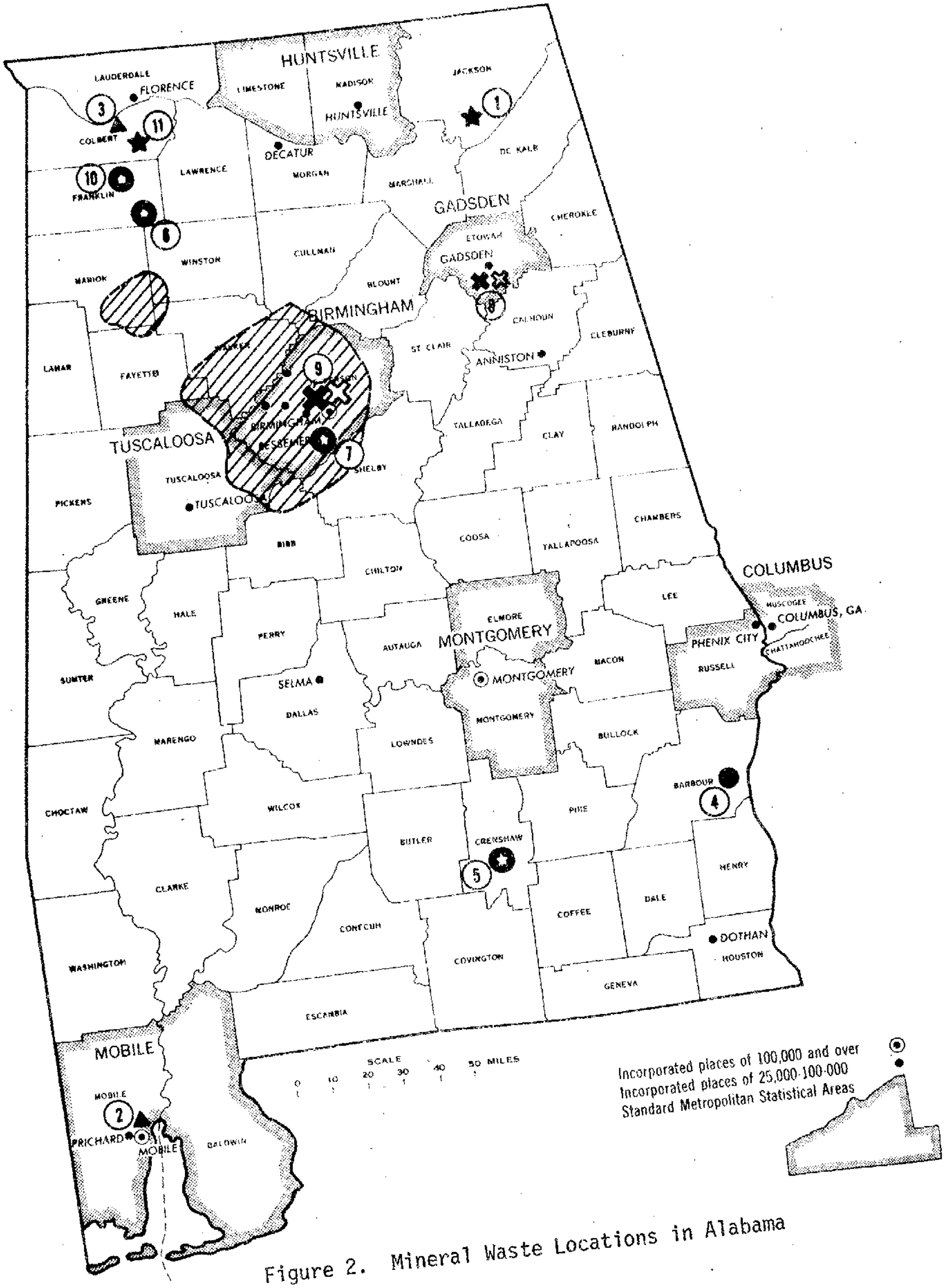

Figure 2. Mineral Waste Locations in Alabama

Table 1. Description of mineral wastes

ALABAMA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Revere Copper & Brass, Inc.	Primary smelter	Scotts-boro	Jackson	Slag			
2	Aluminum	Alcoa Aluminum	Refinery	Mobile	Mobile	Red Mud			
3	Aluminum	Reynolds Metals Company	Listerhill Reduction Plant	Shef-field	Colbert	Muds	150,000 tons/year		486,000 tons stockpiled
4	Aluminum	A.P. Green Harbison Walker	Barbour Open-pit mine	Eufaula	Barbour	Waste rock			
5	Aluminum	Glenwood Mining Company	Horn pit Open-pit mine	Luverne	Crenshaw	Waste rock & tailings		Dolomitic Limestone	
6	Aluminum	Shook and Fletcher	Blackburn Open-pit mine	----	Franklin	Waste rock & tailings		Dolomitic Limestone	
7*	Iron			Bir-mingham	Jefferson	Waste rock & tailings		Dolomitic Limestone	More than 10,000,000 tons stockpiled from past mining
8	Iron and Steel	Republic Steel Corp.	Blast Furnaces Steel Furnaces	Gadsden	Etowah	Blast Fur-nace and Steel Slag	350,000 tons/year of each type slag		

Table 1. Description of mineral wastes (continued)

ALABAMA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
9	Iron and Steel	U. S. Steel Corp.	Blast furnaces Steel furnaces	Bir-mingham	Jefferson	Blast fur-nace and Steel Slag			
10	Limonite	U. S. Pipe and Foundry	Open-pit mine	Russel-ville	Franklin	Waste rock & tailings			70,000 tons stockpiled
11	Phosphor-us	T. V. A.	National Fertilizer Development Center Smelting Facility	Muscle Shoals	Colbert	Slag	25,000 tons/year		

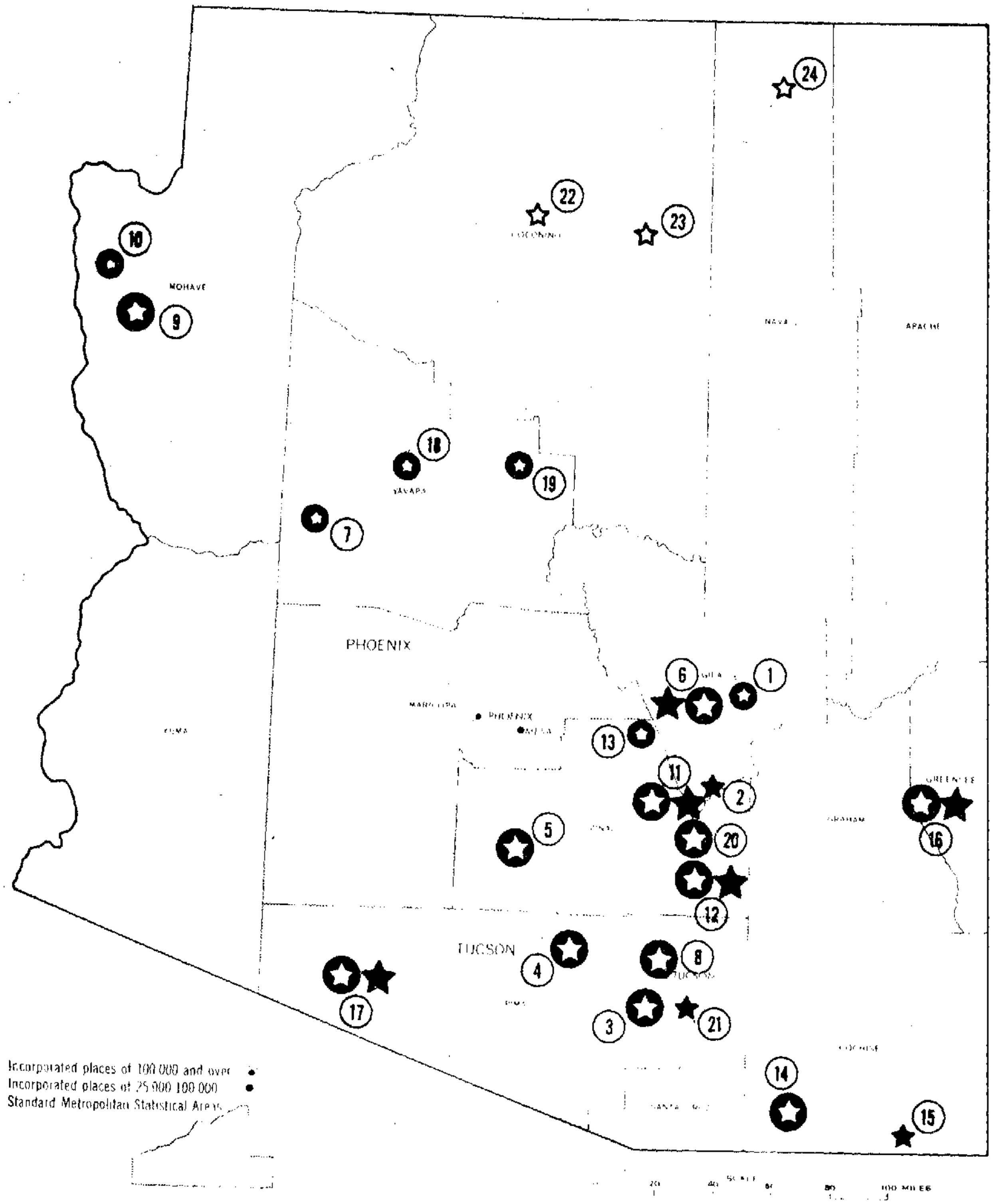

Figure 3. Mineral Waste Locations in Arizona

Table 2. Description of Mineral Wastes

ARIZONA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Asbestos	Jaquays Asbestos Corp.	Chrysotile underground mine	Globe	Gila	Waste rock & tailings			
2	Copper	A.S.A.R. Co.	Smelter	Hayden	Gila	Slag	500,000 tons/year		None of the slag produced is being marketed
*3	Copper		*Mission and San Xavier Open-pit mines	Sahua-rita	Pima	Waste rock & tailings	40,000,000 tons/year	Limestone Arkase, Siltstone	381,000,000 tons stockpiled including San Xavier Mine.
*4	Copper		Open-pit mine	Silver Bell	Pima	Waste rock & tailings	3,000,000 tons/year	Alasite, Volcan-ics, Quartz Monzonite	14,000,000 tons stockpiled
*5	Copper		Sacaton Open-pit mine	Casa Grande	Pinal	Waste rock & tailings	2,000,000 tons/year		72,000,000 tons stockpiled
*6	Copper	Cities Service Co.	Open-pit mines** & smelter	Miami	Gila	Waste rock & tailings & slag	40,000,000 tons/year tailings 27,500 tons/year slag	Schist and granite porphyry	Approximately 50 million tons of mine waste being leached
6	Copper	Ranchers Exploration & Develop-ment Corp.	Bluebird Open-pit mine	Miami	Gila	Waste rock & tailings	5,000,000 tons/year		

* Includes Mission, San Xavier, Twin Buttes, Esperanza, and Sierrita mines.

** Includes Miami, Pinto Valley, Christmas, Inspiration, Bluebird, and Ox Hide mines and smelter at Inspiration.

Table 2. Description of Mineral Wastes (continued)

ARIZONA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*7	Copper	Cyprus Bagdad Mining Corp.	Open-pit mine	Bagdad	Yavapai	Waste rock & tailings	10,000,000 tons/year	Granodiorite and sandstone	48,000,000 tons stockpiled
*8	Copper	Cyprus Pima Mining Co.	Open-pit mine	Tucson	Pima	Waste rock & tailings	16,000,000 tons/year		
9	Copper	Duval Corp.	Mineral Park Open-pit mine	Kingman	Mohave	Waste rock & tailings	6,000,000 tons/year	Quartz, Monzonite, Schist	Approximately 5.5 million tons of mine waste being leached
10	Copper	El Paso Natural Gas Co.	Emerald Island Open-pit mine	Chloride	Mohave	Waste rock & tailings	200,000 tons/year		
*11	Copper	Kennecott Copper Corp.	Ray Open-pit mine smelter	Hayden	Pinal	Waste rock & tailings & slag	10,000,000 tons/year tailings 250,000 tons/year slag		Approximately 185 million tons of mine waste being leached
*12	Copper	Magma Copper Co.	Underground mine smelter	San Manuel	Pinal	Waste rock tailings & slag	16,000,000 tons/year waste rock & tailings 750,000 tons/year slag	Quartz, Monzonite	262,000,000 tons stockpiled
13	Copper		Superior underground mine	Superior	Pinal	Waste rock & tailings	800,000 tons/year	Schist, Diabase, Shale, Limestone	No mining waste available for use
*14	Copper	Phelps Dodge Corp.	Underground mine	Bisbee	Cochise	Waste rock & tailings	5,000,000 tons/year	Quartz, Monzonite and conglomerate	Approximately 47 million tons of mine waste being leached

Table 2. Description of Mineral Wastes (continued)

ARIZONA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
15	Copper	Phelps Dodge Corp.	Smelter	Douglas	Cochise	Smelter slag	800,000 tons/year		
*16	Copper	Phelps Dodge Corp.	Open-pit mine smelter	Morenci	Greenlee	Waste rock & tailings & smelter slag	16,000,000 tons/year tailings 400,000 tons/ year slag	Quartz, Limestone	Tailings used as highway fill material in 1939
*17	Copper	Phelps Dodge Corp.	Open-pit mine smelter	Ajo	Pima	Waste rock & tailings & smelter slag	12,000,000 tons/year tailings 150,000 tons per year slag	Quartz, Limestone	400 million tons of waste accumulated
18	Copper		Prescott, Jerome, and Iron King mines	----	Yavapai	Waste rock & tailings		Quartzite Tuff Andesite	Mines no longer operating
19	Gypsum	Superior Companies	Quarry and concentrator	Camp Verde	Yavapai	Waste rock & tailings			
20	Gypsum		Winkelman quarry and concentrator	Winkelman	Pinal	Waste rock & tailings			
21	Molybdenum	Duval Sierrita Corp.	Sierrita concentrator and smelter	Sahuarita	Pima	Slag & tailings			
22	Uranium	Cotter Corp.	Orphan underground mine	Grand Canyon	Cococino	Tailings			Mines temporarily inactive
23	Uranium			Tuba City	Coconino	Tailings			
24	Uranium			Monument Valley	Navajo	Tailings			

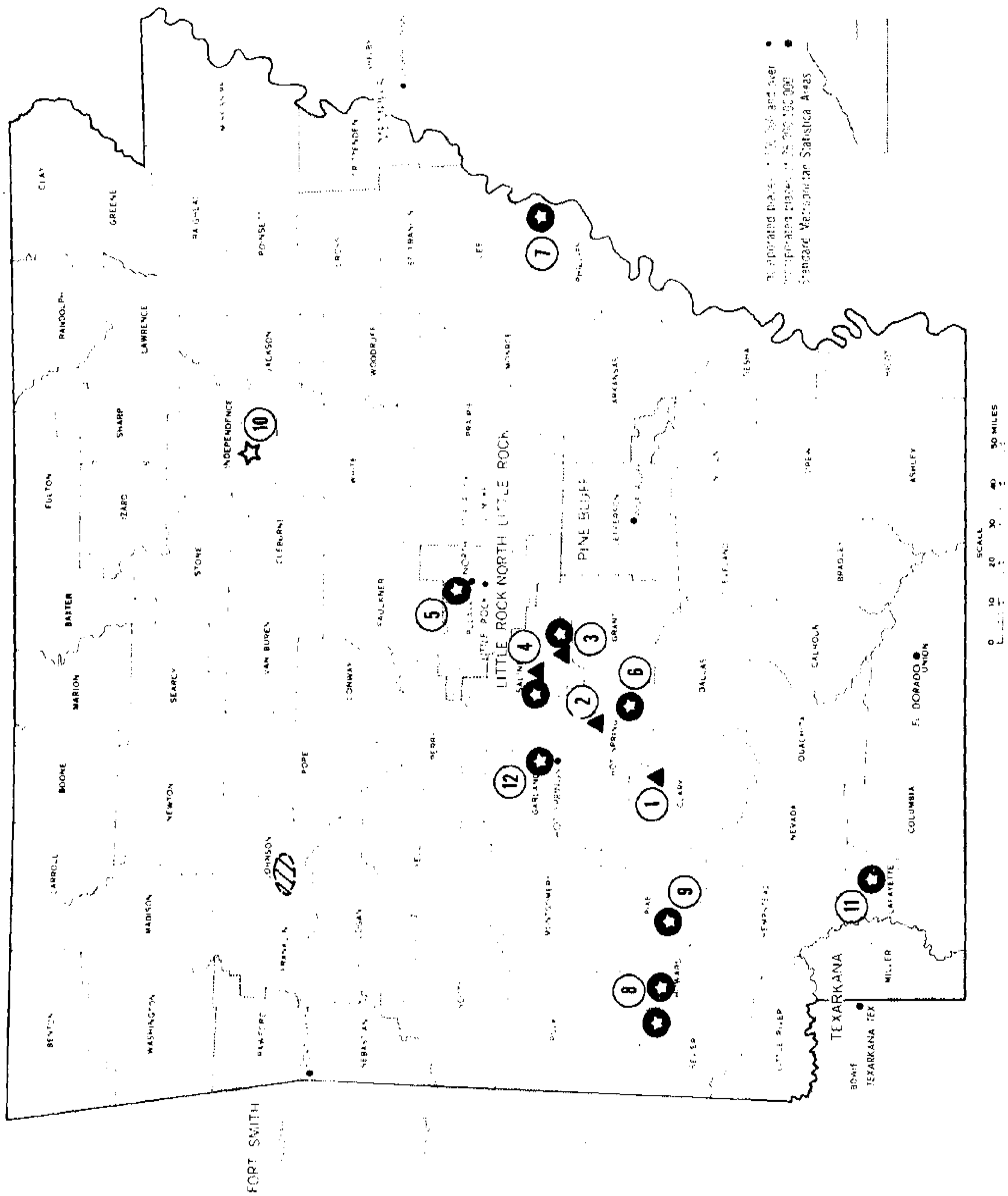

Figure 4. Mineral Waste Locations in Arkansas

Table 3. Description of Mineral Wastes

ARKANSAS

NUMBER	PRODUCT	COMPANY NAME (S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Alumina	Reynolds Metals Co.	Reduction plant	Arka-delphia	Clark	Mud	50,000 tons/year		
2	Alumina	Reynolds Metals Co.	Jones Mill Reduction Plant	Malvern	Hot Springs	Mud	100,000 tons/year		
3	Alumina	Reynolds Metals Co.	Hurricane Creek Alumina plant	Bauxite	Saline	Mud			
	Bauxite	Aluminum Co., of America	Open-pit mine refinery	Bauxite	Saline	Mud			
		Reynolds Mining Co.	Arkansas Open-pit and Under-ground mines	Bauxite	Saline	Waste rock & tailings	5,000,000 tons/year	Nepheline Syenite	500,000,000 tons stockpiled in Saline & Pulaski counties
4	Bauxite	American Cyanamid Co., Ind.	Open-pit mine concentrator refinery	Benton	Saline	Waste rock & tailings Mud		Nepheline Syenite	
5	Bauxite	Stauffer Chem. Co.	Open-pit mine concentrator	N. Lit-tle Rock	Pulaski	Waste rock & tailings	20,000 tons/year		Only small amounts currently available
6	Barite	N. L. Indus-tries, Inc.	Open-pit mine Underground mine	Magnet	Hot Springs	Waste rock & tailings		Shale	Mine closed: 7,500,000 tons mill tailings including N.L. Industries mine
		Dresser Minerals	Underground mine concen-trator	Malvern	Hot Springs	Waste rock & tailings			35,000,000 tons stockpiled including Dresser mineral mine

Table 3. Description of Mineral Wastes (continued)

ARKANSAS

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
7	Gypsum	Arkla Chemical Corp.		Helena	Phillips	Waste rock & tailings			
8	Gypsum	Weyer-haeuser Co.	Open-pit mines	Dierks DeQueen	Howard Sevier	Waste rock & tailings			
9	Gypsum	Dulin Bauxite Co.	Open-pit mine concentrator	Murfre-esboro	Pike	Waste rock & tailings	125,000 tons/year		
10	Manganese		Batesville mine	Bates-ville	Indepen-dence	Tailings			1,000,000 tons washing plant rejects stockpiled
11	Siderite	Leber Mining Co.	Falcon Mine Open-pit mine concentrator	Stamps	Lafayette	Waste rock & tailings			
12	Vanadium	Union Carbide	Open-pit mine concentrator	Hot Springs	Garland	Waste rock & tailings			

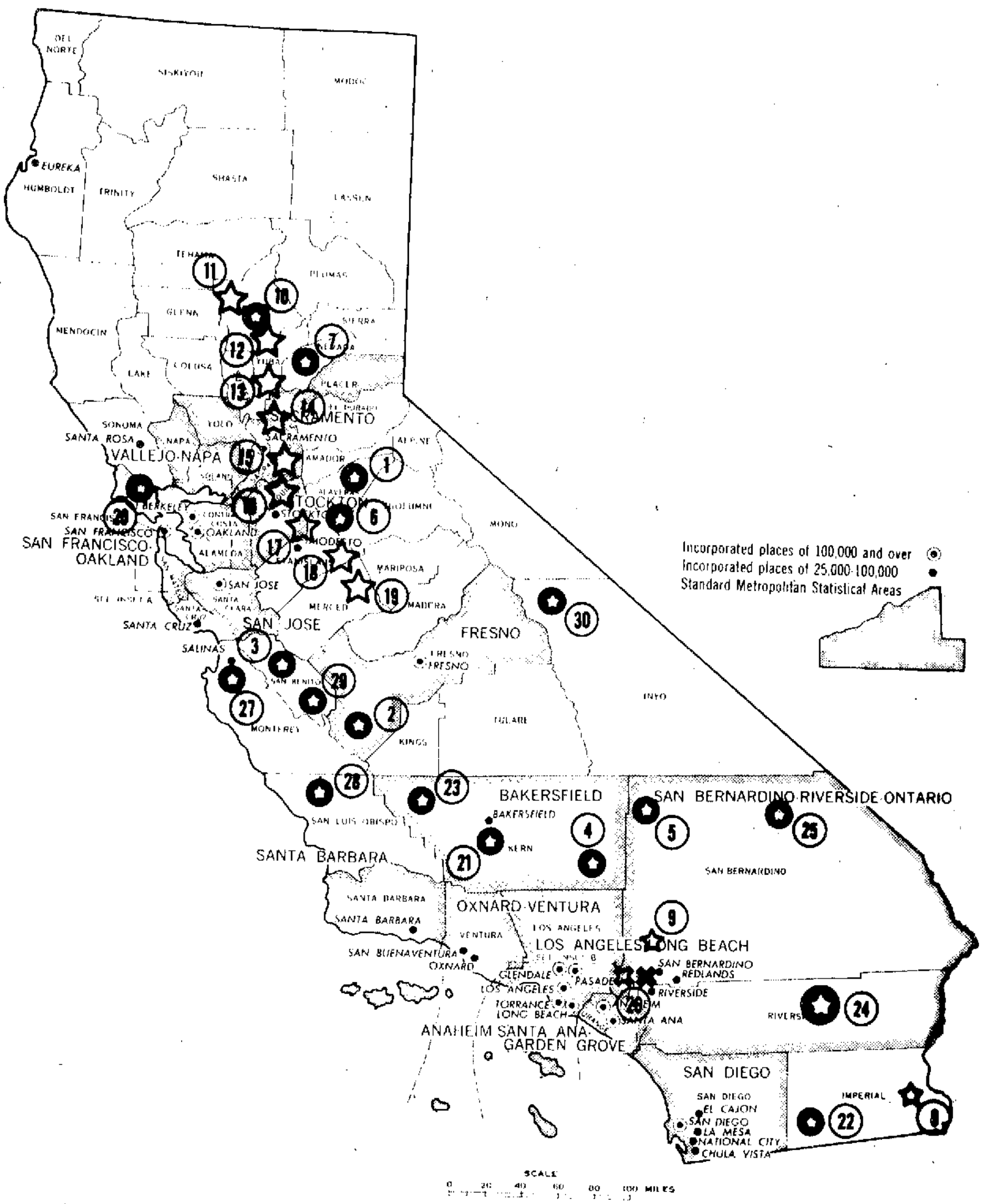

Figure 5. Mineral Waste Locations in California

Table 4. Description of Mineral Wastes

CALIFORNIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Asbestos	Pacific Asbestos Corp.	Open-pit mine	Copper-opolis	Cala-veras	Waste rock & tailings			
2	Asbestos	Vinnell Mining & Materials Corp.	Atlas Asbestos Open-pit mine concentrator	Coalin-ga	Fresno	Waste rock & tailings (Asbestos shorts)	250,000 tons/year	Serpentine gangine rock	Material has been used previously in highway construction
3	Asbestos	Union Car-bide Corp.	Open-pit mine	----	San Benito	Waste rock & tailings			
4	Borax	U.S. Borax & Chemical	Boron Open-pit mine	Boron	Kern	Waste rock & tailings	9,800,000 tons/year	Sandstone Limestone	Mostly arkosic sandstone unsuita-for highway con-struction
5	Boron	Kerr-McGee Corp.	Westland and Trona Plants	Inyo Trona	San Bernardino	Waste rock & tailings	60,000 tons/year	Limestone	500,000 tons stockpiled. Used once in highway construction.
6	Copper			Copper-opolis	Cala-veras	Waste rock & tailings			Inactive Mine Site
7	Gold	A.P.C.O. Oil Corp.	Telegraph and under-ground mine concentrator	Downie-ville	Sierra	Waste rock & tailings	60,000 tons/year		
8	Gold	Picacho Development Corp.	Picacho and Open-pit mine concentrator	----	Imperial	Tailings			
9	Gold	Inland Empire Milling & Mining	Open-pit mine concentrator refinery	Verde-mont	San Bernadino	Tailings	20,000 tons/year		

Table 4. Description of Mineral Wastes (continued)

CALIFORNIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
10	Gold	L & K Development	Lucky Jack Mine underground mine concentrator	Oroville	Butte	Waste rock & tailings			
11	Gold		Gravel dump	Butte Creek	Butte	Dredge tailings			Dredge tailings from previous mining operations are similar in appearance and quality to commercial sand and gravel There have been numerous examples in which mineral wastes from gold dredging operations have been used in highway and building construction projects
12	Gold		Gravel dump	Oroville Honcut Creek	Butte	Dredge tailings			
13	Gold		Gravel dump	Hammonton	Yuba	Dredge tailings			
14	Gold		Gravel dump	Folsom	Sacramento	Dredge tailings			
15	Gold		Gravel dump	Michigan Bar	Sacramento	Dredge tailings			
16	Gold		Gravel dump	Comanche	San Joaquin	Dredge tailings			

Table 4. Description of Mineral Wastes (continued)

CALIFORNIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
17	Gold		Gravel dump	Jenny Lind	Calaveras	Dredge tailings			
18	Gold		Gravel dump	La Grange	Stanislaus	Dredge tailings			
19	Gold		Gravel dump	Snel-ling	Merced	Dredge tailings			
20	Gypsum	Superior Gypsum	Open-pit mine concentrator	Peta-luma	Marin	Waste rock & tailings			
21	Gypsum	Superior Gypsum	Superior Open-pit mine	Bakers-field	Kern	Waste rock & tailings			
22	Gypsum	U.S. Gypsum Co.	Open-pit mine	Plaster City	Imperial	Waste rock & tailings			
23	Gypsum	H.M. Hol-loway, Inc.	Open-pit mine concentrator	Lost Hills	Kern	Waste rock & tailings			
24	Iron	Kaiser Steel	Open-pit mine concen-trator	Eagle Mtn.	Riverside	Waste rock & tailings	10,000,000 tons/year	Limestone, Dolomite, Quartzite	Approximately 20,000,000 tons stockpiled. Some material has been used in highway construction
25	Iron	Standard Slag Co.	Beck Mine Open-pit mine concentrator	Tecopa	San Bernardino	Waste rock & tailings	250,000 tons/year		

Table 4. Description of Mineral Wastes (continued)

CALIFORNIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*26	Iron & Steel	Kaiser Steel Corp.	Blast furnace Steel furnaces	Fontana	San Bernardino	Blast furnace and Steel slag	1 million tons/year blast furnace slag and 600,000 tons/year steel slag		20 million tons of slag in stockpiles. Both slag types have been used in highway construction
27	Magnesium	Kaiser Aluminum	Open-pit mine concentrator	Salinas	Monterey	Waste rock & tailings	600,000 tons/year		
28	Mercury	Buena Vista Mines	Underground mine & smelter	Paso Robles	San Luis Obispo	Waste rock & tailings Slag			
29	Mercury	New Idria Mining and Chemical Co.	Underground mine concentrator smelter	Idria	San Benito	Waste rock & tailings		Shale & sandstone	
30	Tungsten	Union Carbide Corp.	Pine Creek Underground mine concentrator	Bishop	Inyo	Waste rock & tailings	500,000 tons/year		10-15 million tons accumulated

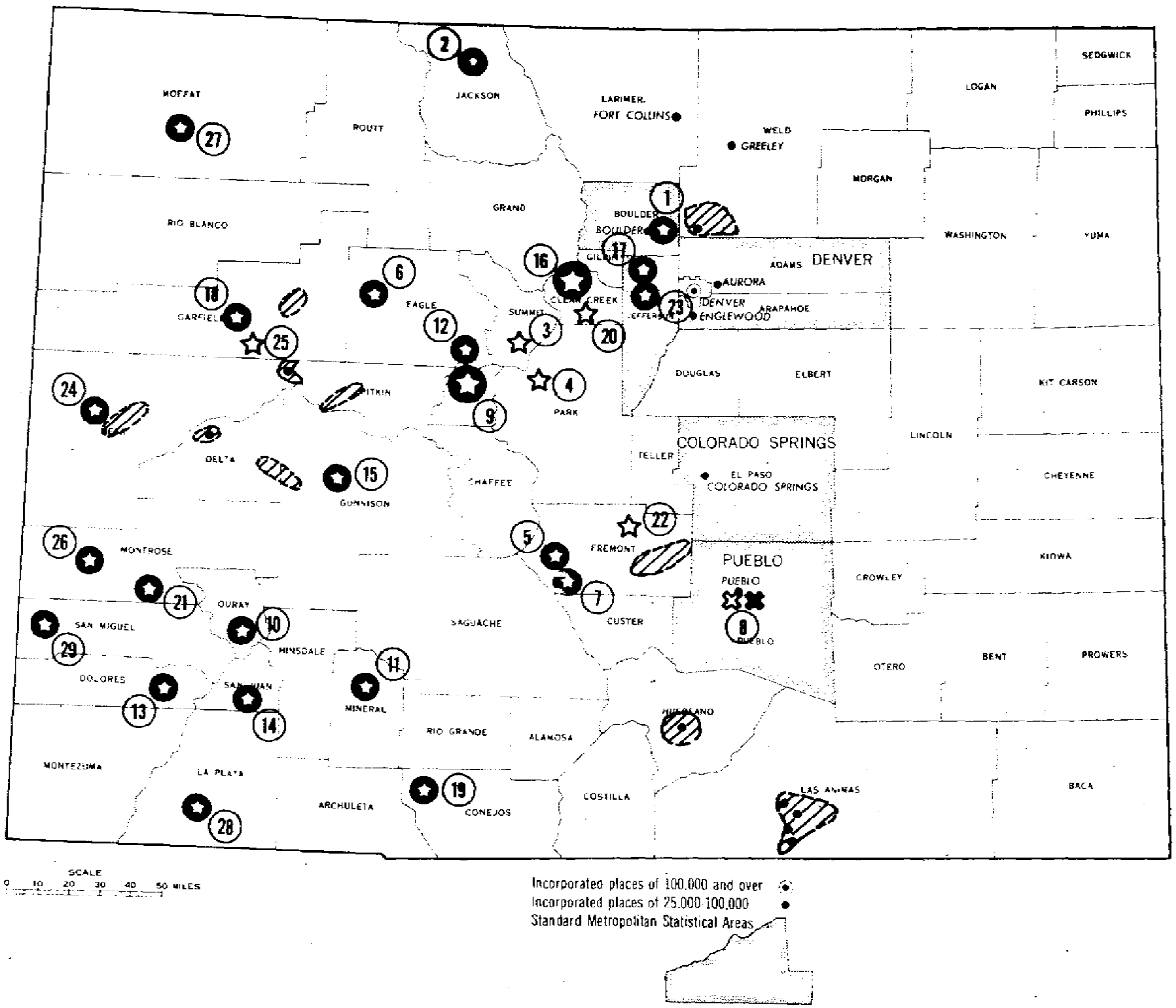

Figure 6. Mineral Waste Locations in Colorado

Table 5. Description of Mineral Wastes

COLORADO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Fluorspar	Industrial Chem. Co.	Underground mine	Boulder	Boulder	Waste rock & tailings			
2	Fluorspar	Ozark Mining Co.	Underground mine	Cowdrey	Jackson	Waste rock & tailings			
3	Gold			Breck-enridge	Summit	Tailings			Some previous use in highway construction
4	Gold			Fair-play	Park	Tailings			
5	Gypsum	Johns-Manville Products Co.	Open-pit mine	Coal-dale	Fremont	Waste rock & tailings			
6	Gypsum	J.R. Simplot Co.	Open-pit mine	Eagle	Eagle	Waste rock & tailings			
7	Iron	Pit Kin Iron Corp.	Open-pit mine	Coal-dale	Fremont	Waste rock & tailings			
8	Iron & Steel	CF&I Steel Co.	Steel mill	Pueblo	Pueblo	Blast furnace slag Steel slag	700,000 tons/year 600,000 tons/year		Both slags have been used in highway construction
*9	Lead	American Smelting & Refinery Co.	Leadville Underground mine concentrator	Lead-ville	Lake	Waste rock & tailings	150,000 tons/year	Dolomite, Granite	Also molybdenum. Total of 300,000,000 tons stockpiled
10	Lead	Camp Bird Colorado Idarado Mining	Underground mine concentrator	Ouary	Ouary	Waste rock & tailings Waste rock & tailings	65,000 tons/year 400,000 tons/year	Sandstone, Quartz	350,000 tons stock-piled waste rock, 6,000,000 tons stockpiled tailings

Table 5. Description of Mineral Wastes (continued)

COLORADO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
11	Lead	Homestake Mining Co.	Bulldog Mtn. Underground mine concentrator	Creede	Mineral	Waste rock & tailings	36,000 ton waste & 50,000 ton tailings annually	Tuffs, Breccias Rhyolites	
		Minerals Engineering Co.	Open-pit mine Underground mine concentrator	Creede	Mineral	Waste rock & tailings	66,000 tons/year	Tuffs, Breccias Quartz	1,000,000 tons stockpiled
12	Lead	New Jersey Zinc Co.	Underground mine concentrator	Gilman	Eagle	Waste rock & tailings	200,000 tons/year	Limestone	
13	Lead	Rico Argentine Mining	Underground mine concentrator	Rico	Dolores	Waste rock & tailings			
14	Lead	Standard Metals Corp.	Silverton Underground mine concentrator	Silverton	San Juan	Waste rock & tailings	100,000 tons/year	Tuffs, Breccias, Quartz	
15	Lead	U.S. Energy Corp.	Keystone Underground mine concentrator	Crested Butte	Gunnison	Waste rock & tailings			
*16	Molybdenum	Amax	Henderson Underground mine concentrator	Empire	Clear Creek	Waste rock & tailings	Anticipate 765,000 tons		Henderson mine to open during 1976 Urad mine closed
			Urad mine and concentrator	Empire	Clear Creek	Waste rock & tailings			26,000,000 tons stockpiled

Table 5. Description of Mineral Wastes (continued)

COLORADO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
17	Oil Shale	Oil Shale Corp.	Tosco Pilot Retort Plant	Golden	Jefferson	Waste rock & tailings		Shale	Spent shale is fine product
18	Oil Shale	Development Engineering	Paraho Pilot Retort Plant	Rifle	Garfield	Waste rock & tailings		Shale	Spent shale is coarse product
19	Silver	Coronado Silver Corp.	Platoro Underground mine concentrator	Platoro	Conejas	Waste rock & tailings		Quartz	40,000 tons tailings stockpiled
20	Silver			Silver-plane	Clear Creek	Tailings			Inactive mine
21	Uranium	Blake Mining Co.	Wedding Bell Underground mine	Nucla	Montrose	Waste rock & tailings			
				Natur-ita	Montrose	Waste rock & tailings			
22	Uranium	Cotter Corp.	Concentrator	Canon City	Fremont	Tailings	100,000 tons/year		
23	Uranium	Cotter Corp.	Schwartz-walder Underground mine	Golden	Jefferson	Waste rock & tailings	50,000 tons annually	Quartz, Feldspar	
24	Uranium	Union Carbide	Open-pit mine Underground mine	Grand Junc-tion	Mesa	Waste rock & tailings			

Table 5. Description of Mineral Wastes (continued)

COLORADO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
25	Uranium	Union Carbide	Rifle concentrator	Rifle	Garfield	Tailings	250,000 tons/year	Sandstone	
26	Uranium	Union Carbide	Uravan Open-pit mine Under-ground mine concentrator	Uravan	Montrose	Waste rock & tailings	300,000 tons/year	Sandstone	
27	Uranium	Union Carbide	Mine and concentrator	Maybell	Moffat	Waste rock & tailings		Sandstone	Mill tailings from previously operated milling plants
28	Uranium	Vanadium Corp.	Mine and concentrator	Durango	La Plata	Waste rock & tailings		Sandstone	Mill tailings from previously operated milling plant
29	Uranium	Union Carbide	Mine and concentrator	Slick Rock	San Miguel	Waste rock & tailings		Sandstone	Mill tailings from previously operated milling plant

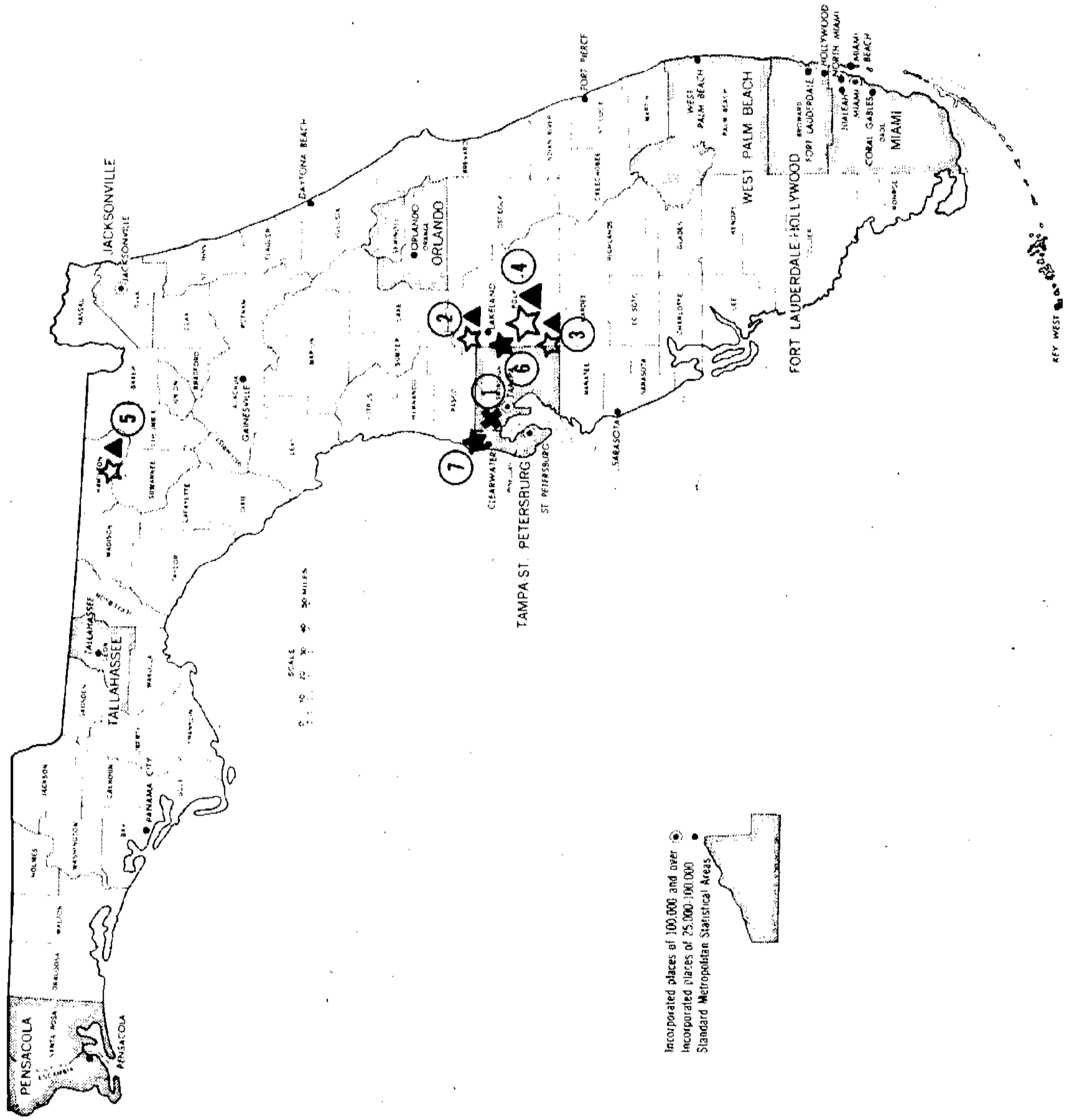

Figure 7. Mineral Waste Locations in Florida

Table 6. Description of Mineral Wastes

FLORIDA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Iron & steel	Florida Steel Corp.	Steel Furnaces	Tampa	Hills-borough	Steel slag			Used as fill at mill sites. No apprecia-ble quantities available
2	Phosphate	Argico Chemical Company	Open-pit mine concentrator	Pierce	Polk	Sand tail-ings, Slimes and Phospho-gypsum	1,000,000 tons/year		
		American Cyanimid	Brewster plant Open-pit mine concentrator	Brad-ley	Polk				
		Borden, Inc.	Tenoroc Open-pit mine concentrator	Lake-land	Polk				25,000,000 tons tailings stockpiled
3	Phosphate	Brewster Phosphate	Haynsworth Open-pit mine concentrator	Brew-ster	Polk	Sand tail-ings, Slimes and Phospho-gypsum	.8 million tons/year		
4	Phosphate	Freeport Chemical Company	Ten (10) Open-pit mine concentrator	Bartow and Fort Mead	Polk	Sand tail-ing, Slimes and Phospho-gypsum	Estimated total of 40,000,000 tons/year		
		W. R. Grace and Company							
		Mobil Chemical Company							

Table 6. Description of Mineral Wastes

FLORIDA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
4	Phosphate	International Minerals and Chemical Corp.		Bartow	Polk	Sand Tailings, Slimes and Phosphogypsum		Clay	
		Swift Agricultural Chemical	Ten (10) Open-pit mine concentrators in general area	Bartow and Fort Mead	Polk	Sand Tailings, Slimes and Phosphogypsum	Estimated total of 40,000,000 tons/year	Clay	
		U. S. Agricultural Chemicals							
5	Phosphate	Occidental Chemical Company	Open-pit mine concentrator	White Springs	Hamilton	Sand tailings, Slimes, Phosphogypsum	12 million tons/year slimes	Clay	
6	Phosphate	Holmes Company	Electric furnace	Pierce	Polk	Phosphate slag			
7	Phosphate	Stauffer Chemical	Electric furnace	Tarpon Springs	Pinellas	Phosphate slag			

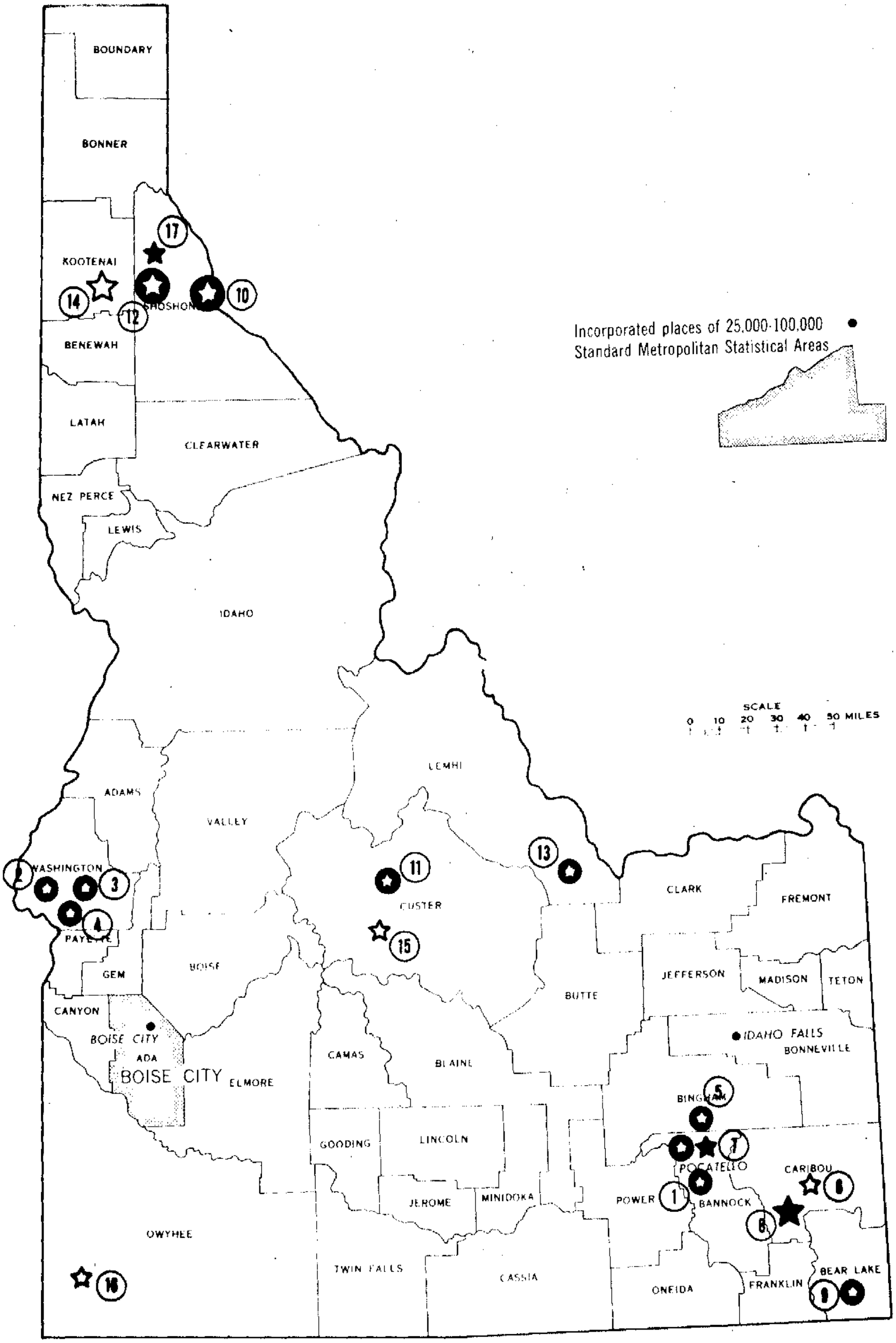

Figure 8. Mineral Waste Locations in Idaho

Table 7. Description of Mineral Wastes

IDAHO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Gypsum	J. R. Simplot	Don plant	Pocatello	Bannock	Waste rock & tailings			
2	Iron	C&W Sand & Gravel Co.	Mine	----	Washington	Waste rock & Tailings			
3	Lead	Canyon Silver Mine	Mine	----	Washington	Waste rock & tailings			
4	Mercury	El Paso National Gas	Open-pit mine concentrator	Weiser	Washington	Waste rock & tailings			
5	Phosphate	J.R. Simplot	Open-pit mine	Ft. Hall	Bingham	Waste rock & tailings			
6	Phosphate		Open-pit mine concentrator	Conda	Caribou	Tailings			Mine and smelter inactive
		Stauffer Chemical Co.	Open-pit mine	Conda	Caribou	Waste rock & tailings	300,000 tons/year		
7	Phosphate	FMC	Open-pit mine smelter	Pocatello	Bannock	Waste rock & tailings & smelter slag	2,000,000 tons/year		Mine and smelter inactive
*8	Phosphate	Monsanto Industrial Chemicals Co.	Open-pit mine smelter	Soda Springs	Caribou	Elemental furnace slag	800,000 tons/year		15-18 million tons stockpiled slag. Some use in highway construction
9	Phosphate	Stauffer Chemical Co.	Open-pit mine concentrator	Montpelier	Bear Lake	Waste rock & tailings	600,000 tons/year		

Table 7. Description of Mineral Wastes (continued)

IDAHO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*10	Silver	American Smelting & Refinery Co.	Underground mine concentrator	Wallace	Shoshone	Waste rock & tailings	150,000 tons/year		More than 20 million tons accumulated
		Sunshine Mining Co.	Underground mine concentrator	Kellogg	Shoshone	Waste rock & tailings	250,000 tons/year		Previously used in construction of embankments for I-90
11	Silver	Clayton Silver Mines	Underground mine concentrator	Clayton	Custer	Waste rock & tailings			
12	Silver	Bunker Hill Co.	Underground mine concentrator	Kellogg	Shoshone	Waste rock & tailings	140,000 tons/year	Quartz	
13	Silver	Universal Exploration	Underground mine	Gilmore	Lemhi	Waste rock & tailings			
14	Silver		Inactive mine	----	Kootenai	Tailings			Millions of tons accumulated
15	Silver	Tungsten	Mine & plant	----	Custer	Tailings	85,000 ton tailings/year		
16	Silver	Earth Resources Co.	Underground mines	Delamar	Owyhee	Tailings			740,000 tons stockpiled
17	Zinc	Bunker Hill Co.	Smelter refinery	Kellogg	Shoshone	Slag residue	40,000 tons/year		

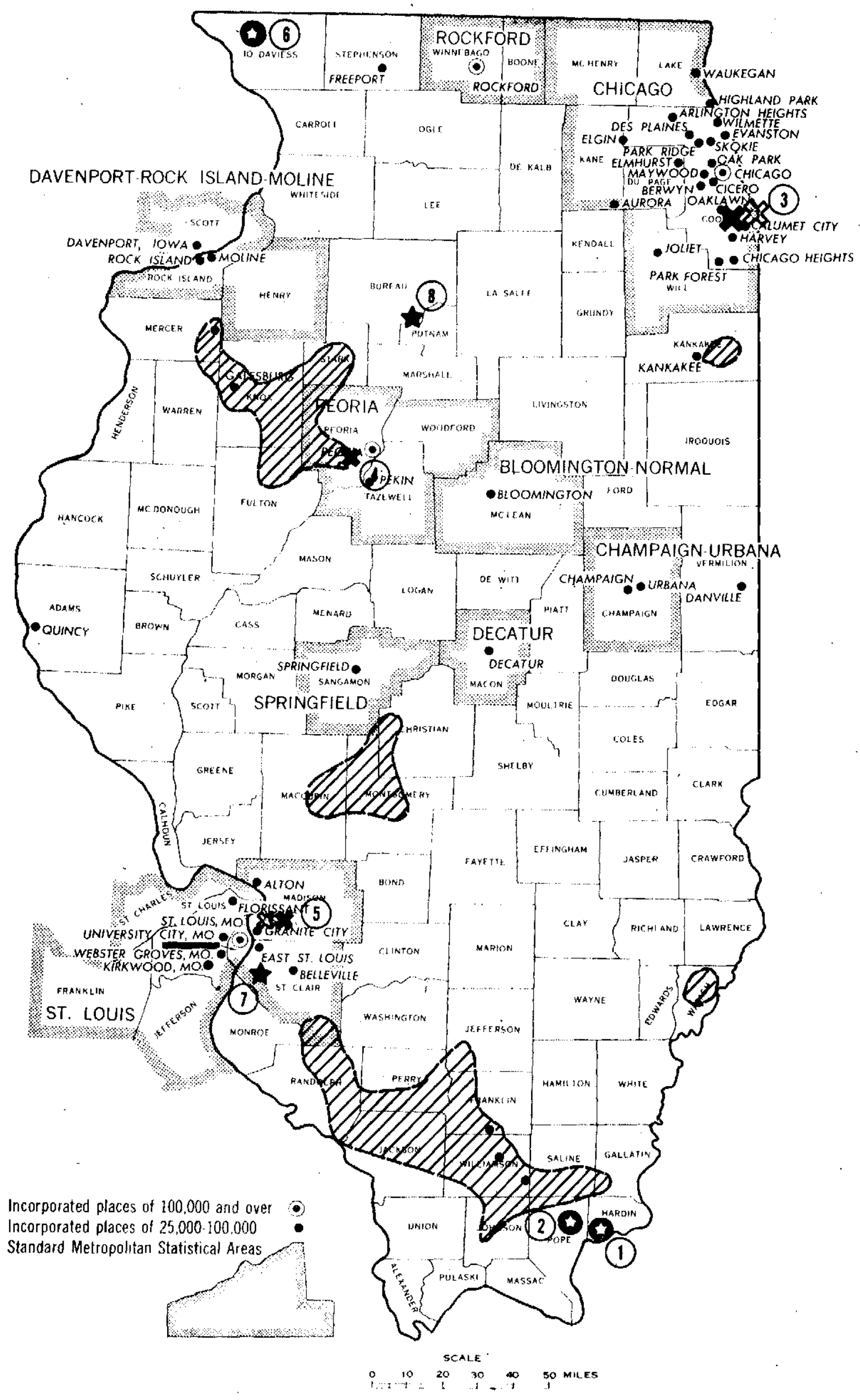

Figure 9. Mineral Waste Locations in Illinois

Table 8. Description of Mineral Wastes

ILLINOIS

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Fluorspar	Minerva Oil Co.	Underground mine concentrator	Cave in Rock	Hardin	Waste rock & tailings	400,000 tons/year	Limestone	Waste rock used as aggregate in highway construction
	Fluorspar	Ozark-Mahoning	Underground mine concentrator	Rosiclare	Hardin	Waste rock & tailings	400,000 tons/year		
2	Fluorspar		Underground mine	Eichorn	Pope	Waste rock & tailings	50,000 tons/year	Limestone	Used as aggregate in highway construction
3	Iron & Steel	Interlake, Inc.		Chicago	Cook	Blast Furnace slag			Slag processed by Illinois Slag & Ballast Co.
		International Harvestor Co.		S. Chicago	Cook	Steel slag			
		Laclede Steel Co.	Steel mill	S. Chicago	Cook	Steel slag			
		Youngstown Sheet & Tube Company	Blast furnaces Steel furnaces	Indiana Harbor	Cook	Blast furnace slag Steel slag	765,000 tons/year 687,000 tons/year		
		Republic Steel Corp.	Blast furnaces Steel furnaces	S. Chicago	Cook	Blast furnace slag Steel slag	225,000 tons/year 415,000 tons/year		Used as aggregate in highway construction
		U.S. Steel Corp.	Blast furnaces Steel furnaces	S. Chicago	Cook				

Table 8. Description of Mineral Wastes (continued)

ILLINOIS

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
4	Iron & Steel	Keystone Steel Wire	Steel furnaces	Peoria	Peoria	Steel Slag	100,000 tons/year		Majority of slag produced is used highway construction
5	Iron & Steel	Lacleed Steel Co. National Steel Corp.	Blast furnaces Steel furnaces	Alton, Granite City	Madison	Blast furnace & steel slags			Some slag used experimentally in highway construction in St. Louis area
6	Zinc	Eagle-Picher Industries	Underground mine concentrator	Galena	Jo Daviess	Waste rock & tailings	500,000 tons/year		1,000,000 tons gravel waste stockpiled 3,000,000 tons flotation sands stockpiled. Coarse material used in highway construction
7	Zinc	Amax Lead & Zinc Co.	Smelter	E. St. Louis	St. Clair	Slag residue	20,000 tons/year		
8	Zinc	New Jersey Zinc Co.	Smelter	Depeu	Bureau	Slag residue			Nearly 1,000,000 tons stockpiled smelter closed

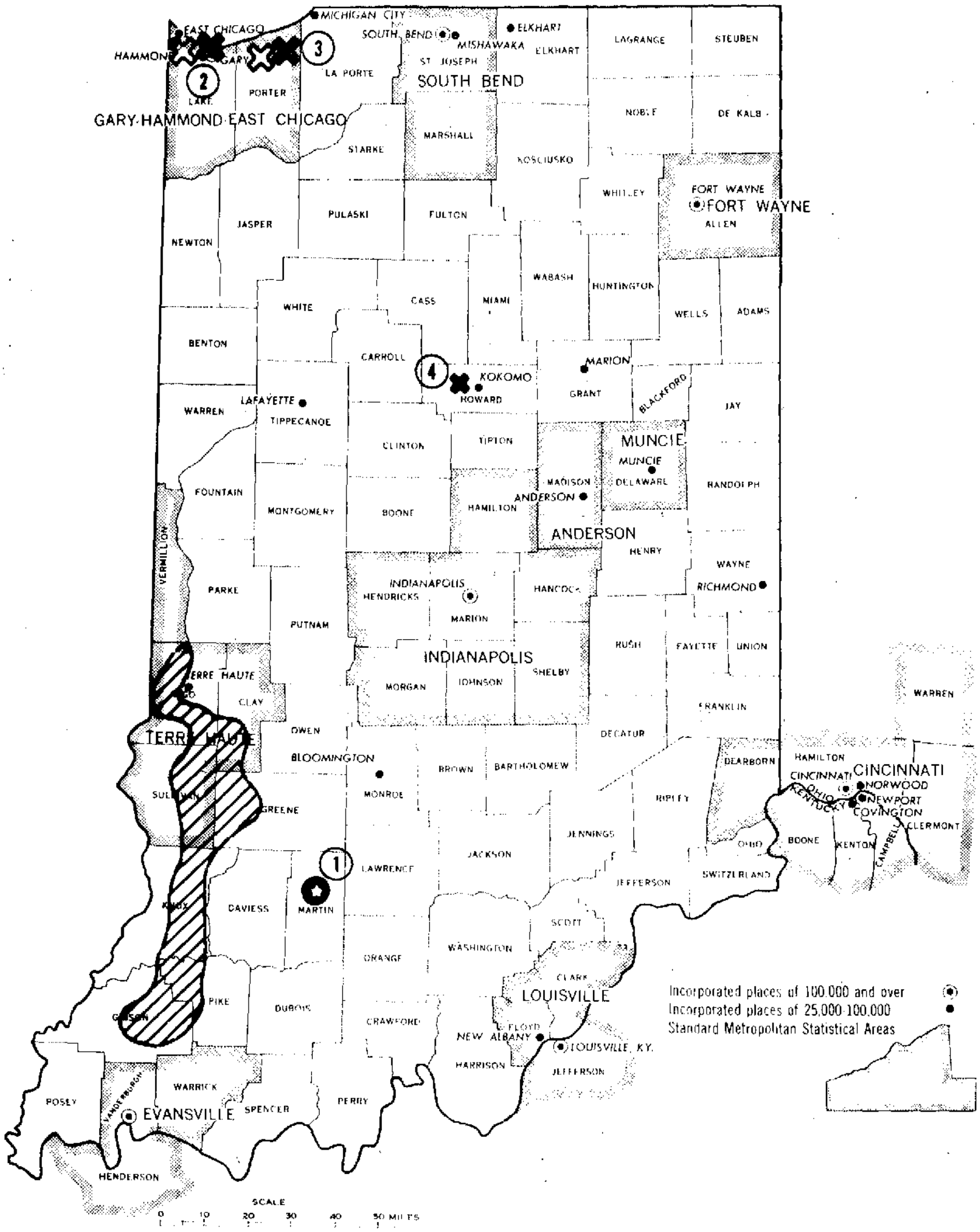

Figure 10. Mineral Waste Locations in Indiana

Table 9. Description of Mineral Wastes

INDIANA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Gypsum	Gold Bond Building Products	Underground mine	Shoals	Martin	Waste rock & tailings	5,000 tons/year waste produced		150,000 tons stockpiled
	Gypsum	National Gypsum Co.	Underground mine	----	Martin	Tailings			
	Gypsum	U.S. Gypsum Co.	Underground mine	Shoals	Martin	Tailings			
2	Iron & Steel	Inland Steel Corp.	Steel mill	E. Chicago	Lake	Slag			All slag produced is currently being marketed
		U.S. Steel Corp.	Steel mill	Gary	Lake	Slag			
		Youngstown Steel & Tube Co.	Steel mill	E. Chicago	Lake	Slag			
3	Iron & Steel	Bethlehem Steel Corp.	Steel mill	West Chester	Porter	Slag			
4	Iron & Steel	Continental Steel Corp.	Steel mill	Kokomo	Howard	Steel slag	50,000 tons/year		None currently used in highway construction

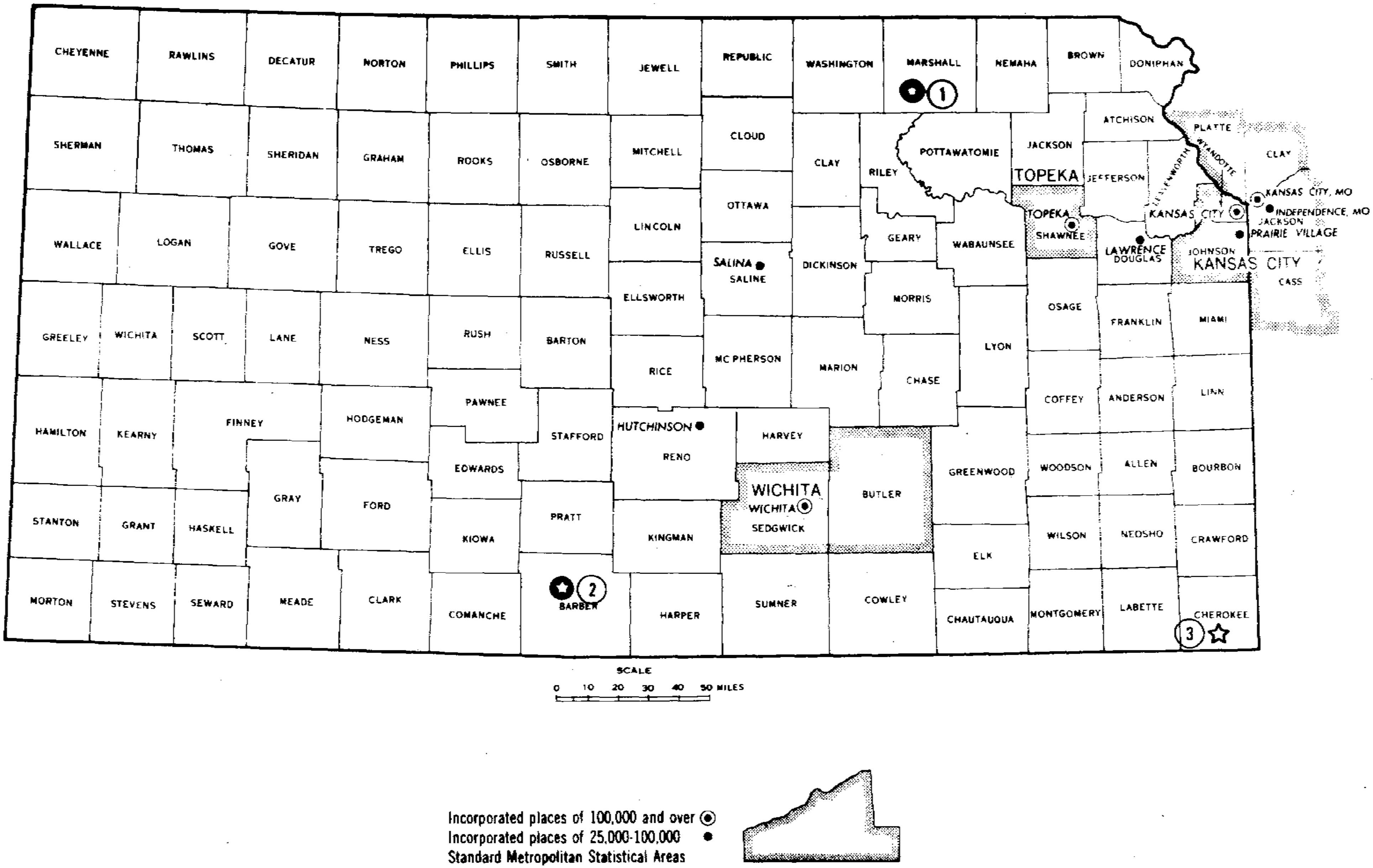

Figure 11. Mineral Waste Locations in Kansas

Table 10. Description of Mineral Wastes

KANSAS

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Gypsum	Georgia Pacific	Underground mine	Blue Rapids	Marshall	Waste rock & tailings			
2	Gypsum	Gold Bond Building Products	Quarry Underground mine	Sun City	Barber	Waste rock & tailings			
3	Lead-Zinc		Tri-State mining	----	Cherokee	Tailings (Chat)		Sandstone, shale	Between 6-7 million tons of waste rock in S.E. portion of state from previous mining operations. Previously used in highway construction

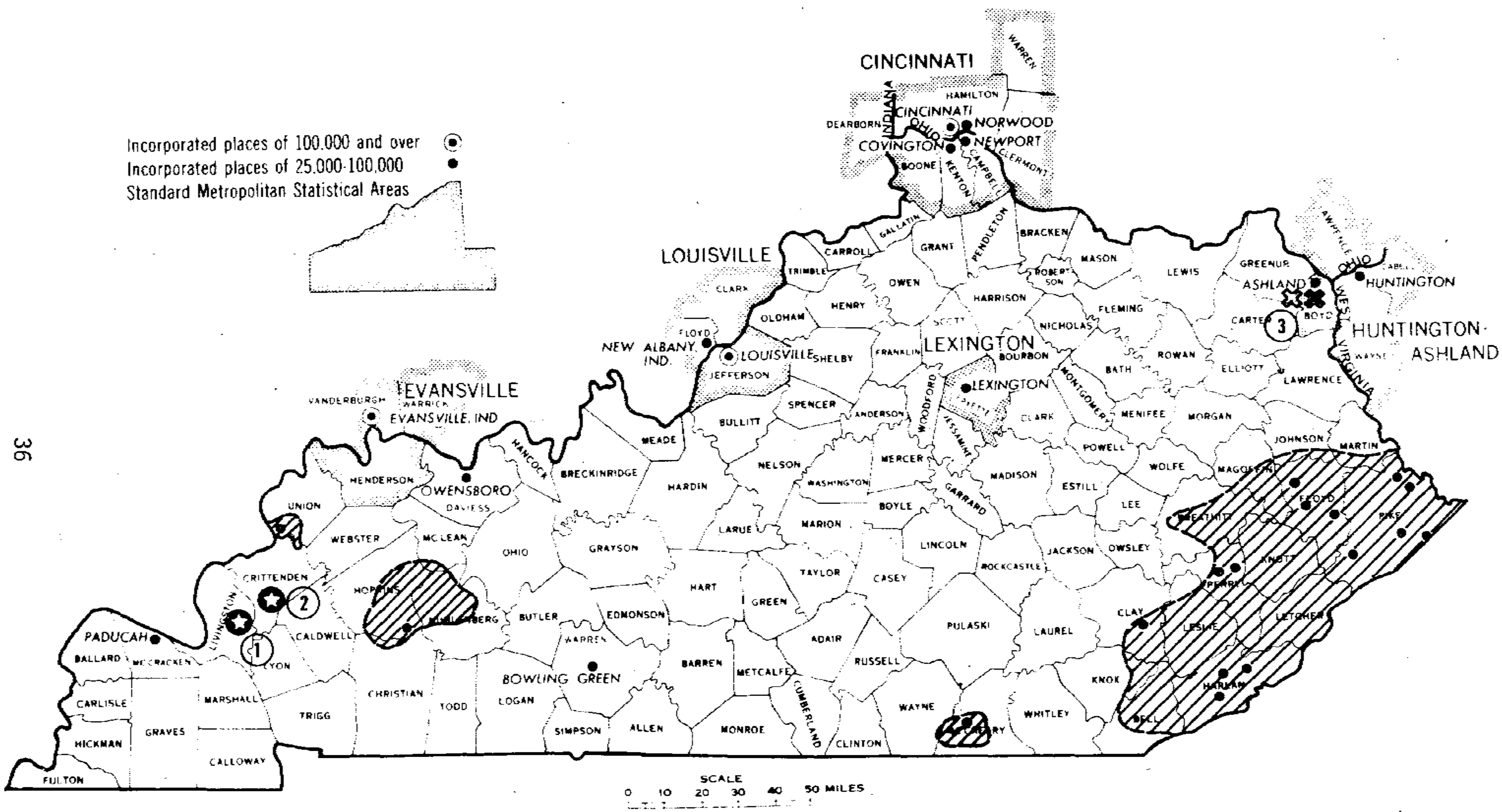

Figure 12. Mineral Waste Locations in Kentucky

Table 11. Description of Mineral Wastes

KENTUCKY

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Fluorspar	Cerro Spar Corp.	Underground mine	Salem	Livingston	Waste rock & tailings		Limestone	
2	Fluorspar	Minerva Oil Co	Underground mine	Marion	Crittenden	Waste rock & tailings		Limestone	75,000 tons/year
		E. G. Sommerlath	Underground mine Open-pit mine concentrator	Marion	Crittenden	Waste rock & tailings		Limestone	
3	Iron & Steel	ARMCO Steel Corp.	Steel mill	Ashland	Boyd	Steel slag			

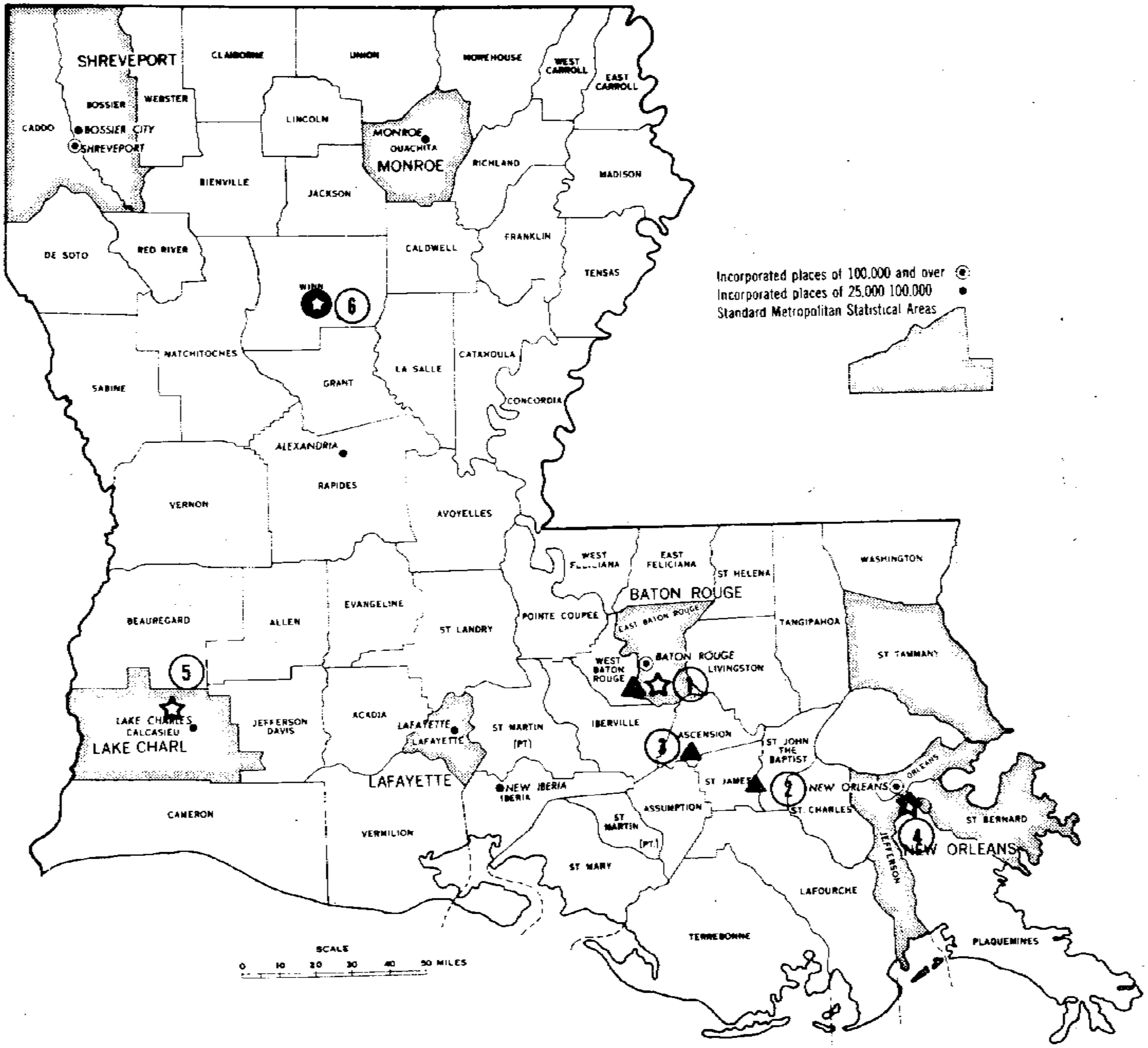

Figure 13. Mineral Waste Locations in Louisiana

Table 12. Description of Mineral Wastes

LOUISIANA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION PARISH	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Kaiser Aluminum & Chemical Corp.	Refinery	Baton Rouge	East Baton Rouge	Mud and Tailings	1,000,000 tons/year		Pisolites used for tank foundations
2	Aluminum		Refinery	Gramer-cy	St. James & St. John	Mud	750,000 tons/year		
3	Aluminum	Ormet Corp.	Refinery	Burn-side	Ascension	Mud	550,000 tons/year		
4	Barite	Dresser Industries	Processing plant	New Orleans	New Orleans	Tailings			
		Milchem Inc.	Concentrator	New Orleans	New Orleans	Tailings			
		N.L. Industries	Concentrator	New Orleans	New Orleans	Tailings			
5	Barite	Dresser Industries	Processing plant	West-lake	Calcasieu	Tailings			
6	Gypsum	Winn Rock Inc.	Quarry & plant	Winn-field	Winn	Waste rock & tailings			

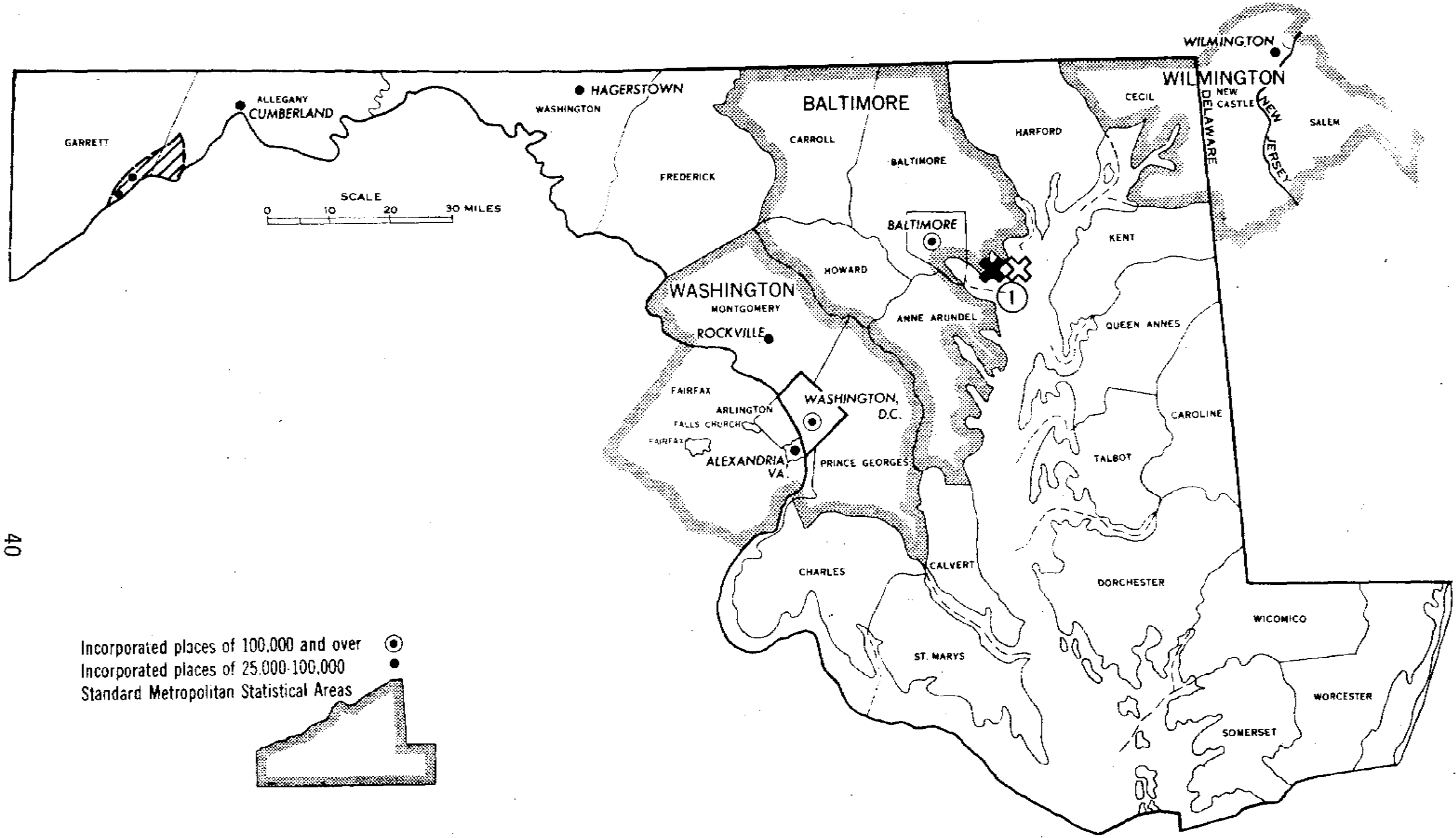

Figure 14. Mineral Waste Locations in Maryland

Table 13. Description of Mineral Wastes

MARYLAND

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*1	Iron & Steel	Bethlehem Steel Corp.	Blast furnaces & Steel furnaces	Spar-rows Point	Baltimore	Blast furnace & Steel slag	Total of 3.3 million tons/year produced. Very little accumulation		Slag marketed in Baltimore, Eastern shore of Maryland, and Virginia Beach area

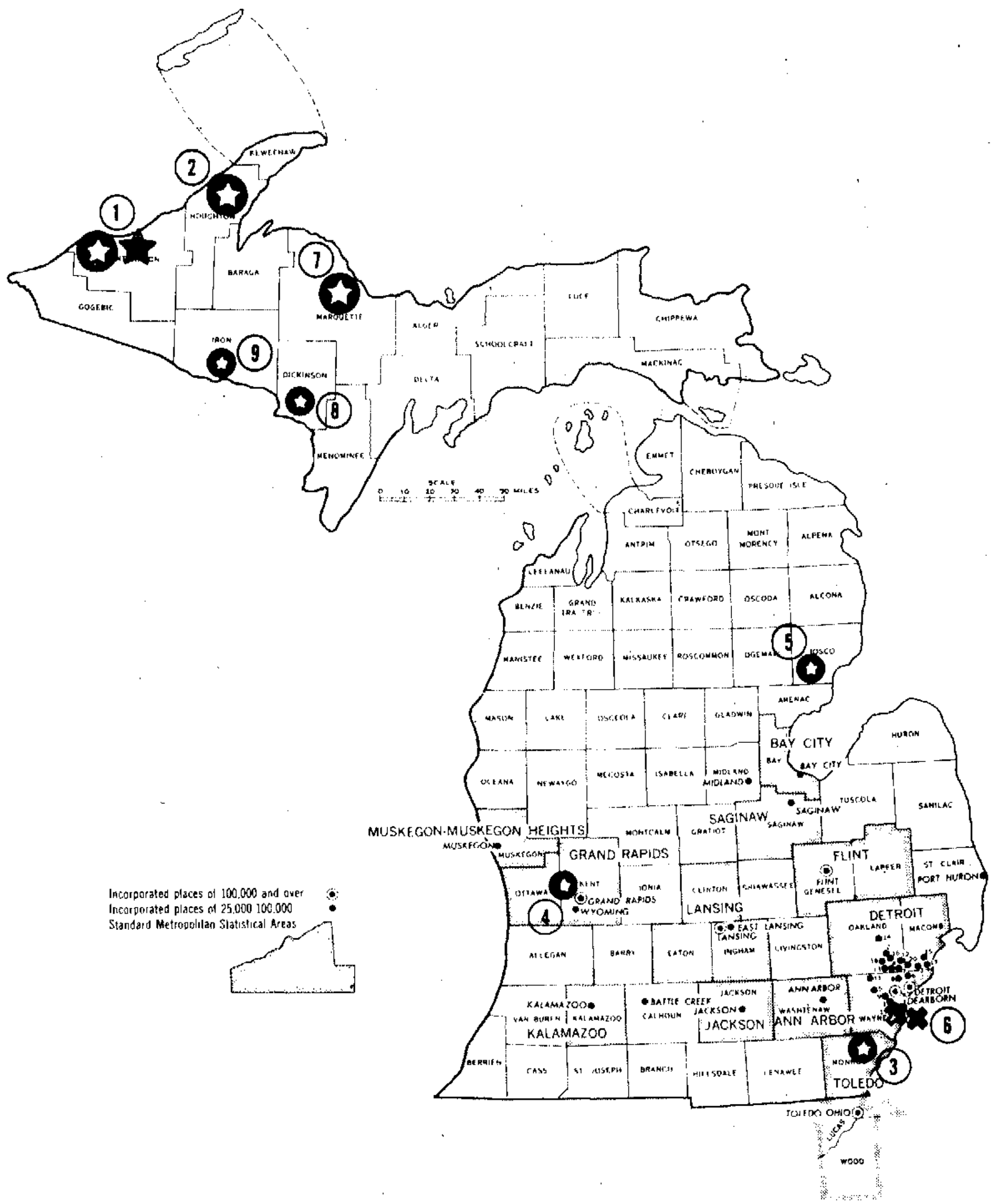

Figure 15. Mineral Waste Locations in Michigan

Table 14. Description of Mineral Wastes

MICHIGAN

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*1	Copper	White Pine Copper Co.	Concentrator Under-ground mine smelter	White Pine	Ontonagon	Waste rock & tailings slag	8,000,000 tons/year 200,000 tons furnace slag/year	Shale, Siltstone, Sandstone	1.25 million tons coarse aggregate stockpiled, 0.3 million tons fines stockpiled, 235,000 tons slag stockpiled
*2	Copper	Calumet	Mine and concentrator	Calumet	Houghton	Waste rock & tailings		Trap rock & conglomerate	Waste rock present-ly used in highway construction
3	Gypsum	Grand Rapids Gypsum Co.	Underground mine	Monroe	Monroe	Waste rock & tailings			
4	Gypsum	Georgia-Pacific Corp.	Underground concentrator	Grand Rapids	Kent	Waste rock & tailings			
5	Gypsum	Michigan Gypsum	Open-pit mine concentrator	Whitte-more	Iosco	Waste rock & tailings			
		Gold Bond Bldg. Products	Open-pit mine	Nation-al City	Iosco				
		U.S. Gypsum Co.	Open-pit mine	Alabas-ter	Iosco	Waste rock & tailings			
6	Iron & Steel	Ford Motor Co.	Blast furna-ces & Steel furnaces	Dear-born	Wayne	Slag	550,000 tons/year blast fur-nace slag 650,000 tons/year steel furnace slag		No large accumulati-tions. Slag is marketed by Edward C. Levy Co.
		Mclouth Steel Corp.	Steel mill	Trenton	Wayne	Slag			

Table 14. Description of Mineral Wastes (continued)

MICHIGAN

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
6	Iron & Steel	National Steel Corp.	Blast furnaces & Steel furnaces	Ecorse	Wayne	Slag			
				River Rouge	Wayne	Slag			
				Detroit	Wayne	Slag			
*7	Iron	Cleveland-Cliffs	Open-pit mine concentrator	Tilden	Marquette	Waste rock	15 million tons/year total		Over 100 million tons accumulated. Some use of waste rock in highway construction.
			Concentrator	Naycauneu	Marquette	Tailings			
		Empire Iron Mining Co.	Open-pit mine concentrator	Palmer	Marquette	Waste rock & tailings			
			Open-pit mine concentrator	Ishpeming	Marquette	Waste rock & tailings	5.5 million tons/year	Quartzites cherts, slates	
			Underground mine	Negaunee	Marquette	Waste rock & tailings			
			Open-pit mine concentrator	Tilden	Marquette	Waste rock & tailings	5 million tons/year		
8	Iron	Hanna Mining Co.	Open-pit mine concentrator	Iron Mt.	Dickinson	Waste rock & tailings	2,000,000 tons/year		
9	Iron	Inland Steel Co.	Underground mine	Iron River	Iron	Waste rock & tailings	225,000 tons/year		

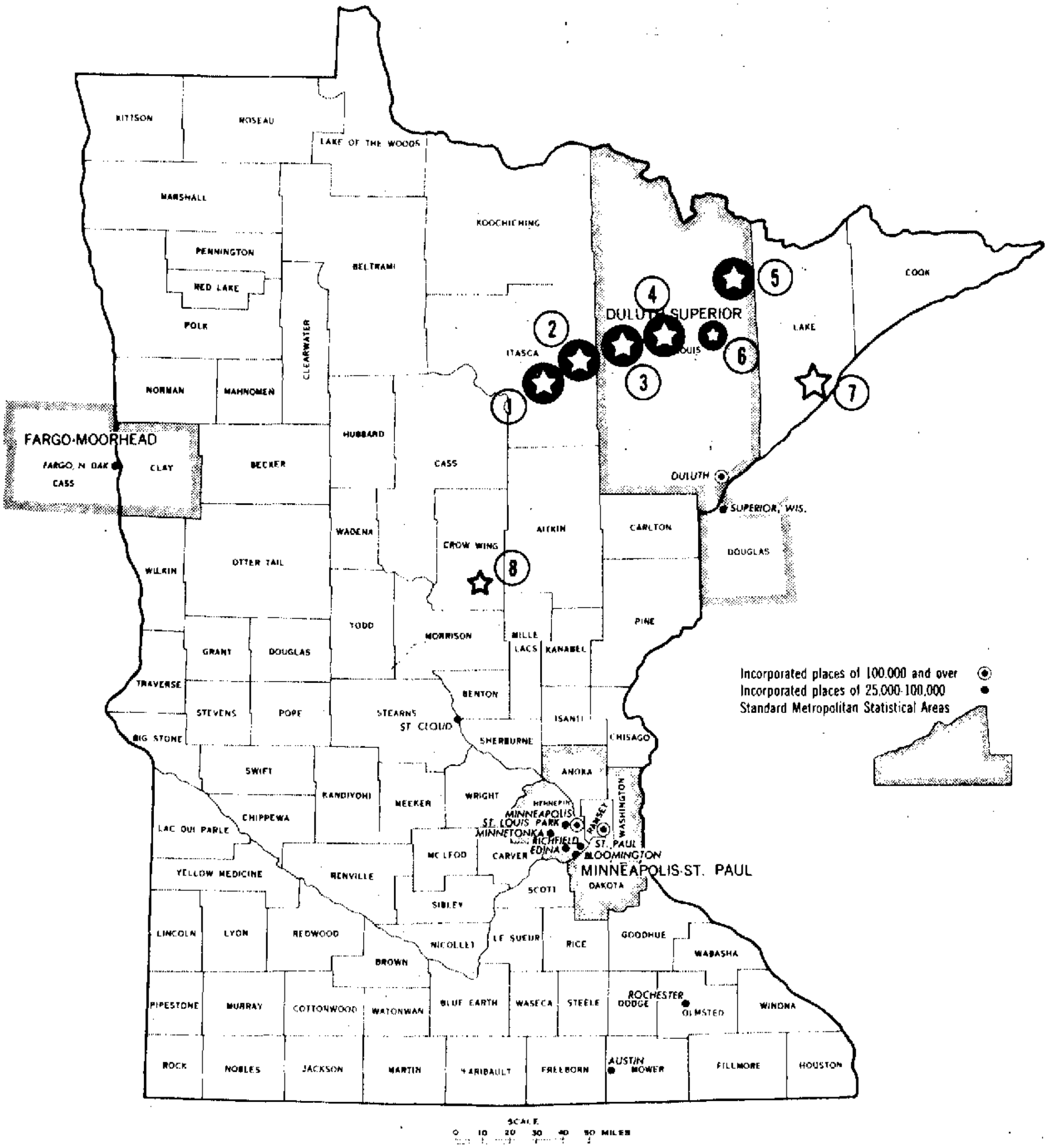

Figure 16. Mineral Waste Locations in Minnesota

Table 15. Description of Mineral Wastes

MINNESOTA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Iron (Tacon- ite)	Cleveland- Cliffs	Open-pit mine concentrator	Coler- aine	Itasca	Waste rock & tailings	15,000,000 tons/year tailings		Coarse tailings used as skid-resistant aggregate
		Jones & Laughlin Steel Corp.	Open-pit mine & concentrator	Calumet	Itasca	Waste rock & tailings			
*2	Iron (Tacon- ite)	Hanna Mining Co.	Open-pit mine concentrator	Kee- walen	Itasca	Waste rock & tailings	3,500,000 tons/year waste rock 14,800,000 tons/year tailings		
			Open-pit mine concentrator	Nash- Wauk	Itasca	Waste rock & tailings	20,000,000 tons/year tailings 1,700,000 tons/year waste rock		
*3	Iron (Tacon- ite)		Open-pit mine concentrator	Hibbing	St. Louis	Waste rock & tailings	Rock 1,000,000 tons/year Tailings 800,000 tons/year		
		Pittsburg Pacific Company	Open-pit mine concentrator	Hibbing	St. Louis	Waste rock		Chert, Siltstone	Waste considered possible future source of iron
		Pittsburg Pacific Company	Open-pit mine	Chis- holm	St. Louis	Waste rock & tailings	1.5 million tons/year tailings		

Table 15. Description of Mineral Wastes (continued)

MINNESOTA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*3	Iron (Taconite)	Pittsburgh Pacific Company	Open-pit mine concentrator	Hibbing	St. Louis	Waste rock & tailings			Tailings have reddish color
		Pittsburgh Pacific Company	Open-pit mine	Chisholm	St. Louis	Waste rock & tailings			
			Open-pit mine concentrator	Hibbing	St. Louis	Waste rock & tailings			
*4	Iron (Taconite)	Coons Pacific Company	Concentrator	Eveleth	St. Louis	Tailings			
		Eveleth Taconite Company	Concentrator Open-pit mine	Eveleth	St. Louis	Waste rock & tailings			About 2.5 million tons/years coarse used for dike construction
		Rhude & Fryberger	Open-pit mine concentrator	Eveleth	St. Louis	Waste rock & tailings	Estimated total of 30,000,000 tons/year		Hundreds of millions tons of waste accumulated
*4	Iron	Rhude & Fryberger	Open-pit mine	Kinney	St. Louis	Waste rock & tailings			
		U.S. Steel	Open-pit mine concentrator	Iron Mtn.	St. Louis	Waste rock & tailings			
			Open-pit mine concentrator	Virginia	St. Louis	Waste rock & tailings	30,000,000 tons/year		Hundreds of millions tons of waste accumulated

Table 15. Description of Mineral Wastes (continued)

MINNESOTA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*5	Iron (Taconite)	Pickands Mather	Open-pit mine	Babbitt	St. Louis	Waste rock & tailings	30,000,000 tons/year		Millions of tons waste stockpiled
		Erie Mining Co.	Open-pit mine concentrator	Hoyt Lake	St. Louis	Waste rock & tailings			
6	Iron		Open-pit mine	Aurora	St. Louis	Waste rock			
*7	Iron (Taconite)	Reserve Mining Company	Concentrator	Silver Bay	Lake	Tailings			Deposition of tailings in Lake Superior is highly controversial
8	Iron (Taconite)	Cuyunga		Crosby	Crow Wing	Tailings	1,000,000 tons/year		

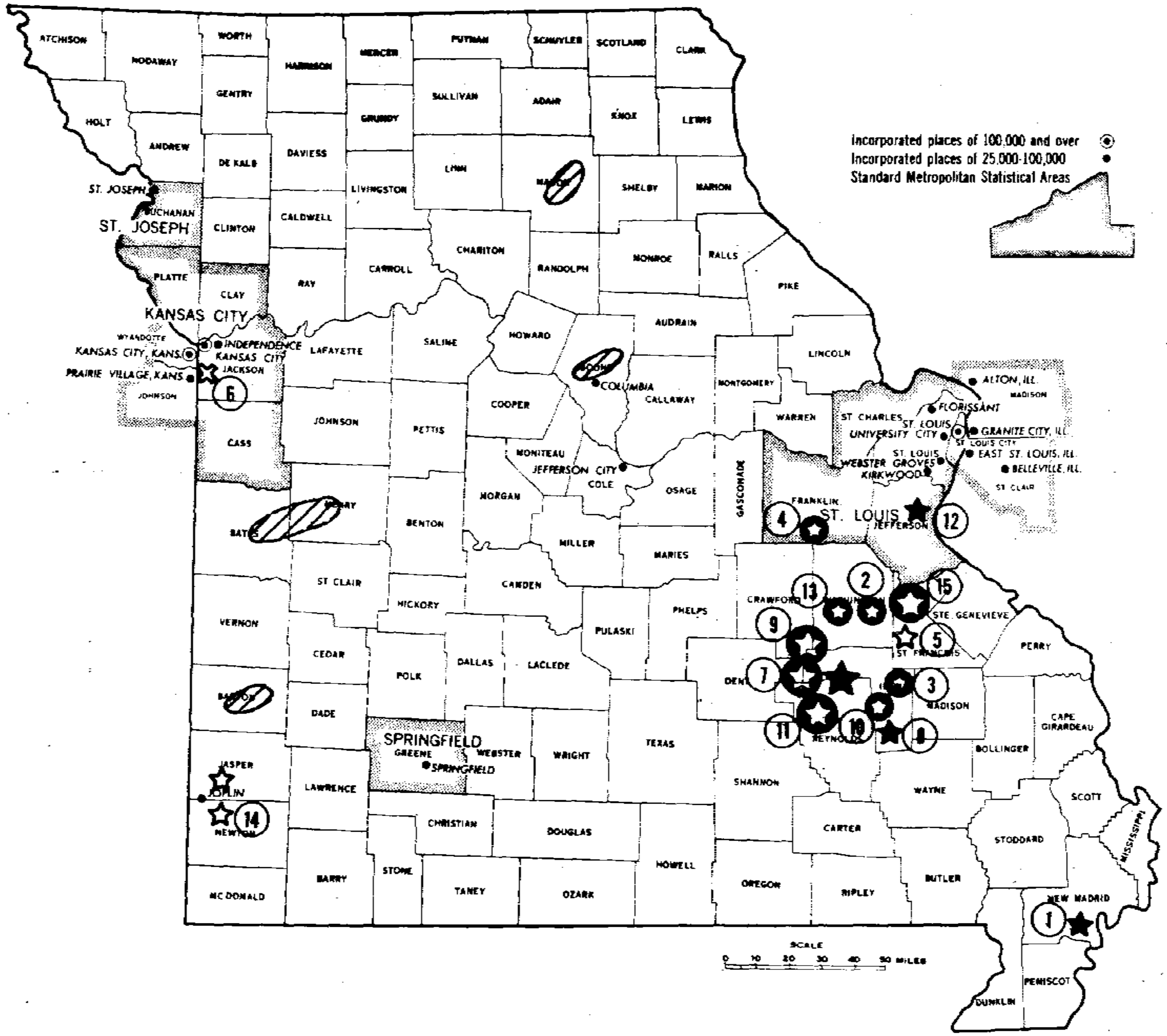

Figure 17. Mineral Waste Locations in Missouri

Table 16. Description of Mineral Wastes

MISSOURI

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Noranda Mines Limited	Smelter	New Madrid	New Madrid	Slag			
2	Barite	N. L. Industries	Open-pit mine	Potosi	Washington	Tailings			Some use of tiff chat in highway construction
		Dresser Minerals	Open-pit mine concentrator	Potosi	Washington	Waste rock & tailings			
		Milchem, Inc.	Open-pit mine concentrator	Mineral Point	Washington	Waste rock & tailings			
		Pfizer, Inc. Minerals	Open-pit mine concentrator	Potosi	Washington	Waste rock & tailings			Operation recently shut down. Very little waste remaining
3	Iron	Hanna Mining Company	Underground mine concentrator	Ironton	Iron	Waste rock & tailings			Over 1,000,000 tons tailings accumulated
4	Iron	Meramec Mining Company	Underground mine concentrator	Sullivan	Franklin	Waste rock & tailings		Andesite, Rhyolite, Dacite	About 13,000 tons waste rock (supplies of waste rock nearly exhausted) and 200,000 tons tailings
5	Iron		Underground mine	Iron Mountain	St. Francois	Tailings			Mine closed. No waste rock left.
6	Iron & Steel	ARMCO Steel Corp.		Kansas City	Jackson	Slag			

Table 16. Description of Mineral Wastes (continued)

MISSOURI

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
7	Lead	Amax Lead and Zinc Company	Underground mine smelter Concentrator	Buick	Iron	Waste rock & tailings and smelter slag	40,000 tons slag/year 1,250,000 tons/year tailings	Dolomite	185,000 tons slag stockpiled
8	Lead	American Smelting & Refining Co.	Smelter	Glover	Iron	Smelter slag			Smelter slag has been used in high-way construction
9	Lead	Cominco American, Inc.	Underground mine concentrator	Bixby	Iron	Waste rock & tailings	1,000,000 tons tailings/ year	New Lead District (Dolomite)	
10	Lead	St. Joe Minerals Company	Underground mine concentrator	Vibur-num	Iron	Waste rock & tailings	1,600,000 tons tailings/ year		
11	Lead	St. Joe Minerals Company	Underground mine concentrator	Brushy Creek	Reynolds	Waste rock & tailings	1,750,000 tons tailings		
		St. Joe Minerals Company	Underground mine concentrator	West Fork	Reynolds	Waste rock & tailings	1,250,000 tons tailings		
12	Lead	St. Joe Minerals Company	Smelter	Hercu-laneum	Jefferson	Smelter slag	70,000 tons/year		Smelter slag has been used in the past as anti-skid material, 1,000,000 tons stockpiled
13	Lead	St. Joe Minerals Company	Underground mine concentrator	Potosi	Washington	Waste rock & tailings			500,000 tons tailings

Table 16. Description of Mineral Wastes (continued)

MISSOURI

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
14	Lead-Zinc		Tri-State District	Joplin	Newton Jasper	Tailings (Chat)		Dolomite	Large accumulation of dolomitic tailings from past mining
15	Lead-Zinc	St. Joe Minerals Company	Old Lead Belt	Bonne Terre	St. Francois	Waste rock & tailings			Mining activity ceased, but 3 million tons waste rock and 20 million tons coarse chat and table tails have accumulated

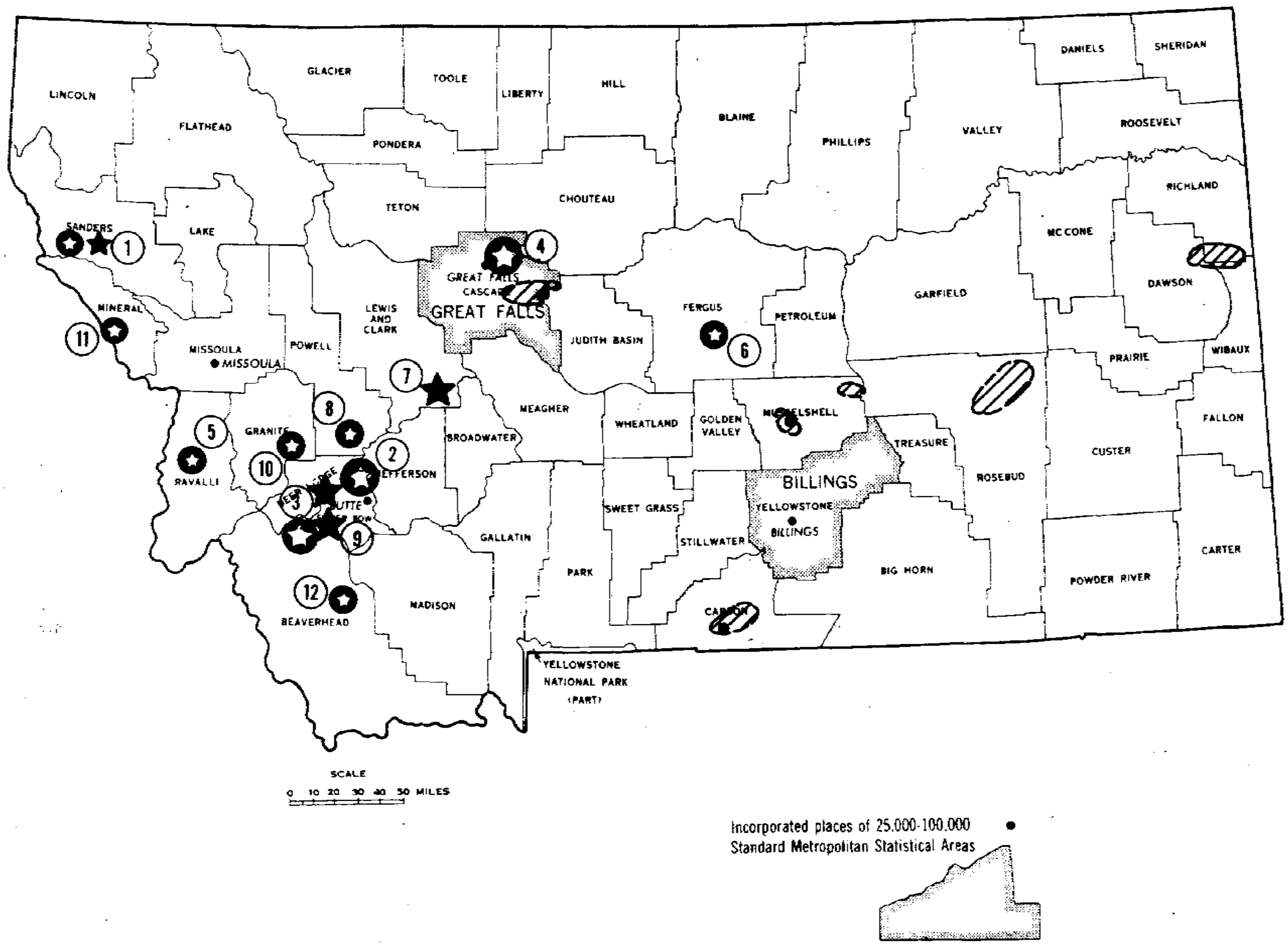

Figure 18. Mineral Waste Locations in Montana

Table 17. Description of Mineral Wastes

MONTANA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Antimony	U.S. Antimony Co.	Underground mine Smelter concentrator	Cox's Gulch	Sanders	Waste rock & tailings & slag			
*2	Copper	Anaconda	Underground Open-pit mine concentrator	Butte	Silver Bow	Waste rock & tailings	Waste rock 10,000,000 tons/year 12,500,000 tons/year tailings	Quartz, Monzonite, Granite	Millions of tons of waste rock and tailings have accumulated
*3	Copper	Anaconda	Smelter concentrator	Anaconda	Deer Lodge	Slag & tailings	350,000 tons/year slag		40,000,000 tons stockpiled
*4	Copper	Anaconda	Underground mine & surface	Great Falls	Great Falls	Waste rock & tailings			
5	Fluorspar	Roberts Mining	Open-pit mine concentrator	Darby	Ravalli	Waste rock & tailings	200,000 tons tailings annually		
6	Gypsum	U.S. Gypsum Co.	Underground mine	Heath	Fergus	Waste rock & tailings			
*7	Lead	A.S.A.R. Co.	Smelter	East Helena	Lewis & Clark	Smelter slag	160,000 tons/year slag		Part of the slag is marketed. 6,000,000 tons stockpiled
8	Phosphate	Cominco American Inc.	Underground mine	Gamson	Powell	Waste rock & tailings			
*9	Phosphate	Stauffer Chemical	Mine smelter	Dillon	Beaver Head	Waste rock Slag & tailings	250,000 tons slag annually	Lime - Silicate	1,000,000 tons furnace slag have been sold for highwayy use. Over 1.75 tons stockpiled

Table 17. Description of Mineral Wastes (continued)

MONTANA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
10	Silver	Inspiration Consolidation, Inc.	Underground mine	Philipsburg	Granite	Waste rock & tailings			
11	Silver	Nancy Lee Mines, Inc.	Underground mine concentrator	Keystone	Mineral	Waste rock & tailings	38,000 tons tailings annually		
12	Tungsten	Minerals Engineering Co.	Mine & mill	Glen	Beaver Head	Waste rock & tailings			

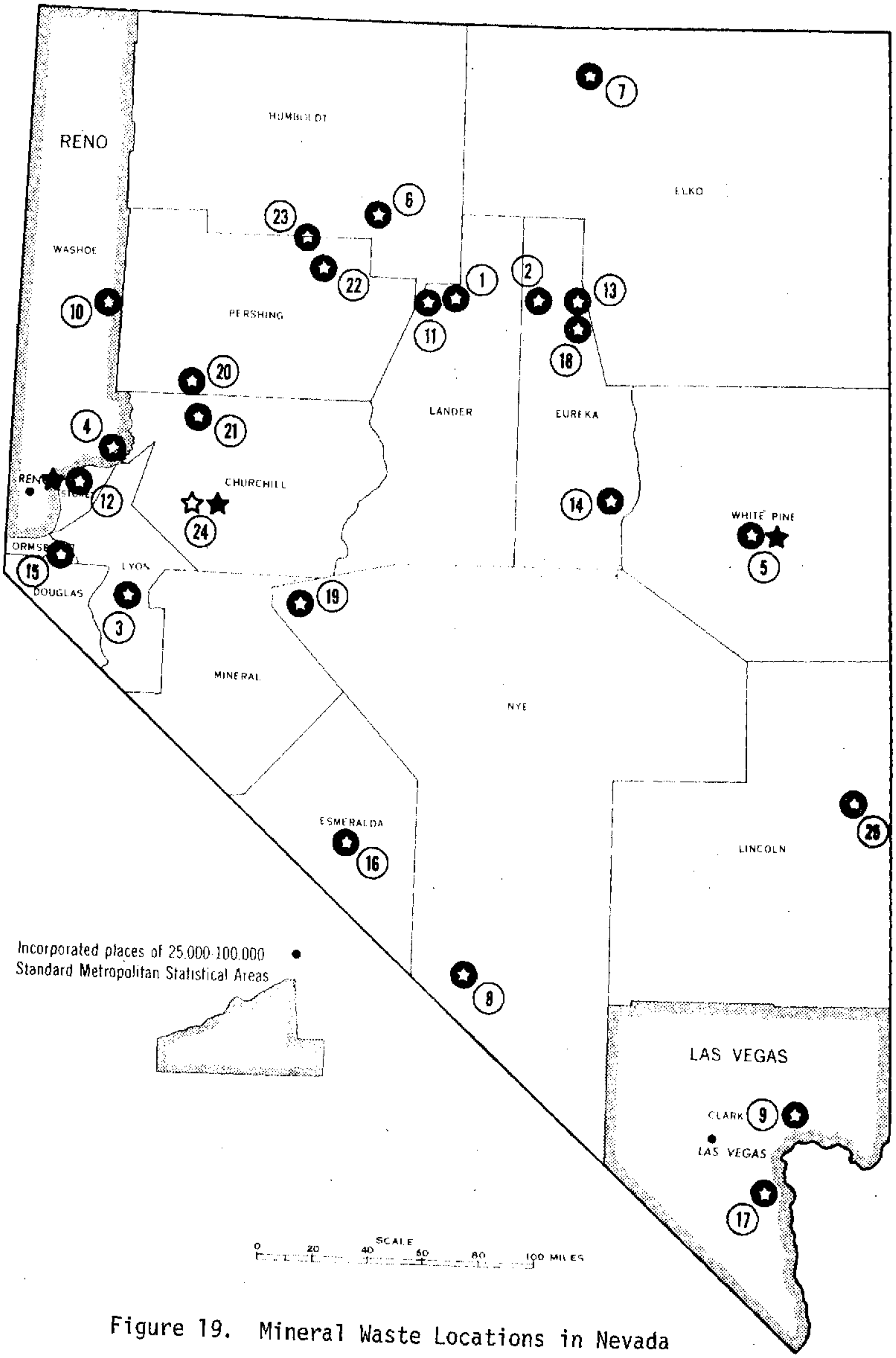

Figure 19. Mineral Waste Locations in Nevada

Table 18. Description of Mineral Wastes

NEVADA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Barite	Dresser Minerals Corporation	Open Pit mine concentrator	Battle Moun-tain	Lander	Waste rock & tailings			
		F. M. C. Corporation	Open-pit mine	Battle Moun-tain	Lander	Waste rock & tailings			
		Milchem, Inc.	Concentrator	Battle Moun-tain	Lander	Waste rock & tailings	180,000 tons/year tailings		
		Milchem, Inc.	Open-pit mine concentrator	Argenta	Lander	Waste rock & tailings	100,000 tons/year tailings		Chert tailings have been used as aggre-gate in resurfacing of I-80 near Battle Mountain
2	Barite	N. L. Industries	Open-pit mine	Durphy	Eureka	Waste rock & tailings			100,000 tons stockpiled
3	Copper	Anaconda Company	Open-pit mine concentrator	Weeds Height	Lyon	Waste rock & tailings			7,000,000 tons tail-ings stockpiled
4	Copper	APCO Oil Corporation	Open-pit mine Solvent-Extraction	Wads-worth	Washoe	Waste rock & tailings			
5	Copper	Kennecott Copper Co.	Open-pit mine concentrator and smelter	McGill	White Pine	Waste rock & tailings & slag	50,000 tons/year of slag		Waste rock 10,000,000 tons stockpiled, Tailings 5,000,000 tons stockpiled

Table 18. Description of Mineral Wastes (continued)

NEVADA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
6	Copper	Ranchers Exploration and Development Co.	Mine and precipitation plant	Winnemucca	Humboldt	Waste rock & tailings			
7	Copper	Cliffs Copper Corporation	Concentrator	Mountain City	Elko	Waste rock & tailings		Chert, Siltstone, and Slate	
8	Fluorspar	J. Irving Crowell, Jr. and Sons	Underground mine	Beatty	Nye	Waste rock & tailings			
9	Gypsum	The Flintkote Company	Open-pit mine	----	Clark	Waste rock & tailings			
		Johns-Mansville Products Corp.	Open-pit mine	----	Clark	Waste rock & tailings			
10	Gypsum	U. S. Gypsum Company	Open-pit mine	Empire	Washoe	Waste rock & tailings			
11	Gold	APCO Industrial Mining Co.	Underground mine	Battle Mountain	Lander	Waste rock & tailings	31,000 tons of tailings per year		
		Cortez Gold Mines	Open-pit mine concentrator	----	Lander	Waste rock & tailings			
		Duval Corporation	Open-pit mine concentrator	Battle Mountain	Lander	Waste rock & tailings		Conglomerate	52,000 tons stockpiled

Table 18. Description of Mineral Wastes (continued)

NEVADA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
12	Gold	APCO Industrial Mining Company	Underground mine concentrator	Sparks	Storey	Waste rock & tailings			
		Curtis Nevada Mines	Smelter concentrator	Sparks	Storey	Smelter slag			
		U.S. Platinum Catalyst	Underground mine	Sparks	Storey	Waste rock & tailings			
13	Gold	Carlin Gold Mining Company	Open-pit mine concentrator	Carlin	Eureka	Waste rock & tailings			
14	Gold	Idaho Mining Corp.	Open-pit mine concentrator	Eureka	Eureka	Waste rock & tailings	750,000 tons/year	Dolomite	
15	Gold	Standard Resources	Open-pit mine concentrator	Carson City	Ormsby	Waste rock & tailings			
16	Gold	Sunshine Mining	Underground mine	Silver Peak	Esmeralda	Waste rock & tailings		Andesite, Dacite	
17	Gold	Intermountain Exploration Co.	Underground mine concentrator	Boulder City	Clark	Waste rock & tailings			New mine recently developed
18	Iron	J. R. Simplot	Open-pit mine	Palisades	Eureka	Waste rock & tailings			Inactive mine
		Nevada-Barth Corp.	Open-pit mine	Carlin	Eureka	Waste rock & tailings		Dolomite	

Table 18. Description of Mineral Wastes (continued)

NEVADA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
19	Magnetite	Basic, Inc.	Open-pit mine	Gabbs	Nye	Waste rock & tailings			New mine under development and just opened
20	Mercury	Crofoot Tungsten Company	Underground mine	----	Pershing	Waste rock & tailings			
21	Tungsten	Crofoot Tungsten Company	Open-pit mine	Love-lock	Churchill	Waste rock & tailings			
22	Tungsten	Crofoot Tungsten Company	Open-pit mine	Imlay	Pershing	Waste rock & tailings			
23	Tungsten	Crofoot Tungsten Company	Underground mine Open-pit mine concentrator	Tung-sten	Pershing	Waste rock & tailings			
24	Tungsten	Kennametal, Inc.	Concentrator Smelter	Fallon	Churchill	Slag & tailings			
25	Zinc		Open-pit mine	Pioche	Lincoln	Waste rock & tailings		Quartzite, Limestone	Over 5 million tons stockpiled

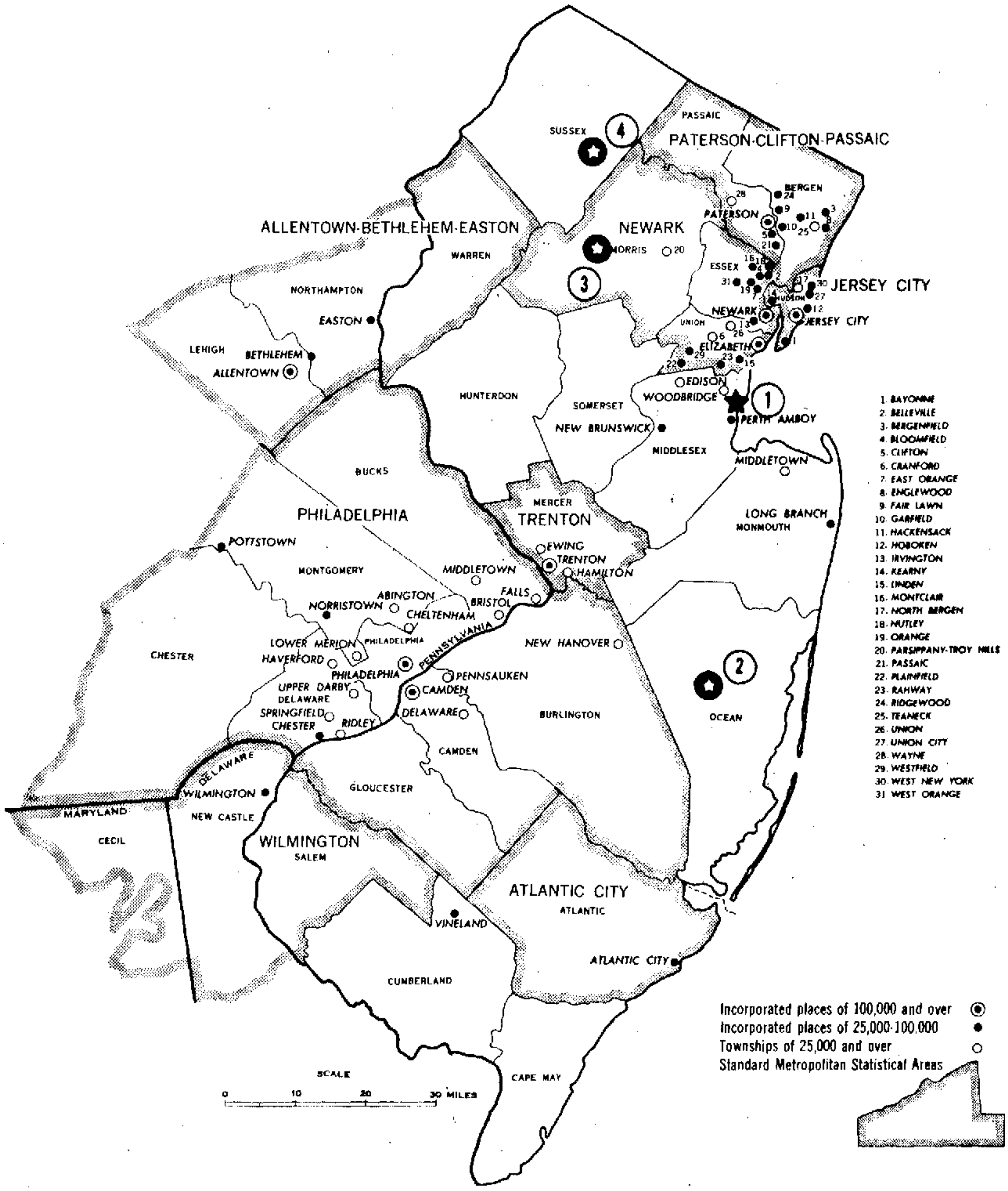

Figure 20. Mineral Waste Locations in New Jersey

Table 19. Description of Mineral Wastes

NEW JERSEY

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Copper	Amax Copper Div.	Smelter	Car-teret	Middlesex	Granulated slag	30,000 tons/ years available for use		Previously used in construction of New Jersey Turnpike
		A.S.A.R. Co.	Smelter	Perth Amboy	Middlesex	Slag			
2	Iron	A.S.A.R. Co.	Open-pit mine concentrator	Lake-hurst	Ocean	Waste rock & tailings			Stockpiled 125,000 tons
3	Iron	Halecrest Company	Underground mine concentrator	Mt. Hope	Morris	Waste rock & tailings		Granite gneiss	Previously operated mine
4	Zinc	N.J. Zinc Co.	Underground mine concentrator	Ogdens-burg	Sussex	Waste rock & tailings		Limestone Dolomite	Over 20 million tons stockpiled

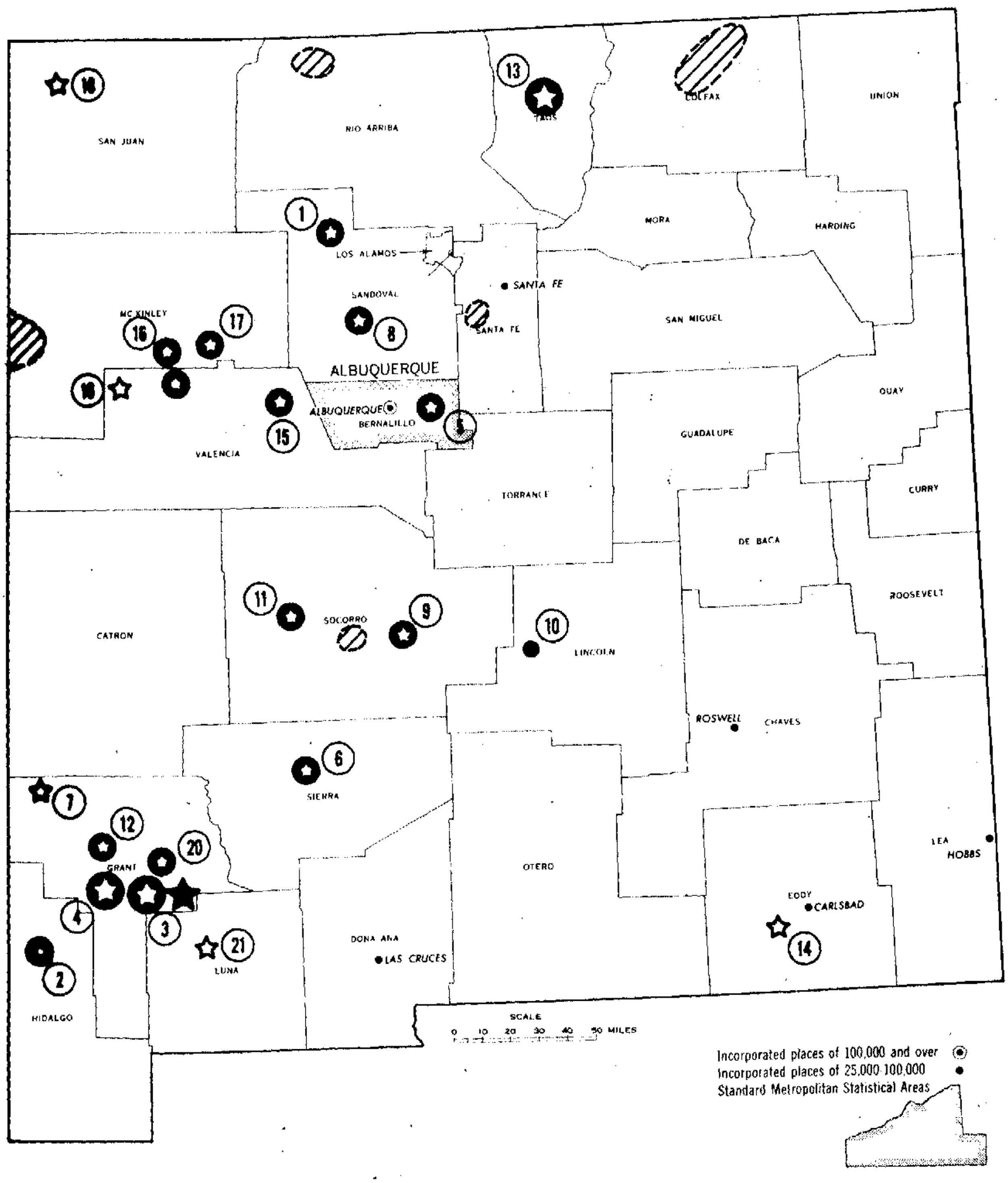

Figure 21. Mineral Waste Locations in New Mexico

Table 20. Description of Mineral Wastes

NEW MEXICO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Copper	Earth Resources Co.	Open-pit mine concentrator	Cuba	Sandoval	Waste rock & tailings			
2	Copper	Federal Resources Corp.	Underground mine concentrator	Lords-burg	Hidalgo	Waste rock & tailings			
*3	Copper	Kennecott Copper	Open-pit mine concentrator smelter	Hurley	Grant	Waste rock & tailings & slag	7.5 million tons/year tailings 200,000 tons/year slag	Quartz	Multi-millions of tons of waste rock accumulated
		U.V. Industries Inc.	Underground mine concentrator	Bayard	Grant	Waste rock & tailings	2.25 million tons tailings annually		Over 7 million tons of tailings stock-piled
		Princess Mine*	Underground mine	Fierro	Grant	Waste rock & tailings			Mine temporarily inactive
		Continental Mill & Shafts #2, #3, & #4	Open-pit mine concentrator	Fierro	Grant	Waste rock & tailings	500,000 tons/year		Mine temporarily inactive
*4	Copper	Phelps Dodge	Open-pit mine concentrator	Tyrone	Grant	Waste rock & tailings	12.5 million tons/year		
		USNR Mining & Minerals	Open-pit mine	Silver City	Grant	Waste rock & tailings	500,000 tons/year		
5	Copper	San Pedro Mining	Underground mine concentrator	Albu-querque	Bernalillo	Waste rock & tailings			

Table 20. Description of Mineral Wastes (continued)

NEW MEXICO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
6	Fluorspar	Win Industries, Inc.	Open-pit mine	Cochise	Sierra	Waste rock & tailings	60,000 tons/year waste rock		
7	Gold	Old Ontario Mining Co.	Underground mine	----	Grant	Tailings			Located in Mogollon gold district
8	Gypsum	White Mesa Gypsum Co.	Open-pit mine	San Ysidro	Sandoval	Waste rock & tailings			
*9	Iron	Dolson Minerals Corp.	Open-pit mine	Socorro	Socorro	Waste rock & tailings			
*10	Iron	Ancho Rico Consolidated	Open-pit mine	Ancho	Lincoln	Waste rock & tailings			
11	Lead	Hydro Nuclear Corporation	Mine concentrator	Magdalena	Socorro	Waste rock & tailings			Over 500,000 tons of waste rock in area
12	Manganese	Luck Mining Co.	Open-pit mine	Silver City	Grant	Waste rock & tailings		Quartz Limestone	
*13	Molybdenum	Moly Corp. Inc.	Open-pit mine concentrator	Questa	Taos	Waste rock & tailings	25,000,000 tons/year of waste	Aplite Porphyry, Andesite, Latile, Rityolite	Some material has been used in highway construction
14	Potash	Potash Co. of America	Underground mine	Carlsbad	Eddy	Tailings	1,250,000 tons annually of waste		40,000,000 tons stockpiled tailings. Tailings are 95% Sodium Chloride
15	Uranium	Anaconda Co.	Open-pit mine concentrator	Languna	Valencia	Waste rock & tailings	1,000,000 tons/year tailings		

Table 20. Description of Mineral Wastes (continued)

NEW MEXICO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
16	Uranium	Four Corners Exploration Co.	Underground mine	Near Grants	McKinley	Waste rock & tailings		Sandstone	
		Homestake Mining Co.	Underground mine	Near Grants	Valencia	Waste rock & tailings		Sandstone	
		United Nuclear Homestake Partners	Underground mine concentrator	Near Grants	McKinley	Waste rock & tailings	850,000 tons/year		
		United Nuclear Mining & Milling Corp.	Underground mine concentrator	Near Grants	McKinley	Waste rock & tailings	500,000 tons/year		
17	Uranium	Kerr-McGee Corp.	Underground mine concentrator	Ambro-sia Lake	McKinley	Waste rock & tailings	1,750,000 tons/year		
18	Uranium	Vanadium Corp.	Uranium Mill	Ship rock	San Juan	Tailings			
19	Uranium		Uranium Mill	Blue-water	Valencia	Tailings			
20	Zinc	A.S.A.R. Co.	Underground mine	Vana-dium	Grant	Waste rock & tailings	800,000 tons/year		
21	Zinc	A.S.A.R. Co.	Concentrator	Deming	Luna	Tailings	100,000 tons/year		

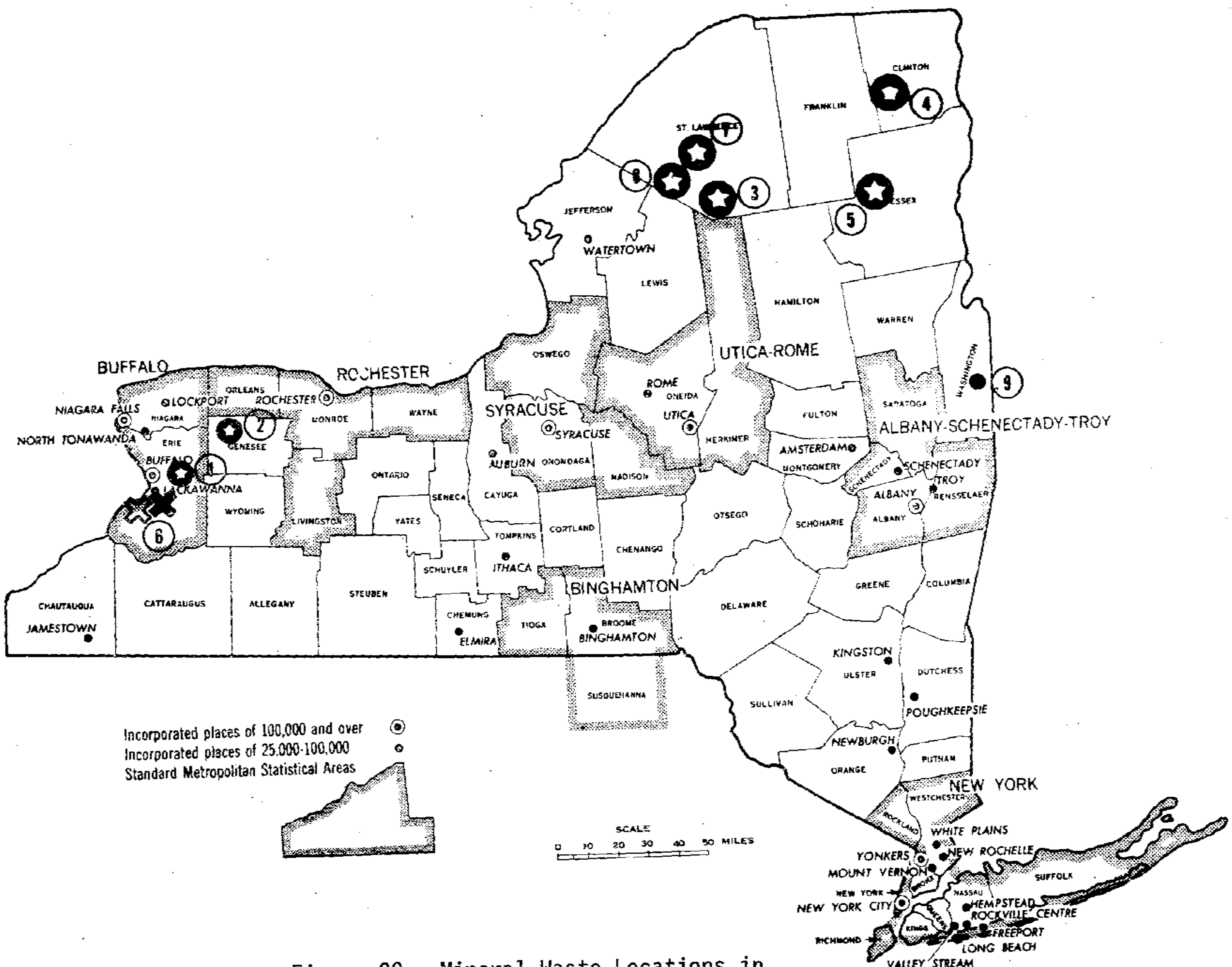

Figure 22. Mineral Waste Locations in New York

Table 21. Description of Mineral Wastes

NEW YORK

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Gypsum	Gold Bond Building Products	Underground mine	Clar-ence Center	Erie	Waste rock & tailings			
		Georgia-Pacific	Underground mine	----	Erie	Waste rock & tailings			
2	Gypsum	National Gypsum Co.	Underground mine	Oak-field	Genesee	Waste rock & tailings			
		U.S. Gypsum	Underground mine	Oak-field	Genesee	Waste rock & tailings			
*3	Iron	Jones & Laughlin Steel Corp.	Open-pit mine concentrator	Star Lake	St. Lawrence	Waste rock & tailings	3,000,000 tons/year	Mica, gneiss, schist	720 million tons accumulated 845 million tons accumulated
*4	Iron		Inactive	Lyon Mountain	Clinton	Waste rock & tailings			Some use in highway construction
*5	Iron	Republic Steel Corp.	Underground mine concentrator	Adiron-dack	Essex	Waste rock & tailings	Temporarily Inactive	Anorthosite	231 million tons stockpiled
		N. L. Industries	Open-pit mine concentrator	Tahawus	Essex	Waste rock & tailings		Anorthosite	
*6	Iron and Steel	Bethlehem Steel Corp.	Steel Mill	Buffalo	Erie	Slag			Over 4.5 million tons accumulated. About 1 million tons year are used in highway construction
		Republic Steel Corp.	Steel Mill	Buffalo	Erie	Granulated Blast fur-nace slag, steel slag	250,000 tons/year 130,000 tons/year		

Table 21. Description of Mineral Wastes (continued)

NEW YORK

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*7	Lead-Zinc	St. Joe Minerals Corp.	Underground mine concentrator	Edwards	St. Lawrence	Waste rock & tailings	850,000 tons/year	Dolomite, Marble	
*8	Lead-Zinc	St. Joe Minerals Corp.	Underground mine concentrator	Balmat	St. Lawrence	Waste rock & tailings		Marble	
9	Slate	Bethlehem Steel Corp.	Inactive	----	Washington	Waste rock			52,000,000 tons accumulated

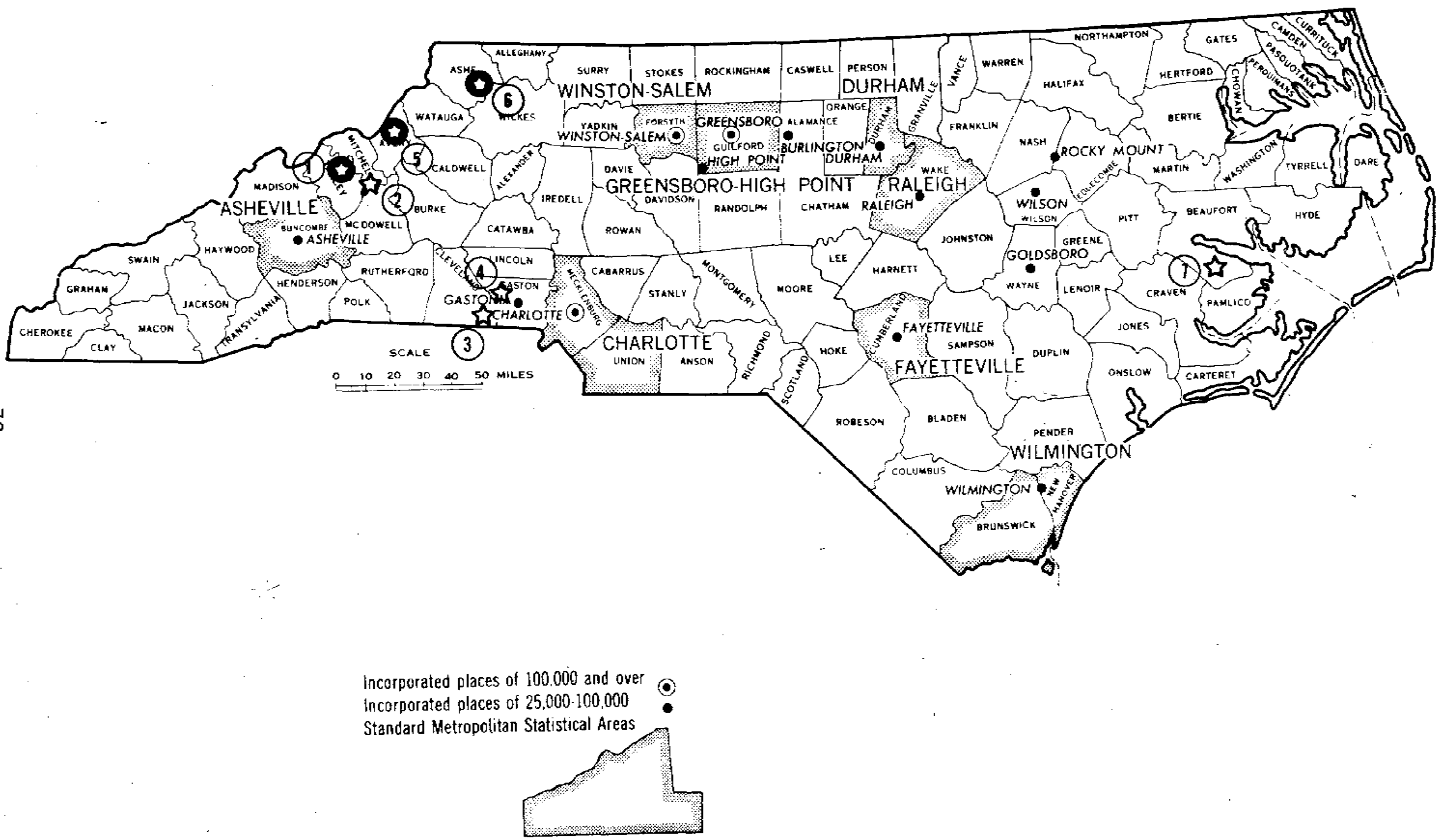

Figure 23. Mineral Waste Locations in North Carolina

Table 22. Description of Mineral Wastes

NORTH CAROLINA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Asbestos	Powhatan Mining Co.	Open-pit mine	Bakers-ville	Yancey	Waste rock & tailings	100,000 tons/year		
2	Feldspar	The Feld-spar Corp.	Quarry concentrator	Spruce Pine	Mitchell	Tailings	100,000 tons/year	Feldspar, Quartz and Mica	Previously used as fill material
		International Minerals & Chemical Corp.	Open-pit mine	----	Mitchell	Tailings			
3	Feldspar	Foote Mineral Co.	Open-pit mine concentrator	Kings Mt.	Cleveland	Tailings	100,000 tons/year	Spodumene	
		Kings Mt. Silica Co.	Open-pit mine concentrator	----	Cleveland	Tailings			
4	Feldspar	Lithium Corp. of America	Open-pit mine concentrator	Besse-mer City	Gaston	Tailings		Spodumene	
5	Iron Ore	Greenback Ind.	Underground mine	----	Avery	Waste rock & tailings			
		Cranberry Magnetite Corp.	Underground mine concentrator	Cran-berry	Avery	Waste rock & tailings			
6	Iron Ore	Ore Knob	Open-pit mine	Jeffer-son	Ashe	Waste rock & tailings			
*7	Phosphate	Texasgulf Inc.	Open-pit mine concentrator	Aurora	Beaufort	Tailings Phosphogyp-sum	5,000,000 tons/year		Phosphogypsum used as sub-base material in highway construc-tion. About 100,000 tons of phosphogyp-sum used locally as base material in swampy area

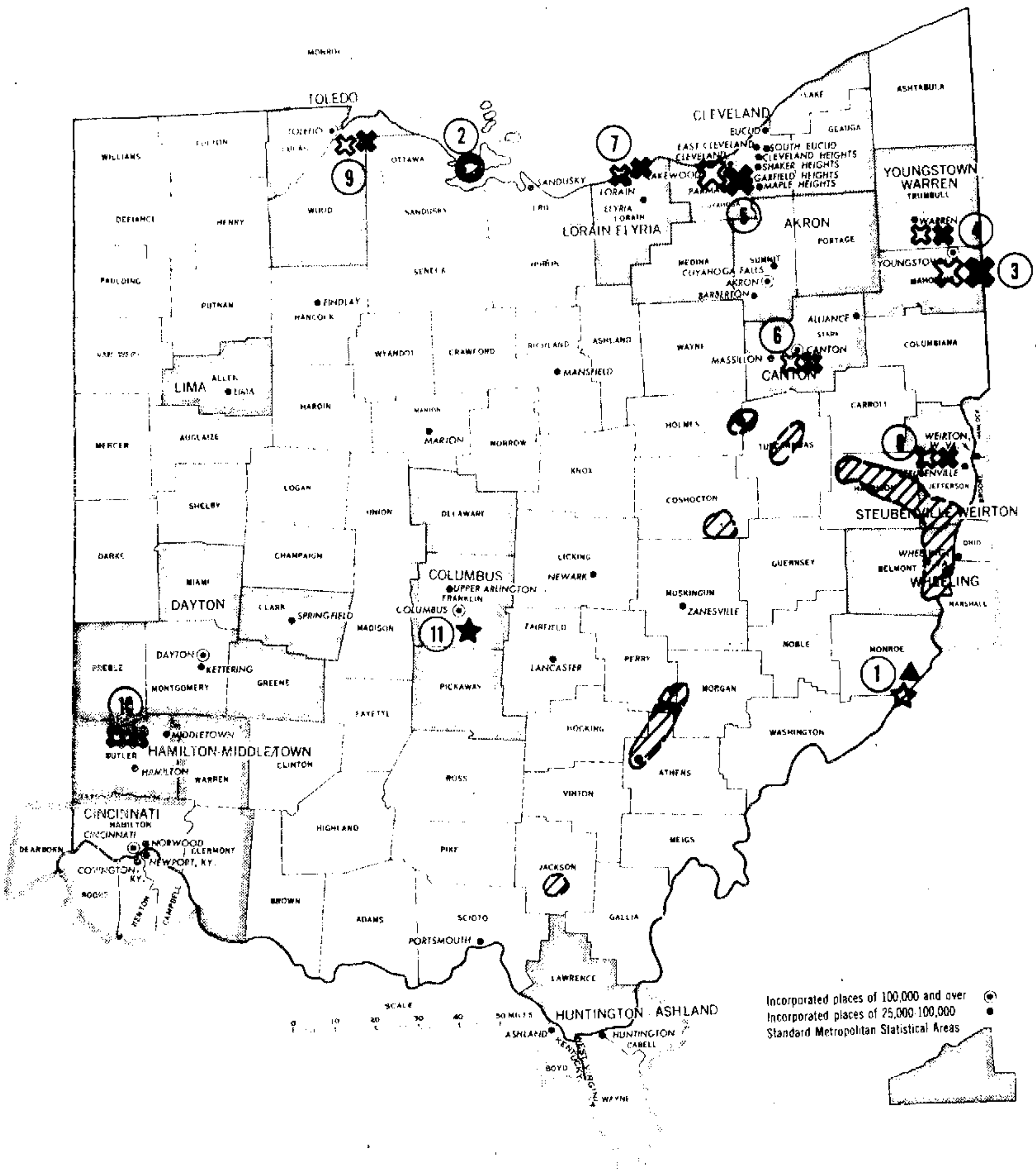

Figure 24. Mineral Waste Locations in Ohio

Table 23. Description of Mineral Wastes

OHIO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Ormet Corp.	Reduction Plant	Hanni-bal	Monroe	Red Mud; Tailings	273,000 tons/year red mud; and 28,000 tons/year tail-ings		3,000,000 tons accumulated red mud; and 143,000 tons tailings accumulated
2	Gypsum	U.S. Gypsum	Underground mine	Gypsum	Ottawa	Waste rock & tailings			
	Gypsum	Celotex Corp.	Open-pit mine	----	Ottawa	Waste rock & tailings			
*3	Iron and Steel	Republic Steel Corp.	Blast furnaces	Youngs-town	Mahoning	Blast fur-nace slag	469,000 tons/year		
		Youngstown Sheet and Tube Co.	Blast fur-naces and steel fur-naces	Camp-bell	Mahoning	Blast fur-nace slag Steel slag	385,000 tons/year 230,000 tons/year		
		Youngstown Sheet and Tube Co.	Blast fur-naces, Steel furnaces, Slag dumps	Youngs-town	Mahoning	Blast fur-nace slag Steel slag	87,000 tons/year 216,000 tons/year		
4	Iron and Steel	Republic Steel Corp.	Blast fur-naces, Steel furnaces	Warren	Trumbull	Slag	300,000 tons/year blast furnace slag, 360,000 tons/year steel slag		
5	Iron and Steel	Republic Steel Corp.	Steel fur-naces, Blast furnaces	Cleve-land	Cuyahoga	Slag	765,000 tons/year 1,000,000 tons/year blast furnace slag		

Table 23. Description of Mineral Wastes (continued)

OHIO

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
6	Iron and Steel	Republic Steel Corp.	Steel furnaces	Canton	Stark	Slag	184,000 tons/year		
7	Iron and Steel	U. S. Steel Corp.	Steel furnaces	Lorain	Lorain	Slag			
8	Iron and Steel	Wheeling-Pittsburg Steel Corp.	Steel furnaces	Steu-benville	Jefferson	Slag			
9	Iron and Steel	Interlake Inc.	Steel furnaces	Toledo	Lucas	Slag			
10	Iron and Steel	Armco Steel Corp.	Steel furnaces	Middle-town	Butler	Slag			
11	Zinc	A.S.A.R. Co.	Smelter	Colum-bus	Franklin	Slag residue			

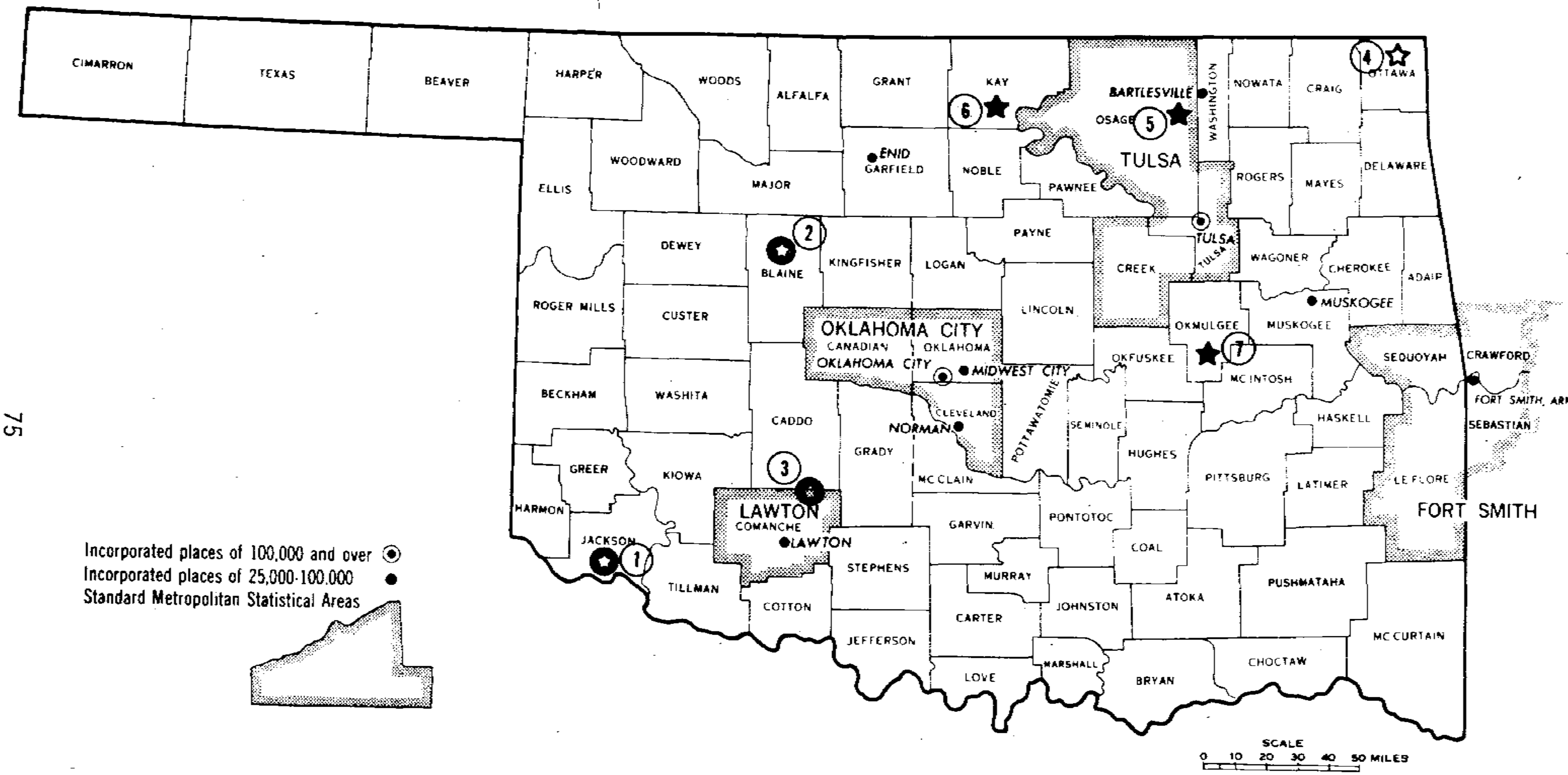

Figure 25. Mineral Waste Locations in Oklahoma

Table 24. Description of Mineral Wastes

OKLAHOMA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*1	Copper	Eagle-Picher Industries	Open-pit mine concentrator	Olustee	Jackson	Waste rock & tailings	1,000,000 tons/year waste	Sandstone Shale	
2	Gypsum	Walton Gypsum Co.	Quarry concentrator	Okeene	Blaine	Waste rock & tailings			
		Universal Atlas Cement	Quarry	----	Blaine	Waste rock & tailings			
3	Gypsum	Texas Gypsum Co.	Open-pit mine	Fletcher	Comanche	Waste rock & tailings			
*4	Lead-Zinc		Tri-State Mining District	----	Ottawa	Tailings (Chat)		Dolomite	Large accumulations from previous mining operations used as aggregate in highway construction
5	Zinc	National Zinc	Smelter	Bartlesville	Washington & Osage	Slag residue	20,000 tons/year		
6	Zinc	Amax	Smelter	Blackwell	Kay	Slag residue			Used in laboratory testing of asphalt mixes
7	Zinc	Eagle-Picher Industries	Smelter	Henryetta	Okmulgee	Slag residue			Smelter closed

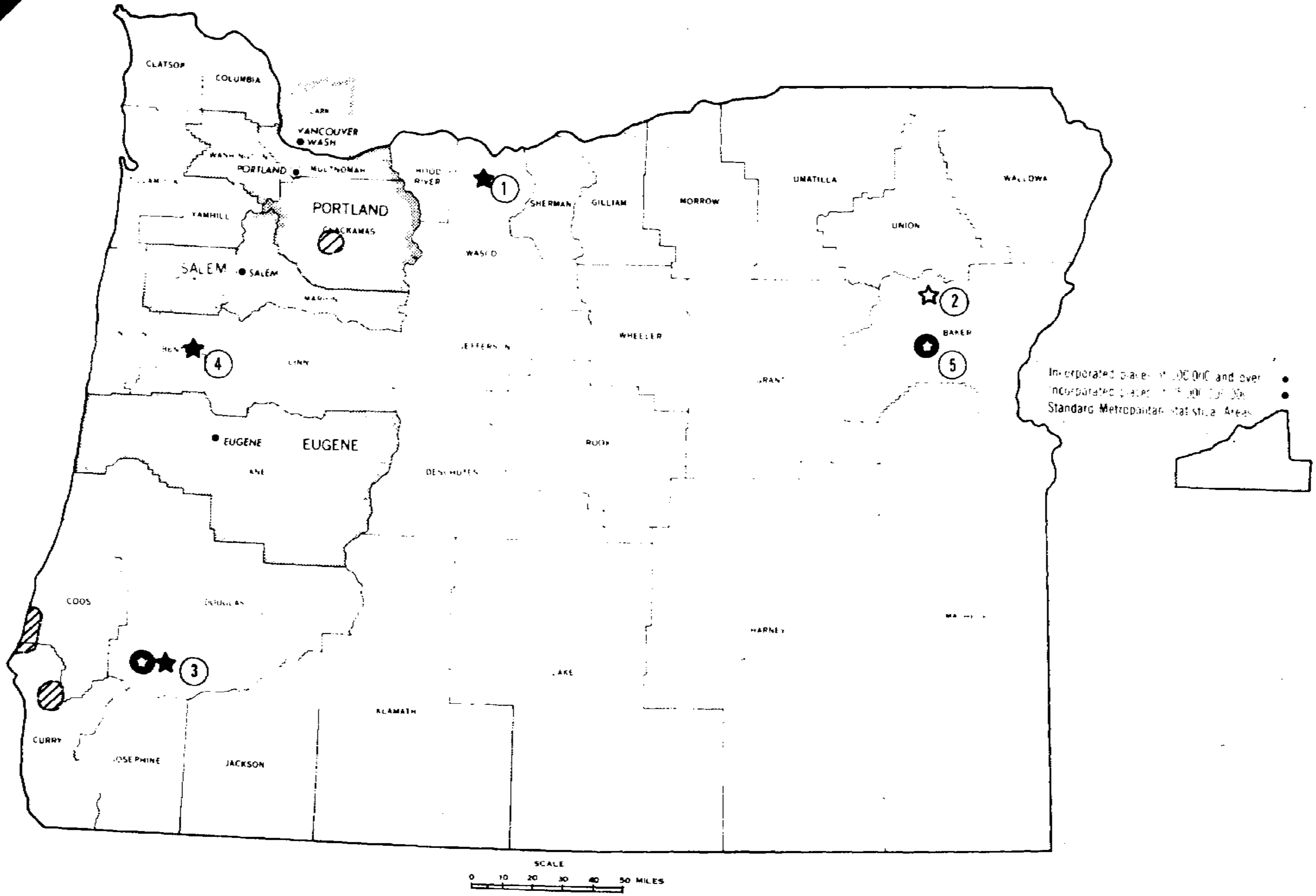

Figure 26. Mineral Waste Locations in Oregon

Table 25. Description of Mineral Wastes

OREGON

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Martin Marietta Aluminum Inc.	Smelter	The Dalles	Wasco	Slag residue			Spent firebrick and cathode carbon also produced
2	Gold	Baker Assets Company	Mine	Pine Creek	Baker	Tailings			
*3	Nickel	Hanna Mining Co.	Open-pit smelter	Riddle	Douglas	Waste rock & tailings Smelter slag	1,000,000 tons/year 800,000 tons/year	Peridotite & Dunite	Over 14,000,000 tons stockpiled Limited use as anti-skid material
4	Titanium	Oregon Metallurgical Corp. (Oremet)	Smelter	Albany	Benton	Slag residue			
5	Tungsten	Frank Ramsey	Mine	----	Baker	Waste rock & tailings			

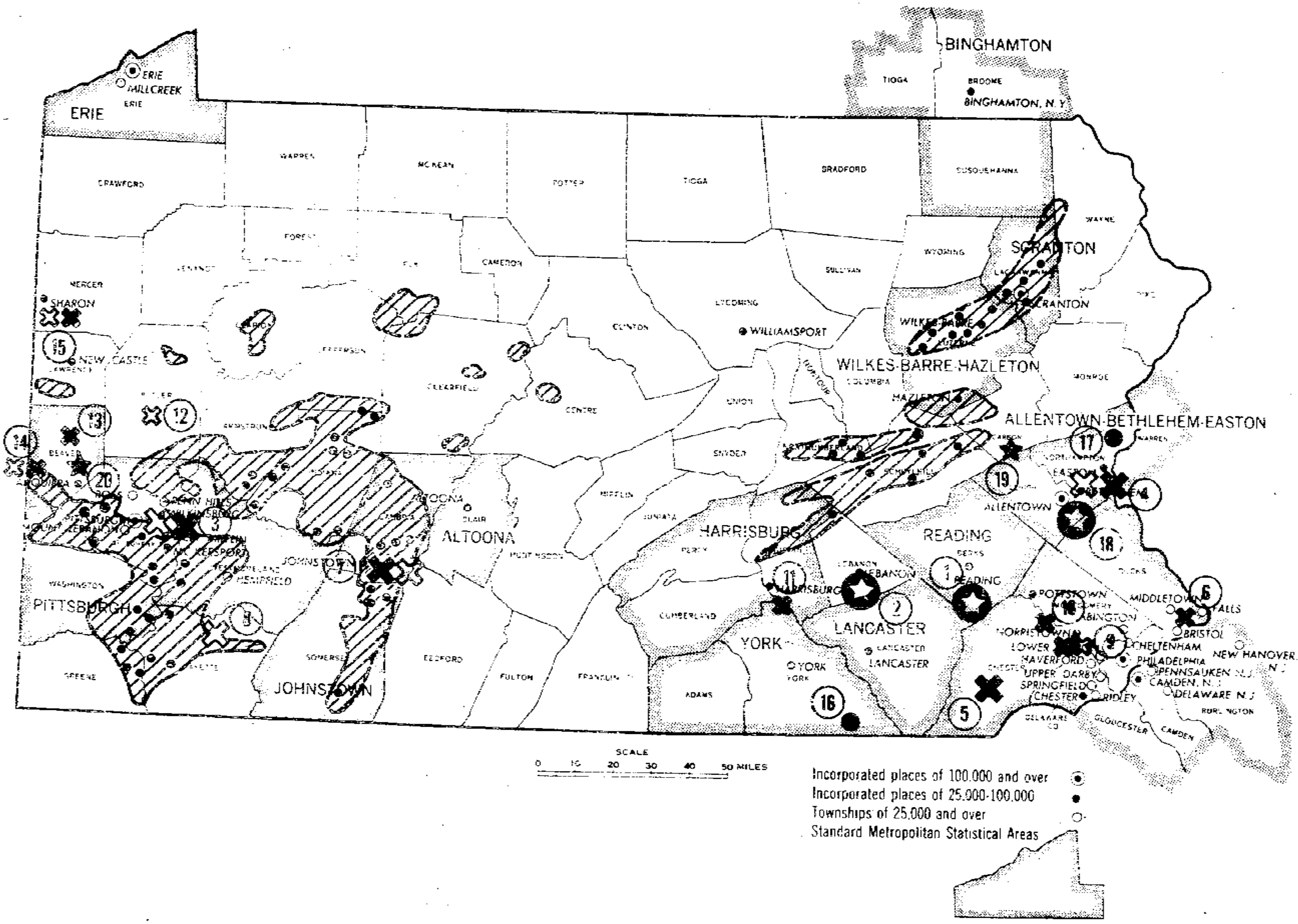

Figure 27. Mineral Waste Locations in Pennsylvania

Table 26. Description of Mineral Wastes

PENNSYLVANIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Iron and Steel	Bethlehem Mines Corporation	Underground mine	Morgan-town	Berks	Waste rock & tailings	10,000 tons/day 400,000 tons waste rock per year 2,000,000 tons tailings per year	Limestone Diabase	Waste rock has been used in highway construction
2	Iron and Steel	Bethlehem Mines Corporation	Underground mine	Corn-wall	Lebanon	Waste rock & tailings		Limestone Diabase	More than 50 million tons accumulated. Mine now closed. Some highway use.
*3	Iron and Steel	U.S. Steel Corp.	Blast furnaces	Pitts-burgh	Allegheny	Blast fur-nace slag	Over 1 million tons/year		45,000,000 tons stockpiled
			Steel fur-naces, Slag dumps			Steel slag	Over 1 million tons/year		20,000,000 tons stockpiled
*4	Iron and Steel	Bethlehem Steel Company	Blast fur-naces, Steel furnaces	Beth-lehem	North-hampton	Slag	750,000 tons/year		14,000,000 tons steel slag stock-piled
5	Iron and Steel	Lukens Steel	Steel furnaces	Coates-ville	Chester	Steel slag			5,000,000 tons steel slag stockpiled
6	Iron and Steel	U.S. Steel Corp.	Steel furnaces	Fair-less Hills	Bucks	Steel slag			
*7	Iron and Steel	Bethlehem Steel Co.	Blast furnaces	Johns-town	Cambria	Blast fur-nace slag	500,000 tons/year		Very little accumu-lation.
			Steel furnaces	Johns-town	Cambria	Steel slag	400,000 tons/year		15,000,000 tons steel slag stock-piled

Table 26. Description of Mineral Wastes (continued)

PENNSYLVANIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
8	Iron and Steel		Slag dump	Vanderbilt	Fayette	Granulated Blast Furnace slag			Approximately 4 million tons stockpiled
9	Iron and Steel	Alan Wood Steel Co.	Steel furnaces Blast furnaces	Conshohocken	Montgomery	Steel slag Blast furnace slag	200,000 tons/year 160,000 tons/year		Slag presently marketed by International Mill Services
10	Iron and Steel	Phoenix Steel Corp.	Steel furnaces	Phoenixville	Chester	Slag			
11	Iron and Steel	Bethlehem Steel Corp.	Steel furnaces	Steelton	Dauphin	Slag			
12	Iron and Steel	Armco Steel Corp.	Steel Mill	Butler	Butler	Slag			
13	Iron and Steel	Babcock and Wilcox Co.	Steel Mill	Beaver Falls	Beaver	Slag			
14	Iron and Steel	Crucible, Inc.	Steel furnaces	Midland	Beaver	Slag	200,000 tons/year steel slag		Slag presently marketed by International Mill Services
15	Iron and Steel	Sharon Steel Corp.	Blast furnaces Steel furnaces	Sharon	Mercer	Blast furnace slag Steel slag	300,000 tons/year 200,000 tons/year		Slag presently marketed by Dunbar Slag Company
16	Slate	G. A. F Corporation	Open-pit mine	Delta	York	Slate waste rock			Mine now closed
17	Slate		Quarry	Pen Argyl	Northhampton	Slate waste rock			

Table 26. Description of Mineral Wastes (continued)

PENNSYLVANIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*18	Zinc		Underground mine concentrator	Center Valley	Lehigh	Waste rock & tailings	500,000 tons/year	Dolomite	20,000,000 tons stockpiled tailings. Some use in agri-culture
19	Zinc	New Jersey Zinc Co.	Smelter	Palmer-ton	Carbon	Slag residue	175,000 tons/year		Over 5,000,000 tons stockpiled residues. Some previous highway use
20	Zinc	St. Joe Minerals Corporation	Smelter	Monaca	Beaver	Slag residue	70,000 tons/year		Some previous use in highway construction

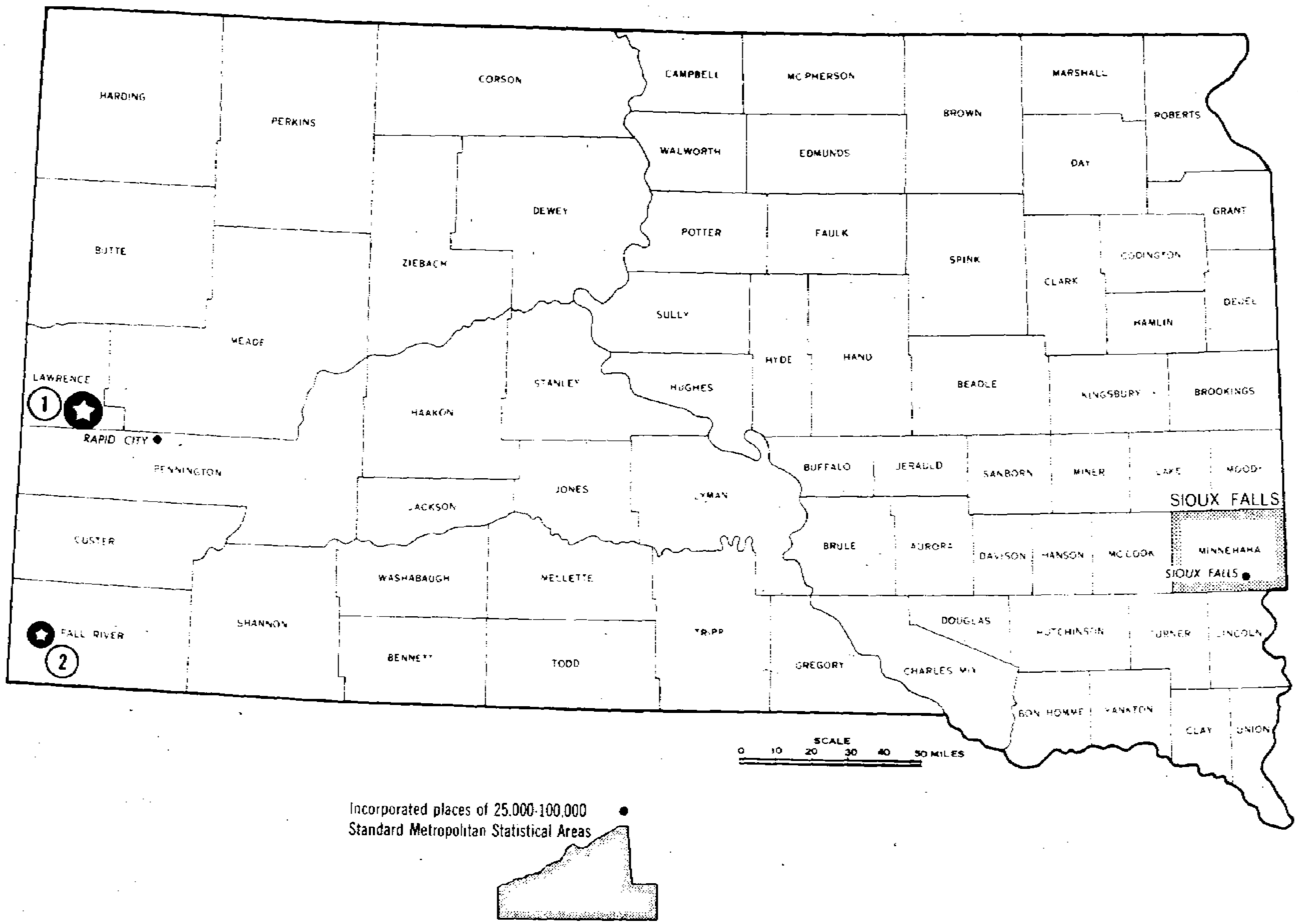

Figure 28. Mineral Waste Locations in South Dakota

Table 27. Description of Mineral Wastes

SOUTH DAKOTA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*1	Gold	Homestake Mining Co.	Underground mine concentrator	Lead	Lawrence	Waste rock & tailings	192,000 tons/year	Schist	3 million tons waste rock accumulated. Previous use in highway construction
2	Uranium	Susquehanna Western Inc.	Underground mine	----	Fall River	Waste rock & tailings			
		T.V.A.; Susquehanna Western Inc.	Concentrator	Edgmont	Fall River	Waste rock & tailings			

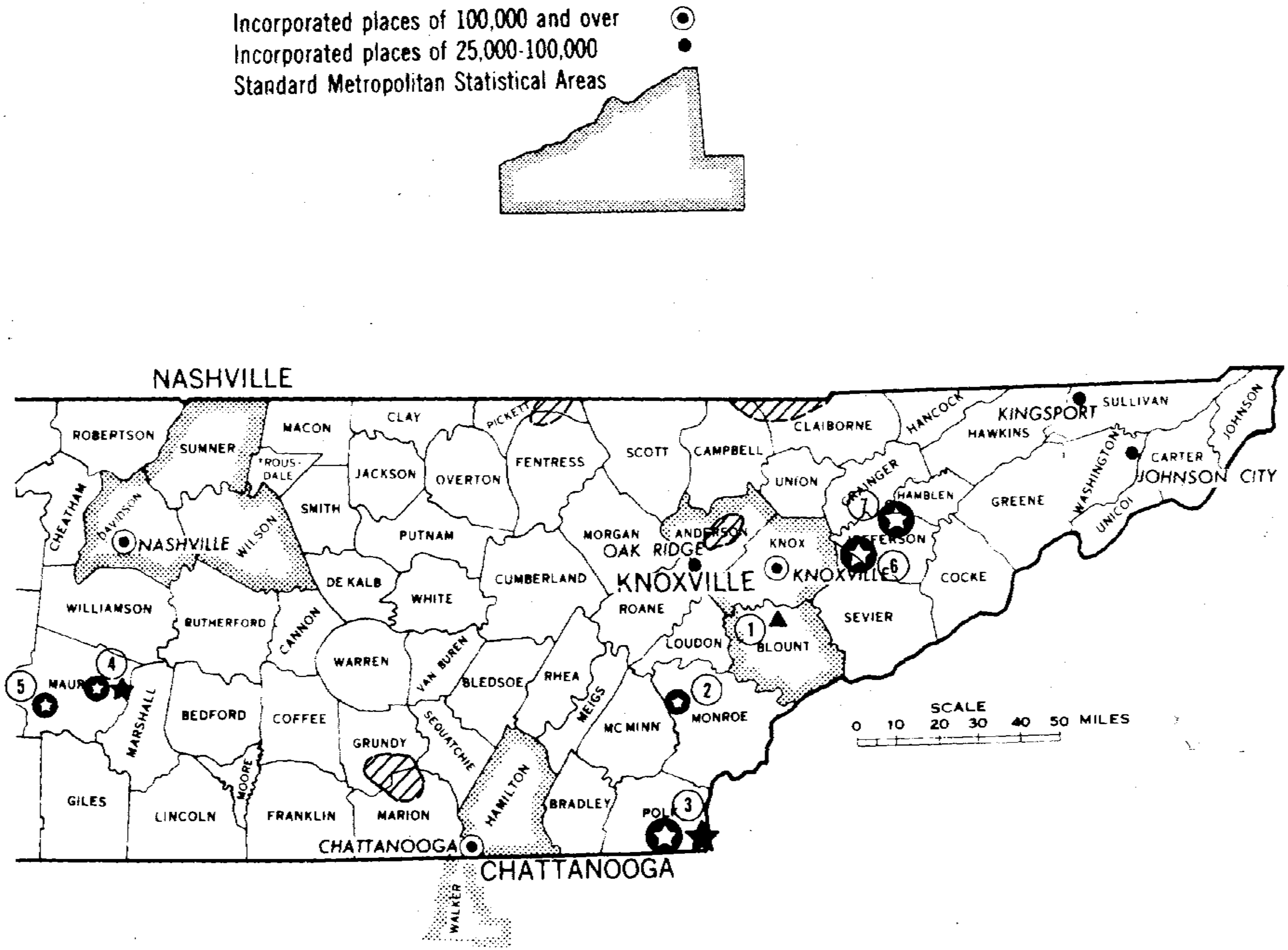

Figure 29. Mineral Waste Locations in Tennessee

Table 28. Description of Mineral Wastes

TENNESSEE

NUMBER	PRODUCT	COMPANY NAME (S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Aluminum Company of America	Smelter	Alcoa	Blount	Mud			
2	Barite	N.L. Industries, Inc.	Open-pit mine	Sweetwater	Monroe	Waste rock & tailings			
*3	Copper	Cities-Service Company	Underground mine smelter concentrator	Copperhill	Polk	Waste rock & tailings & slag	50,000 tons/year 25,000 tons/year	Mica, Schist, Quartzite	Slag sold as iron source for Portland Cement. 200,000 tons stockpiled slag 700,000 tons stockpiled waste rock, 7,000,000 tons stockpiled tailings
4	Phosphate	Monsanto Ind. Minerals	Concentrator Open-pit mine smelter	Columbia	Maury	Waste rock & tailings & slag	1,000,000 tons/year		50,,000 tons stockpiled. Slag used in highway construction
		T.V.A.	Open-pit mine	Columbia	Maury	Waste rock & tailings			
5	Phosphate	Stauffer Chemical Co.	Open-pit mine concentrator	Mr. Pleasant	Maury	Waste rock & tailings			
		M.C. West Inc.	Open-pit mine concentrator	Williamsport	Maury	Waste rock & tailings			
*6	Zinc	A.S.A.R. Co.	Concentrator	Mascot	Knox	Waste rock & tailings	1,500,000 tons/year	Dolomite & Chert	Waste rock tailings marketed by American Limestone for agriculture and construction uses

Table 28. Description of Mineral Wastes (continued)

TENNESSEE

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
7	Zinc		Mine concentrator	New Market	Jefferson	Waste rock & tailings			
		New Jersey Zinc Co.	Underground mine concentrator	Jeffer-son City	Jefferson	Waste rock & tailings		Sphalerite	
		U.S. Steel Corp.	Underground mine concentrator	Jeffer-son City	Jefferson	Waste rock & tailings			

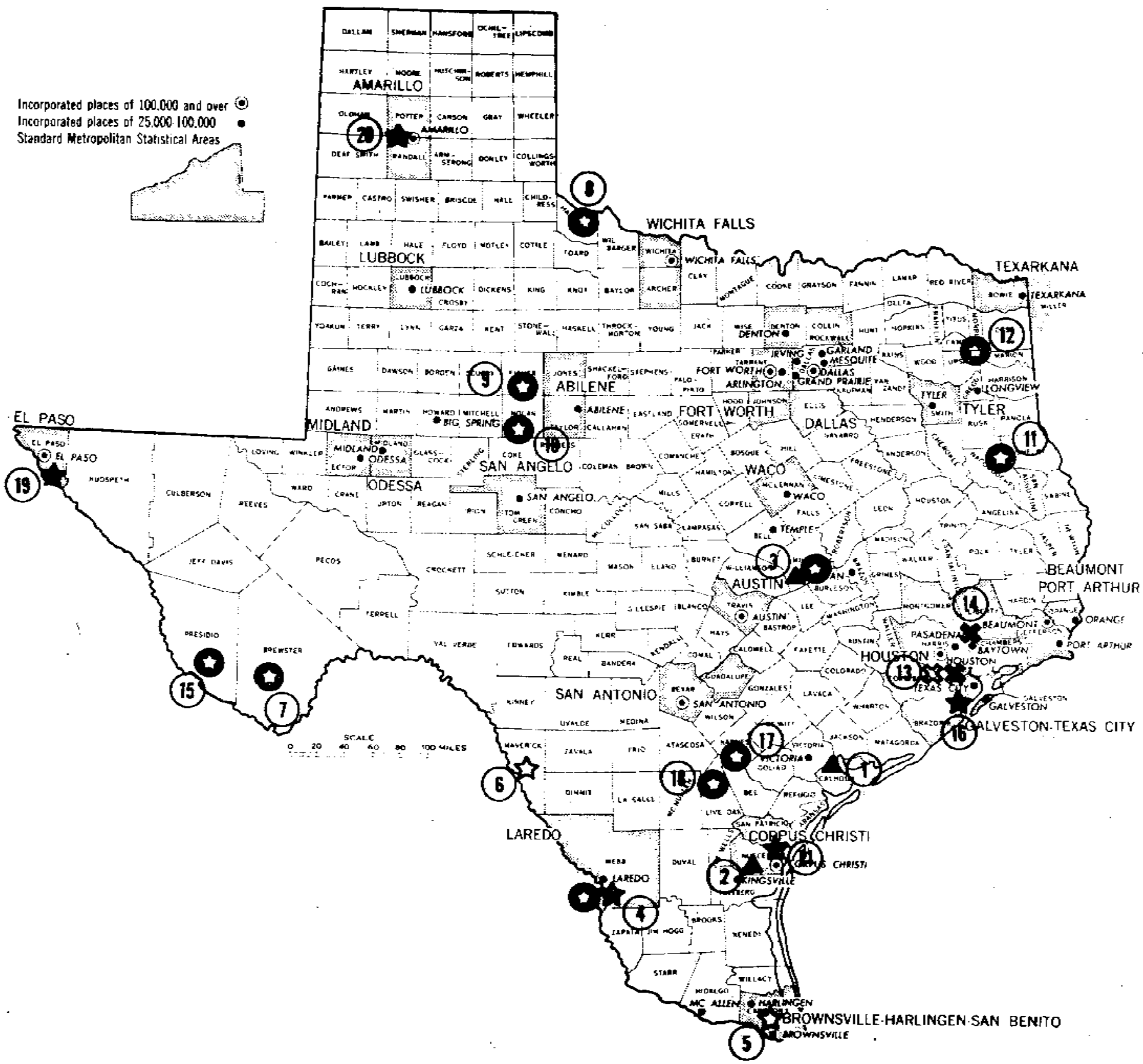

Figure 30. Mineral Waste Locations in Texas

Table 29. Description of Mineral Wastes

TEXAS

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Aluminum Company of America	Smelter	Point Comfort	Calhoun	Mud			Material unsuitable for highway use
2	Aluminum	Reynolds Aluminum Company	Alumina Plant	Corpus Christi	Nueces	Mud			1,500,000 tons/year
3	Aluminum		Open-pit mine smelter	Rock-dale	Milam	Waste rock & tailings & mud			
4	Antimony	N.L. Industries	Open-pit mine smelter	Laredo	Webb	Waste rock & tailings & slag			
5	Barite	Dresser Industries	Processing Plant	Browns-ville	Cameron	Tailings			
6	Fluorspar	Reynolds Metal Company	Concentrator	Eagle Pass	Maverick	Tailings			
7	Fluorspar	D & F Minerals	Mine	----	Brewster	Waste rock & tailings			
8	Gypsum	Georgia-Pacific	Quarry	Quanah	Hardman	Waste rock & tailings			
9	Gypsum	Gold Bond Building Products	Quarry	Rotan	Fisher	Waste rock & tailings			
		Celotex Corporation	Open-pit mine	----	Fisher	Waste rock & tailings			
10	Gypsum	Flintkole Corporation	Open-pit mine	----	Nolan	Waste rock & tailings			Small quantities of waste produced

Table 29. Description of Mineral Wastes (continued)

TEXAS

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
10	Gypsum	U.S. Gypsum Company	Open-pit mine	Sweet-water	Nolan	Waste rock & tailings			
11	Iron	Tex-Iron, Inc.	Open-pit mine concentrator	----	Nacogdo-ches	Waste rock & tailings	100,000 tons/year		
12	Iron	Lone Star Steel Company	Open-pit mine concentrator	Lone Star	Morris	Waste rock & tailings	1,500,000 tons/year iron ore tailings	Limonite Siderite	
13	Iron and Steel	Armco Steel Corporation	Steel furnaces	Houston	Harris	Slags			1,500,000 tons considered retrievable
14	Iron and Steel	U.S. Steel Corporation	Steel furnaces	Baytown	Harris	Slags			
15	Mercury	Anchor Company	Mine	----	Presidio	Waste rock & tailings			
16	Moly-bdenum	Gulf Chemical and Metallurgical Corporation	Smelter	Texas City	Brazoria	Slag			
17	Uranium	Continental Oil Company	Open-pit mine concentrator	Falls City	Karnes	Waste rock & tailings	Estimated 750,000 tons/year		
		Susquehanna Western, Inc.	Open-pit mine	Falls City	Karnes	Waste rock & tailings			
		Pioneer Nuclear, Inc.	Mine	----	Karnes	Waste rock & tailings			
		Tenneco, Inc.	Mine	----	Karnes	Waste rock & tailings			

Table 29. Description of Mineral Wastes (continued)

TEXAS

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
18	Uranium	Susquehanna Western, Inc.	Open-pit mine concentrator	----	Live Oak	Waste rock & tailings			
		Atlantic Richfield Company	Underground Leach Iron Exchange	George West	Live Oak	Waste rock & tailings			
	Uranium	Exxon	Open-pit mine	Ray Point	Live Oak	Tailings			Mine temporarily inactive
19	Zinc	A.S.A.R. Co.	Smelter	El Paso	El Paso	Slag residue	30,000 tons/year		Entire slag production is marketed. Copper also smelted at El Paso
20	Zinc	A.S.A.R. Co.	Smelter	Amarillo	Potter	Slag residue			Smelter recently closed
21	Zinc	A.S.A.R. Co.	Smelter	Corpus Christi	Nueces	Slag residue	35,000 tons/year		Slag sold to local contractor

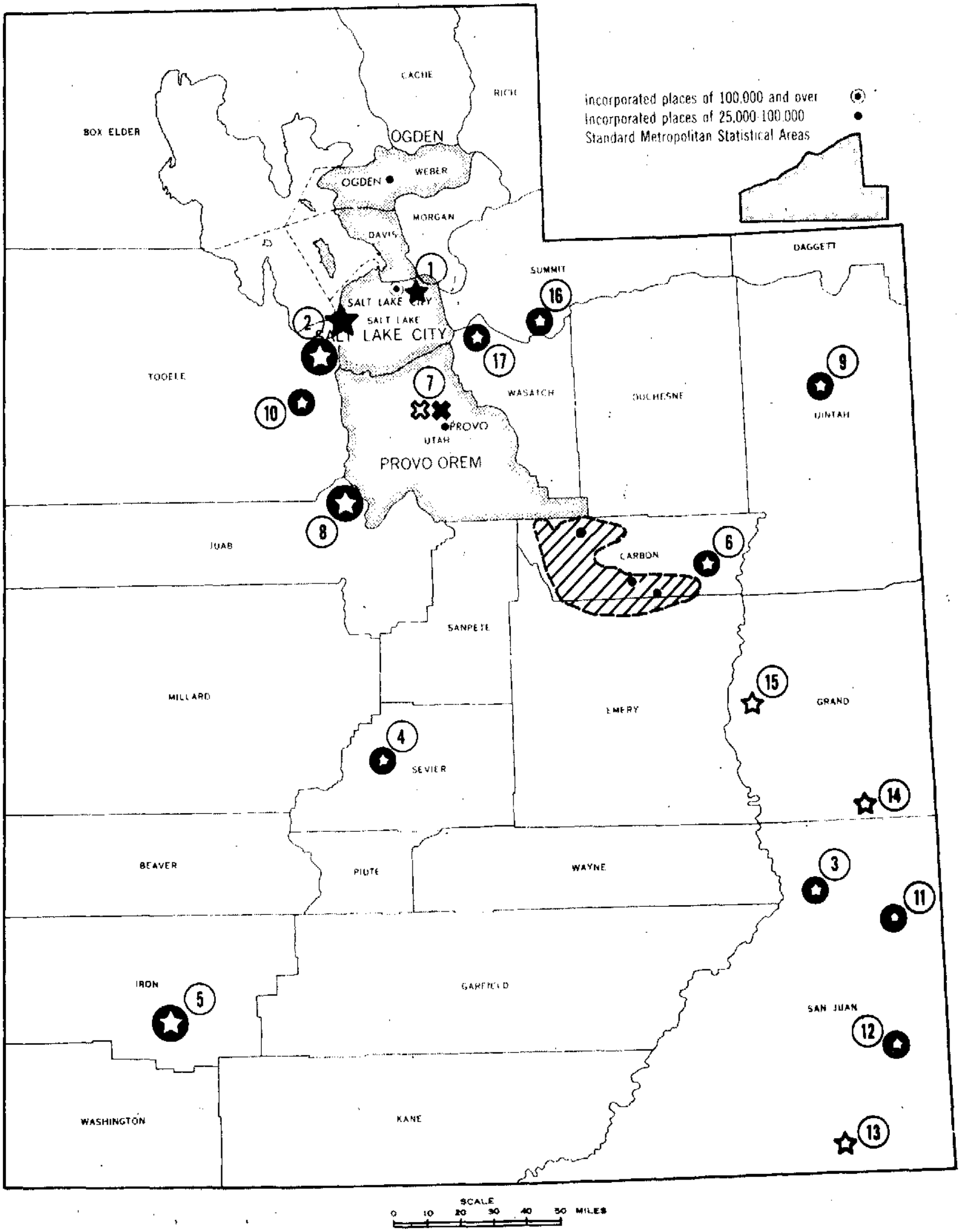

Figure 31. Mineral Waste Locations in Utah

Table 30. Description of Mineral Wastes

UTAH

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Antimony	Intermountain Smelting Corp.	Smelter	Salt Lake	Salt Lake	Smelter slag			Small quantities of waste produced
*2	Copper	Kennecott Copper	Open-pit mine smelter concentrator	Garfield	Salt Lake	Waste rock & tailings & slag	Overburden (Mine Waste) 115,000,000 tons/year (Tailings) 37.5 million tons/year 1.3 billion tons stockpiled (Smelter) slag 600,000 tons/year	Limestone, Quartz and Monzonite	25 million tons air-cooled slag stockpiled 4 million tons granulated slag stockpiled. Slag and coarse tailings have been used in highway construction. Tailing is separated into a coarse fraction
3	Copper	Keystone Wallace Resources	Open-pit mine concentrator	Moab	San Juan	Waste rock & tailings			
		Micro Copper Corp.	Open-pit mine concentrator	Moab	San Juan	Waste rock & tailings			
4	Gypsum	U.S. Gypsum	Open-pit mine	Sigurd	Sevier	Waste rock & tailings			
		Georgia Pacific	Quarry	Sigurd	Sevier	Waste rock & tailings			
*5	Iron	C.F. & I. Steel Corp.	Open-pit mine concentrator	Cedar City	Iron	Waste rock & tailings			Waste rock has been used previously in highway construction
		U.S. Steel Corp.	Open-pit mine concentrator	Iron Springs	Iron	Waste rock & tailings	Limestone, Quartz		

Table 30. Description of Mineral Wastes (continued)

UTAH

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
*5	Iron	Utah International Corp.	Open-pit mine concentrator	Cedar City	Iron	Waste rock & tailings	800,000 tons/year	Primarily Limestone	Some waste rock has been used in highway construction
6	Iron	Kaiser Steel Corp.	Underground	Sunny-side	Carbon	Waste rock & tailings			
7	Iron & Steel	U.S. Steel Corp.	Steel Mill	Geneva	Utah	Slag			Some use in highway construction
*8	Lead	Kennecott Copper	Underground mine	Eureka	Juab	Waste rock & tailings	100,000 tons/year	Limestone, Quartzite	Large quantities stockpiled
9	Phosphate	Stauffer Chemical Co.	Open-pit mine concentrator	Vanal	Uintah	Waste rock & tailings			
10	Silver	McFarland & Hullinger	Underground mine	Ophir	Tooele	Waste rock & tailings			
11	Uranium	Atlas Minerals Div.	Underground mine	La Sal	San Juan	Waste rock & tailings		Sandstone	New mine not in full production
12	Uranium	Mountain West Mines	Underground mine	Bland-ing	San Juan	Waste rock & tailings		Sandstone	
13	Uranium	AZ Minerals	Uranium Mill	Mexican Hat	San Juan	Tailings		Sandstone	Previous milling operation
14	Uranium	Atlas Minerals Div.	Underground mine and concentrator	Moab	Grand	Tailings	375,000 tons/year	Sandstone	
15	Uranium	Union Carbide	Uranium	Green River	Grand	Tailings		Sandstone	Previous milling operation
		Rio Algom Corp.	Underground mine concentrator	Green River	Grand	Tailings			
16	Zinc	Anaconda	Underground mine concentrator	Heber	Summit	Waste rock & tailings			

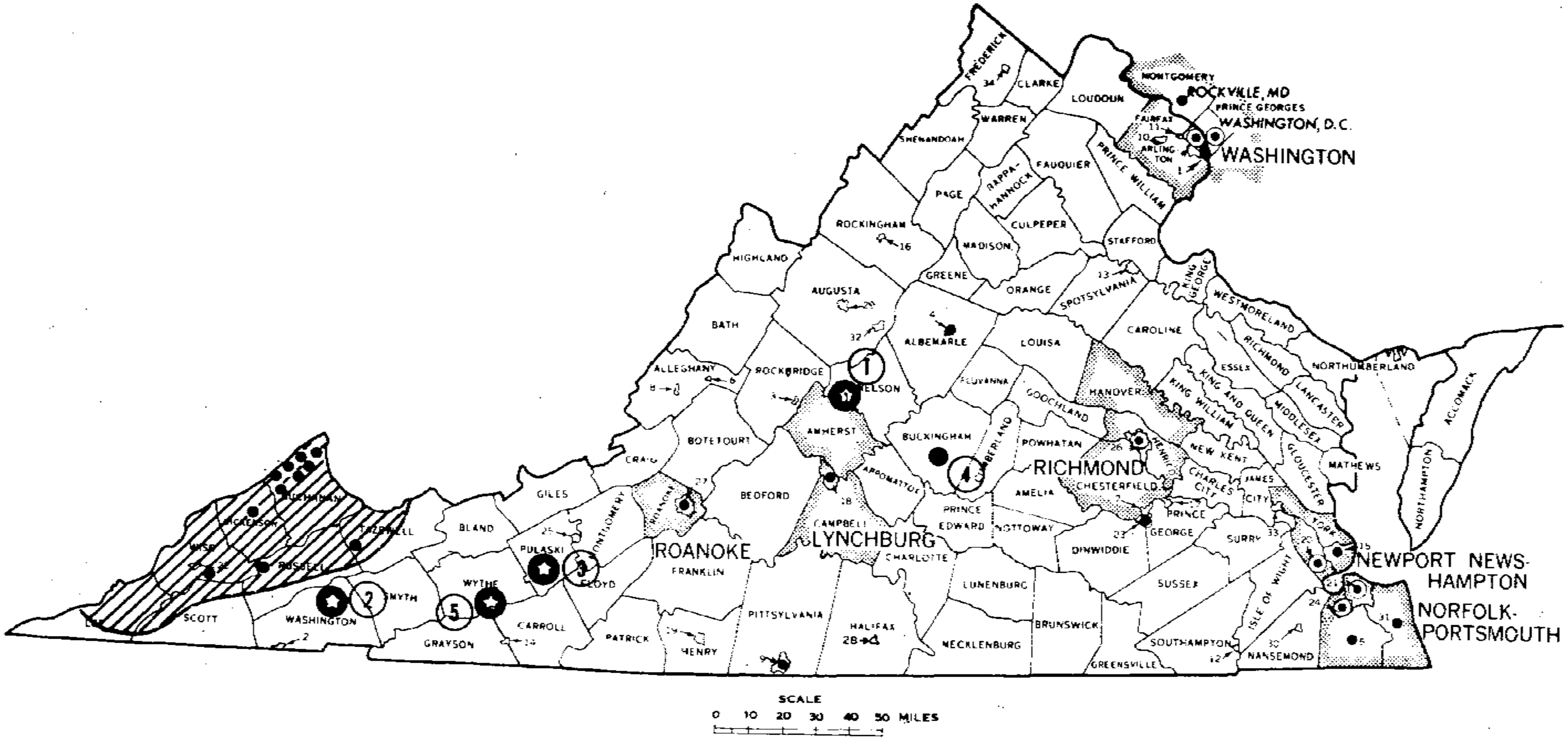

Figure 32. Mineral Waste Locations in Virginia

Table 31. Description of Mineral Wastes

VIRGINIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Feldspar	International Minerals & Chemical Corp.	Open-pit mine	Piney River	Nelson	Waste rock & tailings			
2	Gypsum	U.S. Gypsum Co.	Underground mine	Saltville	Washington	Waste rock & tailings			
3	Iron	Hercules, Inc.	Mine	Hiwasee	Pulaski	Waste rock & tailings			
4	Slate		Mine concentrator	----	Buckingham	Waste rock			Material crushed and used in highway construction
5	Zinc	New Jersey Zinc Co.	Underground mine concentrator	Austinville	Wythe	Waste rock & tailings	550,000 tons/year	Dolomite	More than 20 million tons accumulated

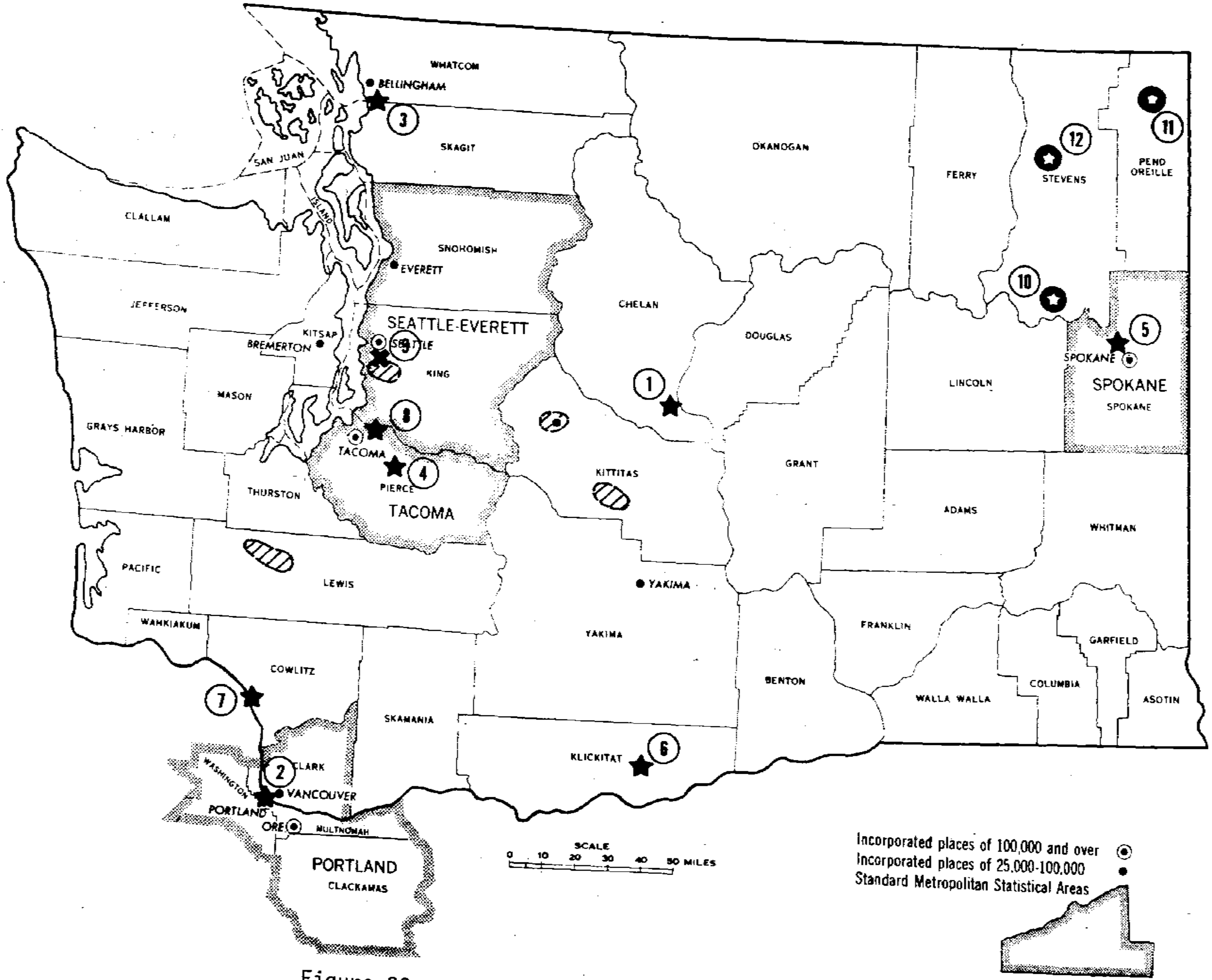

Figure 33. Mineral Waste Locations in Washington

Table 32. Description of Mineral Wastes

WASHINGTON

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Aluminum Company of America	Smelter	Wenat-chee	Chelan	Slag			Very little visible solid waste material
2	Aluminum	Aluminum Company of America	Smelter	Van-couver	Clark	Slag			
3	Aluminum	Intalco Aluminum Corp.	Smelter	Bell-ingham	Wahatcom	Slag			
4	Aluminum	Kaiser Aluminum & Chemical Corp.	Smelter	Tacoma	Pierce	Slag			
5	Aluminum		Smelter	Spokane	Spokane	Slag			
6	Aluminum	Martin Marietta Aluminum Co.	Smelter	Golden-dale	Klickitat	Slag			
7	Aluminum	Reynolds Metals Co.	Smelter	Long-view	Cowlitz	Slag			
8	Copper	A.S.A.R. Co.	Smelter	Tacoma	Pierce	Smelter slag	200,000 tons/year		No accumulation in stockpiles
9	Iron & Steel	Bethlehem Steel Corp.	Steel Mill	Seattle	King	Steel slag			No accumulation in stockpiles
10	Uranium	Dawn Mining Co.	Open-pit mine concentrator	Well-pinit	Stevens	Waste rock & tailings	500,000 tons/year		

Table 32. Description of Mineral Wastes (continued)

WASHINGTON

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
11	Zinc	Bunker Hill Co.	Concentrator Underground mine	Meta-line Falls	Pend Oreille	Waste rock & tailings	20,000 tons/year waste rock 250,000 tons/year tailings	Limestone Dolomite	2,000,000 tons stockpiled waste rock. 2,000,000 tons stockpiled tailings
12	Zinc	Coronado Dev. Corp.	Underground mine concentrator	Col-ville	Stevens	Waste rock & tailings			Mine not yet in full stage of development
		Callaham Mining Corp.	Underground mine	Col-ville	Stevens	Waste rock & tailings			
		A.S.A.R. Co.	Mine	----	Stevens	Waste rock & tailings			

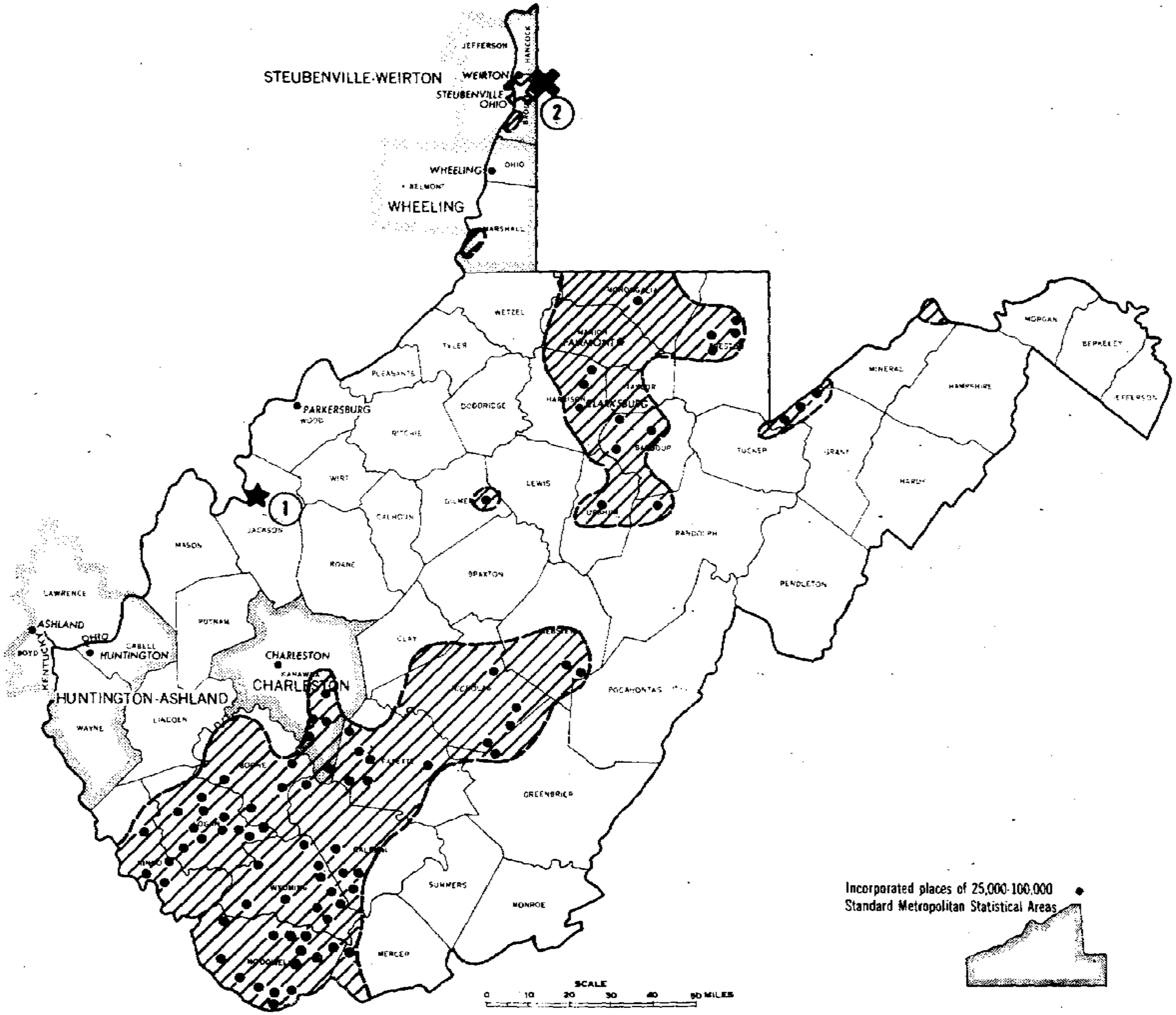

Figure 34. Mineral Waste Locations in West Virginia

Table 33. Description of Mineral Wastes

WEST VIRGINIA

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Aluminum	Kaiser Aluminum & Chemical Corp.	Smelter	Ravens-wood	Jackson	Smelter slag	12,000 tons/year		No significant amount stockpiled
2	Iron & Steel	Weirton Steel Div.	Steel furnaces	Weirton	Hancock	Steel slag Blast fur-nace slag	800,000 tons/year		Large amounts stockpiled

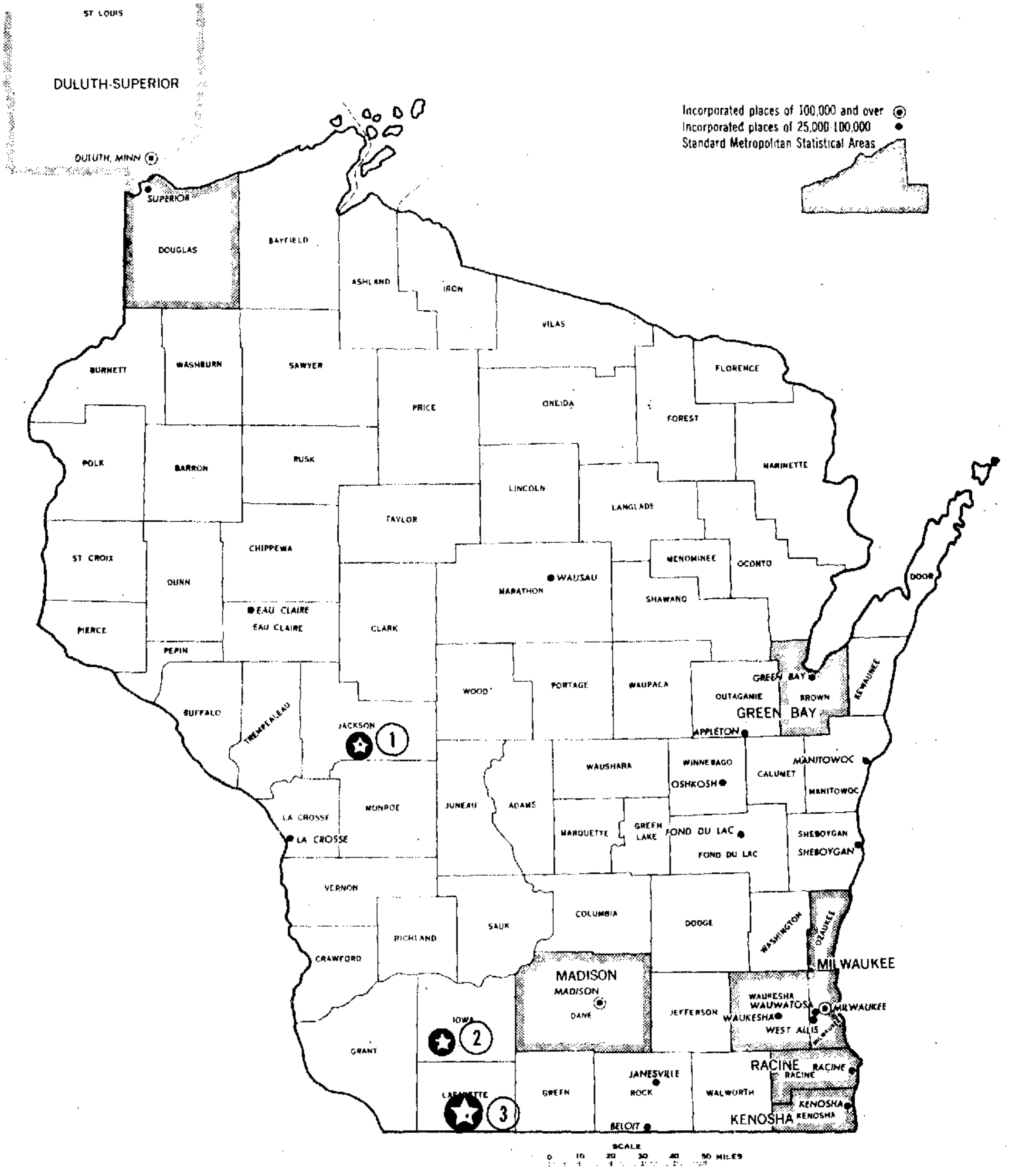

Figure 35. Mineral Waste Locations in Wisconsin

Table 34. Description of Mineral Wastes

WISCONSIN

NUMBER	PRODUCT	COMPANY NAME (S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Iron	Jackson County Iron Co.	Open-pit mine concentrator	Black River Falls	Jackson	Waste rock & tailings	1,000,000 tons/year		
2	Lead-Zinc	Ivey Construction Co.	Underground mine concentrator	Mineral Pit	Iowa	Waste rock & tailings		Dolomite, Limestone	Mine temporarily inactive
3	Lead-Zinc	Eagle-Picher Industries, Inc.		Shulls-burg	Lafayette	Waste rock & tailings	1,000,000 tons/year coarse tailings 3,000,000 tons flotation sands	Dolomite, Limestone	Coarse material has has been used in highway construction

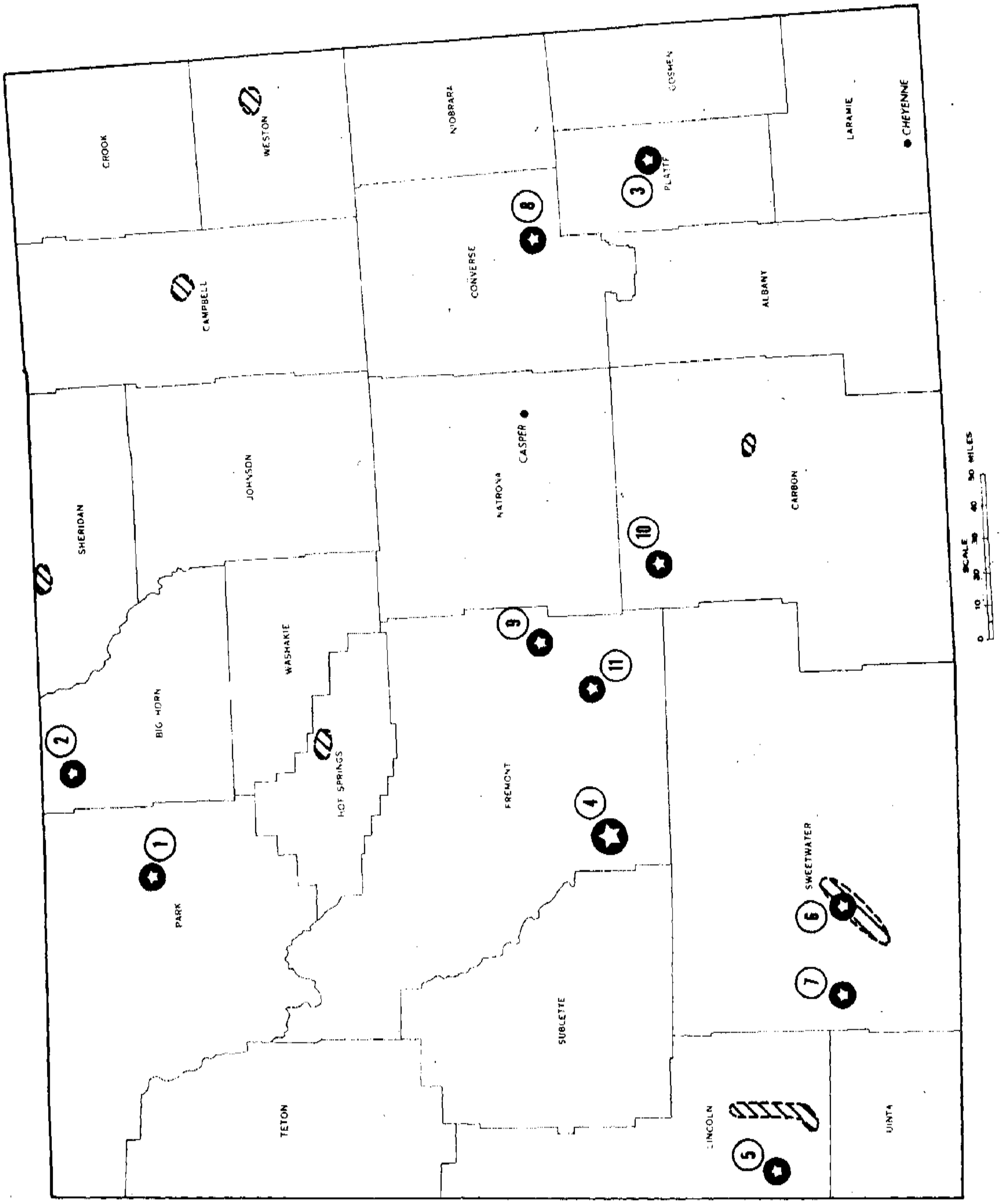

Figure 36. Mineral Waste Locations in Wyoming

Table 35. Description of Mineral Wastes

WYOMING

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
1	Gypsum	Big Horn Gypsum Co.	Open-pit mine	Cody	Park	Waste rock & tailings			
2	Gypsum	Georgia-Pacific	Quarry	Lovell	Big Horn	Waste rock & tailings			
3	Iron	C.F.&I. Steel Corp.	Underground mine concentrator	Guern-sey	Platte	Waste rock & tailings	500,000 tons/year of waste	Dolomite Schist	Several million tons available. Preve-viously used in h highway construction
*4	Iron	U.S. Steel Corp.	Open-pit mine concentrator	Atlan-tic City	Fremont	Waste rock & tailings	6,500,000 tons/year 3,000,000 tons/year	Diorite and Silicified Metasediment	65,000,000 tons stockpiled waste rock 40,000,000 tons accumulated tailings previously used as highway material
5	Phosphate	Co. of Wyoming	Open-pit mine	----	Lincoln	Waste rock & tailings	250,000 tons/year		
6	Soda Ash	Allied Chemical Company	Open-pit mine Underground mine refinery	Green River	Sweetwater	Waste rock & tailings		Trona	
		Stauffer Chemical Company	Underground mine refinery	Green River	Sweetwater	Waste rock & tailings		Trona	

Table 35. Description of Mineral Wastes (continued)

WYOMING

NUMBER	PRODUCT	COMPANY NAME(S)	TYPE OF FACILITY	LOCATION TOWN	LOCATION COUNTY	WASTE CATEGORY	ESTIMATED QUANTITY	MINERALOGY	REMARKS
7	Soda Ash	Texasgulf Inc.	Underground mine	Gran-ger	Sweetwater	Waste rock & tailings			Mine expansion to be completed
		F.M.C. Corp.	Underground mine refinery	West-vaco	Sweetwater	Waste rock & tailings			
8	Uranium	Exxon Corp.	Open-pit mine concentrator	Casper	Converse	Waste rock & tailings	7,500,000 tons/year		Poorly consolidated sand and shale
9	Uranium	Federal-American Partners	Open-pit mine Underground mine concentrator	Gas Hills	Fremont	Waste rock & tailings	1,000,000 tons/year		
		Union-Carbide Corp.	Open-pit mine concentrator	Gas Hills	Fremont	Waste rock & tailings	400,000 tons/year		
		U.S. Energy Corp.	Underground mine	Gas Hills	Fremont	Waste rock & tailings			
		Utah International (Lucky McMine)	Underground mine concentrator	Gas Hills	Fremont	Waste rock & tailings	400,000 tons/year		
10	Uranium	Kerr-McGee Corp.	Open-pit mine	Shirley Basin	Carbon	Waste rock & tailings			36,000,000 tons stockpiled
		Utah International Inc.	Open-pit mine concentrator	Shirley Basin	Carbon	Waste rock & tailings			
11	Uranium	Western Nuclear, Inc.	Open-pit mine underground mine concentrator	Jeffrey City	Fremont	Waste rock & tailings			

2. MINERAL WASTE TRENDS BY STATE

The information presented in this chapter is intended to supplement the location maps and mineral waste tabulations presented in the preceding chapter. This chapter focuses on trends in the current and future generation of mining and metallurgical wastes in principal mining states with respect to:

1. New mines or smelting facilities.
2. Mine and plant expansions.
3. Closures of mines or smelting facilities.

By comparing this information with that of the previous chapter, future shifts in locations and quantities of available mining and metallurgical wastes in certain states can be estimated with some degree of accuracy. In the case of proposed new facilities, it must be realized that most of these facilities represent an extremely large capital investment. Usually, long periods of time are involved in the complete development of new mining and processing facilities. Therefore, some of the trends outlined in this chapter may require a number of years before they are actually in full operation.

This description of mining trends is intended to provide added information to materials engineers and other parties interested in identifying and utilizing mineral wastes. Such supplementary information will be useful in organizing and researching inventories of available material supplies and in planning for future projects in terms of the locations and sources of suitable construction materials.

Information on mineral waste trends has been principally derived from the following sources:

1. Engineering and Mining Journal
2. Keystone Coal Industry Manual
3. Mining Congress Journal

This information is presented in narrative form on an individual state basis. Summaries are included for twenty-five of the thirty-five principal mining states noted in the preceding chapter. In the case of those states not specifically included in this chapter, it means only that no definite information on mineral waste trends in these states was discovered from the literature sources. It could, therefore, be assumed that there will probably be no significant changes in the locations and estimated quantities of mining and metallurgical wastes in such states in the foreseeable future.

2.1 ALABAMA

The mining industry of Alabama is presently centered mainly around coal production. The production of coal in Alabama is almost equally divided between deep mining and strip mining. Nearly all the deposits of brown iron ore in Alabama have been depleted from past years of mining. There are some facilities in the state for the refining of bauxite and phosphate ores.

New Mines or Smelting Facilities

Drummond Company is developing a new strip mine at its Marigold mine in Jasper, which is not yet in full production. The Jefferson Coal Company is constructing a new strip mine at its Jefferson mine in Jefferson County. The Mead Corporation has a new cleaning plant under construction at its Mulga mine in Mulga. The precise date for completion of the work at these facilities is not known at this time.[1]

2.2 ARIZONA

Copper is the principal commodity mined in Arizona. In fact, Arizona is the nation's leading copper producing state and accounts for approximately 50 percent of all domestically produced copper. Gold, silver, iron ore, and coal are other mineral or fuel products mined in Arizona. Because of the dominance of copper in Arizona, mining trends for that state will focus mainly on the copper industry.

New Mines or Smelting Facilities

American Smelting and Refining Company (A.S.A.R. Co.) has begun developmental work for a new underground copper mine and concentrator project near Casa Grande. Anticipated capacity is 9,000 tons (8,100 tonnes) per day. No date is given for project completion.[2]

Cities Service Company expects to complete a new underground copper mine at Miami East by 1978. The new mine has a planned capacity of 2,000 tons (1,800 tonnes) per day of copper ore. Continental Copper also expects to complete a new mine complex of the same capacity at Marble Peak some-

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1 1975 Keystone Coal Industry Manual, pp. 725 - 726.

2 Engineering and Mining Journal, August, 1975, p. 153.

time during 1977.[3]

Hecla Mining Company has just begun copper production at its new Lakeshore complex on the Papago Indian Reservation. The mine complex extracts copper from sulphide and oxide ores. Anticipated capacity is 65,000 tons (58,500 tonnes) of ore per year.[4] Lucky Chance Mine Company will develop a new gold mine at Bloody Basin, north of Phoenix. The vein is in a deposit of gold bearing gravel.[5] No date has been given for starting construction of either project.

Sierra Minerals and 71 Minerals have formed a partnership to develop a new gold-silver mine near Tombstone. The mine will have a planned production of 500 tons (450 tonnes) per day of ore. The date for starting construction is uncertain at this time.[6]

Sovereign Industries has long range plans to develop an iron ore mine and pelletizing plant at Black Mountain. The plant, when completed, is expected to produce 450,000 tons (405,000 tonnes) per year of iron ore pellets. There is no firm date as yet for beginning construction work on this project.[7]

Mine and Plant Expansions

Anamax may expand the capacity of its Twin Buttes copper mine and concentrator facilities from a present level of 63,000 tons (56,700 tonnes) per year to a planned level of 120,000 tons (108,000 tonnes) per year of copper concentrate.

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3 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 76.

4 Engineering and Mining Journal, November, 1975, p. 37.

5 Ibid., p. 239.

6 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 82.

7 Ibid., p. 79.

However, present weak markets render the timetable for this project questionable.[8] Cyprus Bagdad will expand its copper mining complex at Bagdad from 20,000 tons (18,000 tonnes) to 70,000 tons (63,000 tonnes) per year of copper, by 1978. Plans for a smelter at this location have been postponed.[9] Magma Copper plans to complete the expansion of its San Manuel mine during 1976. The capacity of this mine will be increased from 62,500 tons (56,250 tonnes) per day to 75,000 tons (67,500 tonnes) per day of copper ore.[10]

Closures of Mines or Smelting Facilities

Near the end of 1975, the U. S. Environmental Protection Agency published in the Federal Register its long awaited "Proposed Sulphur Dioxide Regulations for Arizona Copper Smelters." These regulations established limits on the amount of SO_2 emitted from smelter stacks, based on ambient air quality monitoring data and operating data provided by each smelter. Nearly all smelters in Arizona have taken very expensive steps to install air pollution control equipment designed to dramatically decrease the emission levels at their facilities, essentially in line with these regulations.

At the present time, it appears that only Phelps Dodge's Douglas smelter will be unable to comply with EPA standards. Phelps Dodge Corporation has already spent more than $20 million in modifications and additions to its Douglas smelter at a time when Federal standards were not known. However, present regulations necessitate the installation of a sulphuric acid plant at Douglas at an estimated cost of $119 million, a step which Phelps Dodge considers economically infeasible. If the installation of such a plant is to be an unconditional requirement in order to continue operating the Douglas smelter, Phelps Dodge will probably close this plant.[11]

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8 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 76.

9 Ibid., p. 76.

10 Ibid., p. 76.

11 Ibid., p. 37.

The Arizona Department of Health Services and its Bureau of Air Quality have been working on proposed amendments to the Arizona plan in the hope of achieving an acceptable agreement with the Environmental Protection Agency. The state hopes to amend and simplify the sulphur emission regulations in order to set currently attainable standards, give smelter operators flexibility in meeting these standards, and require installation of new equipment and new techniques only as they are proven and become available.

One of the main differences between the state plan and the EPA plan is in the time span in which critical emission levels must be maintained. The EPA plan provides that emissions must not exceed certain levels over very short time spans, essentially preventing smelters from operating economically, whereas the state plan proposes monthly limits on the amount of sulphur oxide discharges, with control measures left to the discretion of the smelter operators.

Under the state plan, the Phelps Dodge Smelter at Douglas would be able to continue operating. Arizona's smelter operators are reportedly encouraged by the new amendments and are hopeful that the state plan will gain EPA acceptance.[12]

2.3 CALIFORNIA

The mining industry of California is quite varied. It is characterized by a high tonnage of many different ore products, with large amounts of boron, iron ore, and tungsten being mined in various sections of the state. Very little information is available concerning future mining trends in California.

New Mines or Smelting Facilities

Valley Nitrogen Products will probably complete construction of a new phosphate mining complex at Helm sometime during 1976. This complex will employ the Swenson Isothermal process and will have a planned capacity of 75,000 tons (67,500 tonnes) of P_2O_5 per year.[13]

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12 Engineering and Mining Journal, April, 1976, p. 42.

13 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 85.

Mine and Plant Expansions

U. S. Borax plans to expand the capacity of its boron mine and plant complex at Boron from 500,000 tons (450,000 tonnes) per year of ore to 650,000 tons (585,000 tonnes) per year of ore. Construction will probably be completed sometime during 1977.[14]

2.4 COLORADO

Colorado is a very active mining state. Large quantities of molybdenum, zinc, gold and silver are mined each year in Colorado. In addition, there is also a relatively large tonnage of coal mined each year, which is nearly equally divided between deep and strip mining. A potentially large-scale oil shale industry has also been established on a pilot scale in the northwestern part of the state. Mining trends in Colorado reflect the planned growth in these key industries.

New Mines or Smelting Facilities

After a decade and approximately $400 million in development, Climax Molybdenum (a division of Amax) will begin mining of the Molybdenum ore body at Henderson during the latter half of 1976. Initial production will be at the rate of 2,000 tons (1,800 tonnes) per day of ore with a gradual increase toward an ultimate goal of 30,000 tons (27,000 tonnes) per day of ore by 1979. One of the features of this mine, located in Clear Creek Valley on the eastern edge of the Continental Divide is a 9.6 mile (15.4 kilometers) haulage tunnel from the mine itself to the concentrator located some 50 miles (80 kilometers) west of Denver.[15]

Golden Cycle Corporation plans to reopen the Ajax Gold mine in Cripple Creek sometime during 1976. The mine had been closed since 1974. When reopended, this mine is expected to operate at a capacity of 400 tons (360 tonnes) per day of

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14 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 86.

15 Ibid., p. 92.

ore.[16]

W. R. Grace and the Hanna Mining Company have announced joint development of a surface mine at Craig, subject to company approval. The mine is expected to open in 1979 with a capacity of 3 million tons (2.7 million tonnes) per year.[17]

Several oil shale extraction projects are in the planning stages in Colorado with ultimate development some years away. Gulf Oil Company and Standard Oil Company are now conducting environmental and socio-economic studies for development of an open-pit mining operation on Federal tract C-a in Rio Blanco. Development plans are expected to be completed by mid 1976. Planned capacity of the complex is 100,000 barrels per day of oil. Retorting will be done in a Tosco II retort. This project could possibly be on stream by 1980.[18]

The Colony Development Corporation (Arco, Ashland, Shell, and Tosco) is awaiting a more favorable financial climate in order to proceed with plans to build a 50,000 barrels per day underground mine and plant on a Federal tract in Piceance Creek basin. This project could possibly be completed by 1981, but with estimated costs of $900 million, the financial climate would have to improve for Colony to proceed.[19]

Both Superior Oil Company and Union Oil Company of California have long range plans for underground mine and retorting facilities. However. it is not possible to predict possible dates for starting, much less completing, these projects, since the Superior Oil project is pending land exchange and the Union Oil Project is only in pilot plant study at this time.[20]

Closures of Mines or Smelting Facilities

A number of factors have been responsible for the appar-

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16 Engineering and Mining Journal, November. 1975, p. 32.

17 Mining Congress Journal, September, 1975, p. 8.

18 Engineering and Mining Journal, March, 1976 p. 42.

19 Ibid., p. 46.

20 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 86.

ent lack of growth and development in the oil shale industry at the present time. Lack of a consistent national energy policy, capital availability problems, and continuing oil price controls have contributed to the planned closure of the Paraho oil shale demonstration program near Rifle. Another problem is the lack of Federal loan guarantees and product price supports for derived fuels such as oil shale.

In addition, Arco and Tosco (Oil Shale Corp.) have recently withdrawn from the Shell oil shale project on Federal tract C-b in the Piceance Creek basin, leaving Ashland and Shell Oil Companies to continue the operation at a reduced level.[21]

2.5 FLORIDA

The only significant mining activity in Florida is the industrial phosphate industry. This industry is so large that it provides 75 percent of all domestic phosphate ore production and nearly one-third of the entire world supply of phosphorus. Therefore, mining trends in Florida will be in the phosphate industry.

New Mines or Smelting Facilities

Brewster Phosphates expects to open a new mine and plant in Lonesome during 1977. Expected capacity of this operation will be 3 million tons (2.7 M tonnes) per year of phosphate ore.[22] W. R. Grace will open a new mine in Prarie during 1976. The planned capacity of this mine will be 2.5 million tons (2.25 M tonnes) per year of phosphate ore.[23]

Kerr-McGee will open two new mines, one in Bradford City and the other in Union City. A new plant will also be opened in Bradford City to treat the ore from both of these mines. Mine capacity is expected to be 1.5 million tons (1.35 M tonnes) per year at each location. No definite date for opening has been set at the present time.[24]

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21 Engineering and Mining Journal, March, 1976, p. 42.

22 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 84.

23 Ibid., p. 84.

24 Ibid., p. 84.

Mississippi Chemical plans to complete work on developing a new mine and plant at Hardee City by 1980. The capacity of this installation will be somewhere between 2 and 4 million tons (1.8 and 3.6 M tonnes) per year of ore.[25] Occidental Chemical will be opening a new mine in Columbia City during 1978. Planned capacity will be 3 million tons (2.7 M tonnes) per year of ore.[26] T/A Minerals is due to open a mining complex in Polk City sometime during 1976. The capacity of this complex will be 500,000 tons (450,000 tonnes) per year of ore.[27]

2.6 IDAHO

Mining is one of the key industries in Idaho. A number of commodities are mined in the state including silver, gold, lead, zinc, phosphate rock, and molybdenum. This variety is reflected in the planned expansion of mining activity.

New Mines or Smelting Facilities

For the past several years Cyprus Mines has spent $42.5 million in exploration for a possible molybdenum mine and plant at Thompson Creek. No decision has been made as yet on whether to go ahead with the project.[28]

Two new silver mines are under development in Idaho. Both will probably open sometime in 1976. Coeur d'Alene Mines and A.S.A.R. Co., are jointly developing a mine and concentrator at Coeur. Earth Resources is constructing an open-pit mine at Delamar which will recover gold as a by-product. Both mines will have a capacity of 2.2 million ounces (62.4 million grams) per year of silver.[29]

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25 *Engineering and Mining Journal*, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 84.

26 *Ibid.*, p. 84.

27 *Ibid.*, p. 84.

28 *Ibid.*, p. 81.

29 *Ibid.*, p. 83.

Earth Sciences is involved in two new phosphate mines in Idaho. One is a new mine at Bloomington, expected to open in 1977 at a capacity of 3 million tons (2.7 M tonnes) per year. The other project is a joint venture with National Steel and Southwire in which a new mine and plant are being developed at Soda Springs. No completion date has been set for this project. IMC plans development of a new phosphate mine on the Husky Oil Tract. The mine will produce 2 million tons (1.8 M tonnes) per year of ore and is expected to go into production in 1977.[30]

Mine and Plant Expansions

Beker Industries will complete a $30 million expansion program near Soda Springs during 1977. Plant capacity will be doubled from 2.3 million tons (2.07 M tonnes) to 4.6 million tons (4.14 M tonnes) per year of phosphate ore.[31]

2.7 ILLINOIS

Illinois is primarily a coal mining state. Very little reference has been found for the location of specific new mine sites, although the state's coal mining industry is quite vigorous and future growth is expected.

New Mines or Smelting Facilities

Midland Coal Company is planning to develop a new coal mine and preparation plant complex at its Rapatee mine in Middlegrove. The mine will have an estimated production capacity of 700,000 tons (630,000 tonnes) per year. Time of completion is not known at this time.[32] Inland Steel Company expects to open a new underground coal mine at its McLeansboro mine in Jefferson County during 1978.[33] Monterey Coal Company is constructing an underground mine at its Monterey No. 2 mine in Albers. No date for completion has been announced.[34]

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30 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 84-85.

31 Mining Congress Journal, August, 1976, p. 6.

32 Mining Congress Journal, September, 1976, p. 6.

33 1975 Keystone Coal Industry Manual, p. 738.

34 Ibid., p. 740.

2.8 INDIANA

Like Illinois, Indiana is also predominantly a coal mining state. Very little definite information is available on planned mine openings or closings in Indiana. However, the amount of coal mined in Indiana over the next ten years can be expected to increase.

New Mines or Smelting Facilities

Peabody Coal Company is planning to construct a new underground mine near Booneville. The planned capacity of the mine will be 500,000 tons (450,000 tonnes) per year.[35] No precise completion date is available for this mine.

2.9 KENTUCKY

Kentucky is the nation's leading coal producing state. Aside from some comparatively small fluorspar mining activity in the Northwest part of the state, coal is really the essential mining industry in Kentucky.

New Mines or Smelting Facilities

The Canada Coal Company's Mine No. 2 near Pikeville has a new underground mine, which is not yet in full production. A mechanical cleaning plant is also under construction at this mine.[36] The Johnson Elkhorn Coal Company has an underground mine under construction at the company's mine in Garrett.[37]

The Leslie Coal Mining Company is constructing a new underground mine and cleaning plant at the Leslie Mine in Sidney.[38] The Pontiki Coal Corporation is also developing an underground mine and cleaning plant at its Pontiki mine in Lovely.[39]

A new deep mine is under construction at the South East

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35 Mining Congress Journal, August, 1975, p. 10.

36 1975 Keystone Coal Industry Manual, p. 762.

37 Ibid., p. 776.

38 Ibid., p. 780.

39 Ibid., p. 788.

Coal Company's Caudill's Branch mine at Whitesburg.[40] The Standard Energy Corporation is developing three mines and a cleaning plant at Brownsville. This development consists of an underground, strip, and auger mine.[41] No definite information has been provided regarding the planned capacity or probable date of completion for these facilities.

2.10 MICHIGAN

Michigan is a large producer of iron ore and copper in the Upper Peninsula region of the state. Ore production for each of these mineral commodities is expected to increase in the future in Michigan.

New Mines or Smelting Facilities

The Homestake Copper Company has decided to reopen the Centennial Copper Mine in the Upper Peninsula.[42] Precise date of opening is not known, but should be sometime in the near future.

Mine and Plant Expansions

The Cleveland-Cliffs Iron Company has recently completed the first stage of a 4 million ton (3.6 M tonnes) per year expansion of the mine, concentrator, and pellet plant at its facility in Tilden. The new capacity will now be doubled to 8 million tons (7.2 M tonnes) per year of ore. Ultimately, another 4 million tons (3.6 M tonnes) of capacity will be added. The date for additional expansion is not known at this time.[43]

2.11 MINNESOTA

The production of iron from taconite ores is the dominant mineral industry in the state of Minnesota. Minnesota is the largest iron producing state in the United States and supplies more than half of all the domestic iron produced annually in

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40 1975 Keystone Coal Industry Manual, p. 792.

41 Ibid., p. 793.

42 Mining Congress Journal, October, 1975, p. 13.

43 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 79.

this country. Consequently, mining trends in Minnesota will focus on the iron ore industry.

New Mines or Smelting Facilities

Inland Steel Company is constructing a new concentrator and pelletizing plant at Minorca. Completion of the project is expected sometime during 1977. Rated capacity of the pelletizing plant is to be 2.6 million tons per year (2.34 M tonnes per year) of iron ore pellets.[44]

Mine and Plant Expansions

A number of leading taconite producers in Minnesota are in the process of expanding the capacity of their present operations. The Eveleth Taconite Company expects to complete expansion at its concentrator and pelletizing plant in Eveleth sometime this year. The capacity will be increased from 3.6 million tons (3.24 M tonnes) to 6 million tons (5.4 M tonnes) of iron pellets per year. Hibbing Taconite is expanding the capacity of its pelletizing plant at Hibbing from 6 million tons (5.4 M tonnes) to 9 million tons (8.1 M tonnes) per year. Project completion will be in 1978, with initial production this year.

Another example of pelletizing plant expansion is taking place at the National Steel Pellet plant in Keewatin, where capacity is expected to increase in 1977 from 2.5 million tons (2.25 M tonnes) to 6 million tons (5.4 M tonnes) per year of pellets. U. S. Steel will also be expanding operations at its Virginia concentrator. The capacity of this facility will be increased from 12 million tons (10.8 tonnes) to 18 million tons (16.2 M tonnes) per year of pellets. Project completion is expected to be completed by 1978.[45]

2.12 MONTANA

Montana is one of the leading copper producing states. Sizeable quantities of phosphate rock are also mined in Montana. Mining activity in Montana also includes gold, silver, lead, coal, and iron ore. However, copper is the principal mining industry in Montana, with expected growth in the strip

44 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 79.

45 Ibid., p. 79.

mining of coal also projected.

Mine and Plant Expansions

A third electric smelting furnace plant is now being installed by the Anaconda Company at its smelter in Anaconda.[46] No definite information is available on the capacity of this new plant or the expected date of completion.

2.13 NEVADA

Nevada is one of the most active mining states. It is the leading gold producing state and among the highest producers of silver and copper.

New Mines or Smelting Facilities

Apco Oil Company plans to complete development of a new gold mine complex at Gooseberry sometime this year. The planned capacity of this complex is 250 tons (225 tonnes) per day of ore. Copper Range Company will be reopening its gold mine and refinery at Round Mountain during 1976. This property has been closed since 1960. It will operate at a capacity of 82,000 ounces (2.3 million grams) per year of refined gold.

Minerals Engineering is seeking financing to develop a new gold concentrator at Virginia City to separate gold/silver ore. No date for completion of this concentrator has as yet been established. The capacity of this concentrator is expected to be 1,000 tons (900 tonnes) per day of ore.[47]

Mine and Plant Expansions

Standard Slag will complete expansion of its gold mine at Atlanta during this year. The capacity of this mine is to be increased from 200 tons (180 tonnes) per day to 500 tons (450 tonnes) per day of gold-bearing ore.[48]

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46 Rampacek, Carl and Dunham, James T. "Copper Ore Processing - U. S. Practices and Trends." Mining Congress Journal, February, 1976, p. 43 - 50.

47 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 82.

48 Ibid., p. 82.

2.14 NEW MEXICO

New Mexico is one of the most diverse mining states, being a principal producer of copper, gold, silver, lead, and uranium. Some coal is also mined in the northwestern part of the state. Since New Mexico is the nation's largest uranium producing state, mining trends will be primarily oriented toward uranium production.

New Mines and Smelting Facilities

There are eight new uranium mines or plants planned or in development in New Mexico. Anaconda Company is building a new open pit mine at Laguna. The mine will open at a capacity of 12,000 tons (10,800 tonnes) per week of ore. Beker Industries is now constructing a new uranium plant at Carlsbad, which will open in 1978 at a capacity of 23,500 tons (21,150 tonnes) per year of UF_6. Gulf Oil is developing a new underground mine at Mount Taylor. Completion of this mine is scheduled for 1978.

Sohio Petroleum will be opening a new mine complex at Bibo sometime in 1976. The capacity of this complex will be approximately 1,000 tons (900 tonnes) per day of ore. Sohio Reserve Oil is also planning to open a new mine complex during 1976 at its L-Bar Project at a rated capacity of 1.5 million pounds (680,000 kilograms) per year of concentrate.

United Nuclear is constructing a new mine and plant at Church Rock. This facility, scheduled to open in 1977, will be rated at 3,000 tons (2,700 tonnes) per day of ore. Western Nuclear is in the process of completing the development of two new mines, both of which are expected to come on stream during 1976. One mine, located at Grants, has a planned capacity of 600,000 pounds (273,000 kilograms) per year of U_3O_8. The capacity of the other mine, located at Smith Lake, is not known at this time.[49]

The Peabody Coal Company is now developing a new $65 million surface mine in the San Juan Basin. Although the planned capacity of this mine is not known, the mine is expected to commence operation by mid - 1978.[50]

Construction of the first flash furnace smelter to be

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49 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 83 - 84.

50 Mining Congress Journal, August, 1975, p. 9.

built in the United States is nearing completion for the Phelps Dodge Corporation at Hidalgo in southwestern New Mexico. The facility will have a production capacity of 100,000 tons (90,000 tonnes) per year.[51]

2.15 NORTH CAROLINA

North Carolina is an important producer of phosphate and feldspar. Smaller quantities of asbestos and iron ore are also mined in North Carolina. However, mining trends in this state will focus on phosphate, its principal commodity.

New Mines or Smelting Facilities

Two new phosphate mines will open in Beaufort City during 1976. One, being developed by Agrico and Kennecott will have a planned capacity of 4 to 5 million tons (3.6 to 4.5 M tonnes) of ore. The other, being developed by FMC, will have a planned capacity of 2.5 million tons (2.25 M tonnes) of ore.

Mine and Plant Expansions

Texasgulf is expanding the capacity of its mine complex at Lee Creek from 510,000 ton (459,000 tonnes) per year to 680,000 tons (612,000 tonnes) per year of P_2O_5. The expansion work at this complex is expected to be completed this year.[52]

2.16 OHIO

The production of coal constitutes the most significant mining activity in the state of Ohio. The southeastern part of the state is a large coal production area. Therefore, the focus of mining trends in Ohio will be on the coal industry.

New Mines or Smelting Facilities

The Quarto Mining Company has a new underground coal mine under construction at its Powhatan Mine No. 4 in Powhatan

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51 Rampacek, Carl and Dunham, James T. "Copper Ore Processing - U. S. Practices and Trends." Mining Congress Journal, February, 1976, p. 43 - 50.

52 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 84 - 85.

Point. No definite information is available regarding mine capacity or expected date of completion.[53]

2.17 OKLAHOMA

The principal mining and smelting activity in Oklahoma is the lead-zinc industry. Most of the lead-zinc ore in the state has been mined; however, there is still some smelting of zinc ores in Oklahoma. Mining trends will relate to this smelting activity.

New Mines or Smelting Facilities

Engelhard Minerals will complete construction of a new electrolytic smelting facility to replace a horizontal retort smelter at the company's Bartlesville refinery. The completion of this facility is scheduled for sometime this year. Planned capacity of the new smelter is 56,000 tons (50,400 tonnes) per year of finished zinc.[54] The effect of this new facility on the future generation of smelter slag is not known at this time.

2.18 PENNSYLVANIA

Pennsylvania is one of the nation's key coal mining states, particularly bituminous coal. There are also some sizeable iron ore and zinc mines, as well as two zinc smelting facilities. Since coal is the principal commodity mined in Pennsylvania, mining trends in the state will be primarily oriented toward the coal industry.

New Mines or Smelting Facilities

The Lucky Strike Coal Corporation is developing a new underground anthracite mine at No. 1 slope near Hazleton in Luzerne County. Full production is expected sometime during 1976.[55]

The Cambria Division of Bethlehem Mines has a new mine No. 38E under construction, with full production of 400,000 tons (360,000 tonnes) per year expected during 1978.[56]

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53 1975 Keystone Coal Industry Manual, p. 826.

54 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 78.

55 1975 Keystone Coal Industry Manual, p. 836.

56 Mining Congress Journal, September, 1975, p. 6.

This mine will produce bituminous coal.

Emerald Mines Company has a new underground mine under development at its Emerald Mine No. 1 in Greene County.[57] Solar Fuel Company is constructing a new mechanical cleaning plant at Stoystown in Somerset County.[58] Projected opening dates and capacities for each of these bituminous coal projects are not known at this time.

Mine and Plant Expansions

The Lucky Strike Coal Corporation is also expanding its Bliss-Truedale anthracite strip mine in Luzerne County.[59] It is not known when the mine will be expanded to full production capacity.

St. Joe Minerals plans to complete expansion of its zinc smelter facility at Monaca in Beaver County sometime during 1976. The capacity at this smelter will be increased from 245,000 tons (220,500 tonnes) per year of zinc to 285,000 tons (256,500 tonnes) per year of zinc.[60]

2.19 TENNESSEE

The mineral products most predominant in Tennessee are phosphate, copper, and zinc. Copper smelting and refining is also performed in the southeastern corner of the state. There is also a comparatively small area of coal mining in the northern part of the state.

New Mines or Smelting Facilities

The New Jersey Zinc Company and Union Miniere are jointly developing three new zinc mines and a zinc refinery all in the area of Clarkville. The planned capacity of the refinery will be 90,000 tons (81,000 tonnes) per year of zinc. Com-

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57 1975 Keystone Coal Industry Manual, p. 857.

58 Ibid., p. 872.

59 Ibid., p. 836.

60 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 78.

pletion of the development is expected sometime in 1979.[61]

Stauffer Chemical will be completing work on the construction of a new phosphate processing plant at Mount Pleasant sometime later this year. There is no available information at this time on the projected capacity of this plant.[62]

2.20 UTAH

Utah is a diversified mining state. It is the second highest producing copper state, after Arizona. It is also a major producer of gold, iron ore, lead, silver uranium, and zinc. Some coal is also mined in Utah and there is the potential for large-scale future development of oil shale reserves in the northeastern portion of the state.

New Mines or Smelting Facilities

Anaconda Corporation has begun developmental work on a new underground copper mine complex at the company's Carr Fork Mine in Tooele. This complex is scheduled to come on line during 1979 at a planned capacity of 10,000 tons (9,000 tonnes) per day of copper concentrate.[63]

Getty Oil and Gold Standard are planning to develop at some future time a gold mine and refinery with a capacity of 250,000 ounces (7,094,000 grams) per year of gold. No definite date has been given for completion of this project.[64]

Valley Camp of Utah, Inc., has a new underground coal mine under development at the Utah No. 2 mine near Clear Creek.[65] There is no available information on planned capacity or completion date for the project.

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61 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 78.

62 Ibid., p. 85.

63 Ibid., p. 76.

64 Ibid., p. 82.

65 1975 Keystone Coal Industry Manual, p. 890.

TOSCO has initiated long-range planning for the development of a new underground mine for the production and extraction of shale oil at Sand Wash. Planned capacity of the shale facility is expected to be 75,000 barrels per day of crude oil. Planning is now underway, although completion of the project is not expected until 1985 at the earliest.[66]

White River Shale Oil will eventually be opening a new underground mine at the White River Project. The mine will probably be completed by 1980. Planned capacity of this mine is expected to be 50,000 barrels per day of crude oil.[67]

2.21 VIRGINIA

There is one large zinc mine in Virginia and a number of coal mines in the southwest portion of the state. Mining trends in Virginia are oriented toward the coal industry, since it is a growing industry in this state.

New Mines or Smelting Facilities

Alabama By-Products has formed a partnership with the Alixia Mining Corporation and the Island Creek Pochahantas Company for the development of a new underground coal mine in Buchanan County. The planned capacity of this facility is 1 million tons (900,000 tonnes) per year of coal. Full production is expected by 1980.[68]

Paramount Elkhorn, Inc., has a new underground coal mine under construction at Esserville. No information has been provided on the planned capacity and estimated completion date of this project.[69]

2.22 WASHINGTON

Mining in Washington state is comprised primarily of cop-

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66 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 86.

67 Ibid., p. 86.

68 Mining Congress Journal, May, 1978, p. 11.

69 1975 Keystone Coal Industry Manual, p. 898.

per, lead-zinc, and uranium mining activity, with some coal production. Therefore, mining trends will focus on information pertaining to these commodities.

New Mines or Smelting Facilities

Brenmac Mines is making long range plans to develop a copper mining complex at or near Sultan. No definite target date is available for commencing and completing this work. Planned capacity will eventually be approximately 10,000 tons (9,000 tonnes) per year of copper.[70]

Western Nuclear will soon begin construction on a new uranium open pit mine and plant near Sherwood. The facility is expected to open in 1979 at a planned capacity of 2,000 tons (1,800 tonnes) per day of ore.[71]

2.23 WEST VIRGINIA

Until recently, West Virginia has traditionally been the nation's leading coal producing state. Although Kentucky now produces more coal each year, West Virginia still accounts for over 100 million tons of coal produced annually. Since coal is the only mining activity of consequence in West Virginia, mining trends in that state will focus on the coal industry.

New Mines or Smelting Facilities

Burford, Inc., has a new strip mine under development at its Burford No. 1 Mine site in Randolph County. This new strip mine is not yet in full production.[72] The Olga Coal Company has a new underground mine under development at its War Creek Mine in Coalwood.[73] United Pochahantas Coal Company is developing a new underground mine at its United No. 18

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70 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 76.

71 Ibid., p. 84.

72 1975 Keystone Coal Industry Manual, p. 914.

73 Ibid., p. 940.

Mine site in Crumpler.[74] The West Virginia United Coal Company has a new underground mine under construction at its Wyoming No. 1 Mine in Wyoming County.[75] No further information is known about the completion date or capacity of these mines.

2.24 WISCONSIN

The mining industry of Wisconsin consists primarily of iron ore and lead-zinc production. However, recent discoveries of copper-zinc ore in Wisconsin are reflected in the future mining trends for this state.

New Mines or Smelting Facilities

Noranda Exploration is making long range plans to develop a new copper-zinc open pit mine at Rhinelander. This project has reached the initial proposal stage and construction will begin once environmental clearance has been given. This mine, when developed, will have a planned capacity of 350,000 tons (315,000 tonnes) per year of ore.[76]

2.25 WYOMING

Wyoming is the nation's second leading producer of uranium and one of the leading iron ore producing states. Large deposits of low sulfur coal are located in Wyoming and will be developed in future years. In addition, there are valuable oil shale deposits in the Green River Basin in the southwestern part of the state.

New Mines or Smelting Facilities

Exxon plans to complete construction of a new 1 million tons (900,000 tonnes) per year underground uranium mine at Highland sometime during 1977. Kerr-McGee Nuclear will be opening a new underground mine located in the Powder River Basin at Bill Smith sometime in 1976. The planned capacity of this new mine is 700 tons (630 tonnes) per day of ore.

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74 1975 Keystone Coal Industry Manual, p. 949.

75 Ibid., p. 951.

76 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 76.

Petronomics will be reopening a closed uranium mill and open pit mine in the Shirley Basin during 1978. This complex will have a capacity of 1,000 tons (900 tonnes) of ore per day when it is reopened. United Nuclear is constructing a new underground mine at Morton Ranch with completion scheduled for 1977.[77]

The Carter Mining Company has a new strip mine under development for the production of coal at its Rawhide mine in Gillette. No information is available on the anticipated completion of this mine.[78] The Cordero Mining Company and Sunoco Energy Development Company (a subsidiary of Sun Oil Company) will put a new coal mine into production by January, 1977. Initial production will be 2 million tons (1.8 M tonnes) per year with ultimate development to 12 million tons (10.8 M tonnes) per year by 1981.[79]

Mine and Plant Expansions

Western Nuclear is now expanding its uranium mine and plant operation in Crooks Gap from 600,000 pounds (272,700 kilograms) per year to 2 million pounds (909,000 kilograms) per year of U_3O_8. This expansion program will probably be completed by 1979.[80]

The foregoing information summarizes trends in the future production of mining and metallurgical wastes which are known at the present time. Hopefully, this information will be of value to all who are interested in or concerned about the possible use of mineral wastes in some form of highway construction.

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77 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 83.

78 1975 Keystone Coal Industry Manual, p. 959.

79 Engineering and Mining Journal, June, 1976, p. 15.

80 Engineering and Mining Journal, 1976 Survey of Mine and Plant Expansion, January, 1976, p. 83.

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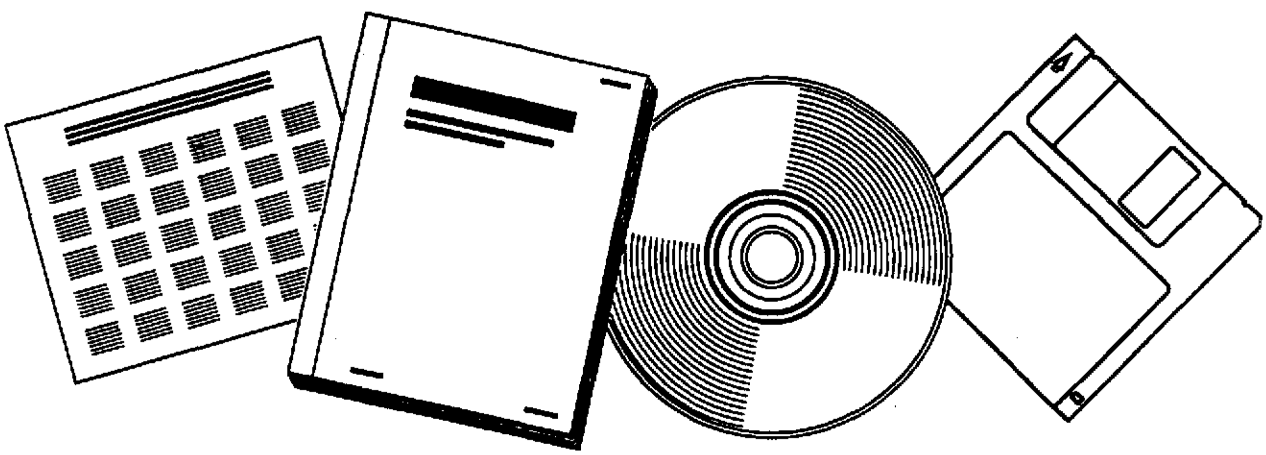
INJECTION OF NATURAL GAS IN THE BLAST FURNACE AT HIGH RATES: FIELD TEST RESULTS AT NATIONAL STEEL GRANITE CITY DIVISION - TOPICAL REPORT

CHARLES RIVER ASSOCIATES, INC.
BOSTON, MA

OCT 95



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Injection of Natural Gas in the Blast Furnace at High Rates: Field Test Results at National Steel -- Granite City

Prepared by:
Charles River Associates Incorporated

Gas Research Institute

Industrial Products Department
October 1995

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Commercial blast furnace tests conducted at National Steel Corporation's A furnace to demonstrate the benefits of natural gas as a supplemental fuel at high injection rates are described. The tests were carried out at the injection rates from 150 to 220 pounds per ton of hot metal (lb/THM), and productivity increases of about 21% were obtained at the highest injection level. Furnace operation was smooth, and the control of hot metal chemistry was held or improved at the high injection rates. The scrap charge on the burden was increased and had an adverse effect on burden permeability. This limited the amount of wind the furnace could accept, and required oxygen enrichment. While overall productivity increased, the marginal productivity was significantly lower. An overall coke replacement ratio of about 1.2 pounds of coke per pound of gas was achieved, but the marginal replacement ratio fell. This is believed to be a result of the poor burden permeability and high supplemental oxygen consumption and the practice of maintaining a constant coke slit. A chronological listing of test events is presented in the appendix.

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INJECTION OF NATURAL GAS IN THE BLAST FURNACE AT HIGH RATES: FIELD TEST RESULTS AT NATIONAL STEEL GRANITE CITY DIVISION

TOPICAL REPORT

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for

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Contractor	Charles River Associates Incorporated GRI Contract Number: 5092-237-2526
Principal Investigators	J.C. Agarwal, F.C. Brown, D.L. Chin, and G.S. Stevens
Report Period	November 1994–October 1995
Objective	To demonstrate the benefits of natural gas injection as a supplemental fuel through a series of tests at high rates in a commercial blast furnace.
Technical Perspective	While coke is the primary source of energy for the blast furnace, essentially all furnaces in North America inject supplemental fuels at the tuyere to reduce coke consumption and increase productivity. Coke consumption is reduced by substitution of carbon in the coke with carbon and hydrogen from the supplemental fuel. Productivity increases are achieved by enriching the blast air with oxygen to increase the driving rate of the furnace. While injection of natural gas at high rates (greater than 150 lb/THM) has been demonstrated, operators have divergent opinions as to the optimum way to achieve maximum benefits for various practices. Tests on a commercial-scale furnace are required to determine furnace performance for specific practices and to develop the aim values for optimum benefits.
Technical Approach	A test plan was developed to demonstrate the effects of natural gas injection at high rates on an operating blast furnace: National Steel's A furnace at Granite City. The test plan called for injecting natural gas at rates of 150, 200, 250, and 300 lb/THM and operating the furnace with scrap on the burden to achieve maximum productivity gains. The results of tests at injection rates up to 250 lb/THM are reported here.
Results	Tests were carried out at injection rates from about 150 lb/THM up to 220 lb/THM, and productivity increases of about 21 percent (to 8.7 TPD/CCF) were obtained at the highest rate. Furnace operation was smooth, and the control of hot metal chemistry was held or improved at the high injection rates. The scrap charge on the burden was increased from about 120 to about 240 lb/THM during the tests, and had an adverse effect on

burden permeability. This limited the amount of wind the furnace could accept, and required oxygen enrichment at levels up to 1.4 lb/lb natural gas. While overall productivity increases of 2.1 tons of hot metal per ton of oxygen consumed were achieved, the marginal productivity was only about 1.2 tons at the higher injection rates. An overall coke replacement ratio of about 1.2 lb coke/lb gas was achieved, but the marginal replacement ratio fell to about 0.7 at the higher injection rates. This is believed to be a result of the poor burden permeability and high supplemental oxygen consumption and the practice of maintaining a constant coke slit.

Project Implications

The results of this field test prove the technical and operational value of natural gas injection at rates above 200 lb/THM. During the field test, prior natural gas injection practices were successfully changed to show the economic value of increasing blast furnace production with natural gas injection and scrap on the burden. The 22 percent increase in production has strategic implications for integrated steel companies that want to increase the operating flexibility of the blast furnace to maximize production when demand is high. GRI plans to perform additional test work for development of the practice and demonstrate of the value from injection rates up to 300 lb/THM. GRI is also planning additional tests to maximize coke replacement under steady production requirements, to minimize the oxygen requirements for natural gas injection, and to develop practices for dual injection of natural gas with coal or oil.

Richard K. Clark
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1
Executive Summary

Supplemental fuels are injected at the tuyere level of blast furnaces to reduce coke consumption and increase productivity. These fuels include natural gas, coke oven gas, oil, tar, and coal. The economic benefits derived from supplemental fuel injection are of two types: 1) the reduction in costs of hot metal production arising primarily from decreased coke consumption, and 2) the value of the increased production of hot metal — and steel — that can be sold. Essentially all blast furnaces in North America inject supplemental fuel. Approximately 70 percent inject natural gas in the range from 80 to 210 pounds per ton of hot metal (lb/THM) or from 1,800 to 4,700 standard cubic feet per ton of hot metal (scf/THM). Currently, natural gas injection rates average 110 lb/THM or 2,500 scf/THM. The total amount of gas consumed in North American blast furnaces now exceeds 101 billion cubic feet per year (bcfy).

Natural gas use in blast furnace injection has increased substantially in recent years as operators became aware of its operating and economic benefits. While results of some blast furnace tests were published showing gas injection at higher-than-average rates, there are significant differences among operators in the way aim values are set for high gas injection rates — particularly values for the raceway adiabatic flame temperature (RAFT). These differences in aim values cause significant differences in the amount of coke savings and productivity gains that can be achieved and hence affect the economic benefits that can be realized.

This report presents the results of a series of tests on the operation of a commercial blast furnace, National Steel's A furnace at Granite City, Illinois, at gas injection rates up to 220 lb/THM, or 4,900 scf/THM. The objectives of the test program were to develop process technology for high rates of gas injection at high productivity with use of metallics on the burden, and to provide the steel industry with a baseline manual for this practice. A test plan for the experimental work was developed to define both the proposed aim values and the expected furnace performance at the baseline conditions (150 lb/THM gas injection, scrap charged to the burden) and for operation at gas injection rates of 200, 250, and 300 lb/THM. Throughout the tests, the furnace was operated primarily to meet National's commercial requirements for hot metal and secondarily as a vehicle to obtain test data.

Executive Summary

The furnace operated in the baseline condition from December 1994 through March 1995, and this constituted Phase A of the tests. During this time, upgrades were carried out to the oxygen and gas delivery systems, as part of Phase C, to permit gas to be injected at higher levels.

Natural gas injection rates were increased in Phase B of the tests, which coincided with the reline of National's B furnace at Granite City. The gas injection rates were ramped up to meet the target injection level of 250 lb/THM. A total of about six weeks of steady operation were evaluated. The final phase of the tests, operation at an injection level of 300 lb/THM, has not been initiated at this time.

Operating data obtained from National's data acquisition system were reviewed and checked for consistency and screened to eliminate data obtained when the furnace was experiencing transient conditions due to scheduled and unscheduled maintenance requirements and other upsets in operating conditions unrelated to the tests. The resulting steady-state data, representing about ten weeks of operation, were used to evaluate furnace performance at each condition. The results of the furnace performance are summarized in Table S-1.

Table S-1. Summary of Tests at National Steel Granite City A Furnace

Process Parameter	Units	Period			
		150 lb/THM	Ramp to 200 lb/THM	200 lb/THM	Ramp to 250 lb/THM
Natural Gas Injection	lb/THM	146	174	192	219
Blast					
Temperature	°F	1,787	1,789	1,791	1,794
Moisture	gr/SCF	5.8	5.3	5.6	6.8
Delivered Wind	MCF/THM	38.8	33.0	31.2	30.4
Supplemental O_2	lb/THM	127	209	266	308
AISI RAFT	°F	3.467	3,431	3,428	3,329
Pressure Drop	PSI	22.8	24.4	24.6	24.5
Burden (dry)					
Scrap	lb/THM	121	183	214	242
Coke	lb/THM	810	751	741	723
Production					
Hot Metal	TPD	3,635	4,162	4,303	4,396
Productivity	TPD/CCF	7.2	8.2	8.5	8.7
H.M. Temperature/StD.	°F	2,699/15	2,702/12	2,696/15	2,696/9
H.M. Silicon/StD.	%	0.78/0.11	0.60/0.05	0.57/0.08	0.56/0.03
H.M. Sulfur/StD.	%	0.025/0.004	0.024/0.003	0.024/0.005	0.018/0.003
Operating Parameters					
Thermal + Chemical Energy Above 2,800°F	MMBTU/THM	0.65	0.70	0.75	0.77
Solution Loss	lb mol/THM	7.9	7.5	6.1	4.3
Hydrogen Utilization	%	47.1	45.7	47.1	49.8

These descriptions of furnace performance show that, for the National Granite City A furnace:

- Productivity increases of 21 percent (760 TPD, 8.7 TPD/CCF) were achieved by increasing the scrap charge from about 120 to about 240 lb/THM and increasing oxygen injection from about 150 to about 220 lb/THM.

- Burden permeability decreased as more scrap was added, and this limited the amount of wind the furnace could accept. The furnace was driven by using large amounts of supplemental oxygen, up to about 1.4 lb O_2/lb natural gas. The marginal increase in productivity was about 3 tons of hot metal per ton of total oxygen delivered to the furnace at an injection rate up to about 175 lb/THM, but decreased to about 1.2 tons/ton at higher injection rates.

- While the RAFT decreased as gas was injected at higher levels, the high consumption of supplemental oxygen limited the decrease to about 190°F/100 lb/THM gas injected, only about two thirds of the decrease found in other furnaces injecting gas at high rates. This practice resulted in increasing values of thermal-plus-chemical energy released at the hearth, whereas the value of this parameter is nearly constant in other gas-injecting furnaces.

- The overall hydrogen utilization efficiency increased throughout these tests. The resulting increase in stack reduction brought about a decrease in the extent of the solution loss reaction that was greater than could be accounted for by the increase in the amount of scrap charged.

- A replacement ratio of about 1.2 lb coke saved/lb gas injected was obtained over the range of gas injection tested, but up to 0.15 lb/lb savings could have been attributed to the increase in metallics charged. Furthermore, the marginal replacement ratio decreased from about 1.3 at 175 lb/THM gas injection to about 0.7 at higher injection rates. Also, carbon utilization efficiency decreased at injection rates above 175 lb/THM, with the top gas CO/CO_2 ratio increasing from 1.06 to 1.21.

- The results seem to show that a combination of poor burden permeability and the burdening practice led to the decline in marginal replacement ratio. The high oxygen enrichment decreased the amount of sensible heat that could be contributed by nitrogen, thus increasing combustion requirements for burden heating. Also, the practice of running a constant coke slit under conditions in which limited skip capacity constrained the maximum ore-to-coke ratio that could be charged may have resulted in poor coke utilization.

- Burden descent was smooth and furnace operation was stable over the range of natural gas injection levels tested in spite of the decreased burden permeability. The control of hot metal chemistry was held or improved at high gas injection rates, and the only significant changes required in operating practice were the need to inject steam between the bells and to activate a redesigned top fire suppression system at injection levels above 150 lb/THM.

These findings are generally consistent with the results for other furnaces injecting natural gas at higher-than-average rates: significant productivity gains and smooth furnace operation can be achieved at high injection rates. The unusually high oxygen consumption and low carbon combustion efficiency appear to be related to poor burden permeability and the practice of maintaining a constant coke slit.

2
Introduction

A. PROJECT HISTORY AND OBJECTIVES

North American blast furnaces have injected small amounts of natural gas (about 50 lb or 1,100 scf/THM) since early 1950. In 1987, the Gas Research Institute (GRI) reviewed the technology of fuel injection in North America and issued a white paper entitled "The Use of Natural Gas in the Blast Furnace Area." [1] Although there were references in the foreign literature (primarily Russian) of blast furnaces operating at natural gas injection rates up to 250 lb/THM, there was no information on which reliable operating and economic practices could be developed for domestic blast furnace operations. Therefore, GRI began a multi-pronged approach to develop the operating practices and disseminate the required information. The major elements of the approach were to:

1. Analyze existing domestic natural gas injection practice.

2. Develop a technical and economic model for comparison of natural gas, oil, and coal injection in the blast furnace.

3. Run a controlled set of field experiments on a well-instrumented commercial blast furnace to obtain reliable experimental information on natural gas injection rates of up to 250 lb/THM.

Under this approach, GRI analyzed the operating information available at Warren Consolidated Industries (WCI)[2] and issued a report to show the evaluation of operating data and practices for natural gas injection at 160 lb/THM over extended periods and natural gas injection rates up to 183 lb/THM for shorter periods. The Iron & Steel Society also published a detailed description of the operating behavior of the WCI blast furnace, and used the analysis of the WCI work to provide valuable insights on the effectiveness of natural gas as a control

[1] "The Use of Natural Gas in the Blast Furnace Area." J.C. Agarwal and F.C. Brown. Gas Research Institute, February 1988.
[2] *Direct Injection of Natural Gas in Blast Furnaces at High Rates: An Analysis of Historical Operating Data at Warren Consolidated Industries.* Gas Research Institute (GRI 89/0239), 1989.

tool in blast furnace operation.[3] The WCI report was used to design the subsequent field test of gas injection performed at Armco's #3 blast furnace in Middletown, Ohio.

In 1991, LTV Steel (LTV) reported the results of natural gas injection tests of up to 230 lb/THM on the Cleveland C-6 blast furnace.[4] LTV's primary interest was to increase productivity of the blast furnace while another blast furnace was relined. These operating results were also useful in formulating other field tests.

To further develop economic operating practices for gas injection, GRI developed a thermochemical model of the blast furnace to project the comparative economics of injecting various fuels into the blast furnace.[5] The analysis took into account various operating parameters and capital costs of injection systems and the assigned value of increased hot metal productivity. These analyses have proved to be extremely valuable in planning field tests, in evaluating the results of these field tests, and in analyzing the comparative economic benefits of natural gas and coal injection in those blast furnaces where such options were available.

In 1992, GRI sponsored a field experiment at Armco Steel (now A-K Steel) to inject natural gas at rates up to 250 lb/THM on their #3 blast furnace at Middletown. This blast furnace is well instrumented, has a 29.5-foot diameter, is capable of reaching a 2,000°F hot blast temperature, and had adequate oxygen available to experiment with the high rates of natural gas injection up to 250 lb/THM. The objective of this field test was to develop the process technology necessary to inject high rates of natural gas and to analyze the performance of the blast furnace under relatively stable conditions. Excellent results were obtained from this field experiment. The results were published[6] and showed that for natural gas injection rates of up to 200 lb/THM, the coke consumption decreased 25 percent and the productivity increased by 10 percent

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[3] "Natural Gas Injection at W-1 Blast Furnace." W.G. Sherwood, Warren Consolidated Industries, Inc. *Ironmaking Conference Proceedings*. AIME, 1991.
[4] "Blast Furnace Operation with High Oxygen & Fuel Injection Rates." R.F. Hall Jr., D.E. Heinz, and K.S. Nanavati, LTV Steel Company. *Iron & Steel Maker*, August 1991.
[5] *A Model for Economic Comparison of Natural Gas, Oil, and Coal Injection into the Blast Furnace*. Gas Research Institute (GRI 92-0352), September 1992.
[6] *Injection of Natural Gas in the Blast Furnace at High Rates: Field Experiments at Armco Steel Company*. Gas Research Institute (GRI-92/0353), April 1993.

over baseline production. The oxygen consumption was approximately 1 pound of oxygen per pound of natural gas. Furthermore, the prevailing concept of maintaining a high raceway adiabatic flame temperature (RAFT) for high rates of gas injection practice was shown to be in error — during the tests, RAFT was lowered by about 700°F with no adverse effect on the blast furnace. For gas injection rates between 200 and 250 lb/THM, the results were inconclusive because the injection period was too short to make any meaningful quantitative analysis. Even so, the blast furnace operated smoothly at the 250 lb/THM gas injection rate. Armco decided to end the field experiment program in response to a lower demand for hot metal.

Subsequent to the field trials, A-K Steel has reported very high productivity on its #3 Middletown furnace by injecting over 180 lb/THM of natural gas and by charging over 250 lb/THM of metallic iron as hot briquetted iron.[7]

As a result of the increased confidence of blast operators that high rates of natural gas injection can indeed be used in the blast furnaces, more than ten blast furnaces were injecting natural gas at rates over 150 lb/THM by the end of 1993. However, many important operating questions still remained. In 1994, GRI decided to conduct a series of field tests to meet the following objectives for injection rates of up to 250 lb/THM or more:

1. Optimize the results obtained at A-K Steel by injecting high rates of natural gas with lesser or no quantities of metallic iron. The objective is to obtain high hot metal production without using excessive amounts of expensive briquetted iron or scrap in the charge.

2. Maximize blast furnace productivity for optimal operating flexibility so swings in hot metal demand can be accommodated both technically and commercially.

[7] "Sustained Production in Excess of 9 tons per day/100 ft^3 WV at Middletown's No. 3 Blast Furnace." D.A. Kercsmar, Y. Yamauchi, W. Dilbert and J. Kleather, A-K Steel Corporation. *Iron & Steel Maker*, July 1994.

3. Decrease coke consumption and obtain more definite information on replacement ratios at high rates of gas injection when high productivity is not required.

4. Minimize oxygen use based on technical and operating support for lower RAFT practices.

5. Co-inject natural gas with coal and oil to maximize the economic benefits from dual-injection practices.

The general approach used to arrange these field tests consists of the following steps:

- Visit targeted host sites and discuss the overall objectives of the field tests.

- Obtain an expression of the host site's operating management's interest in running the selected field test.

- Obtain an estimate of the cost of required equipment upgrades to the ironmaking facilities to run the test. In many instances, the host sites needed larger equipment to deliver and measure greater amounts of natural gas and oxygen.

- Enter into a subcontract for performing the field test, to supply the necessary funds to upgrade the facilities, and to obtain a cofunding commitment from the host steel company.

- Obtain baseline operating data necessary to develop a test plan for the host steel company.

- Provide a test plan to blast furnace operating management detailing the test objectives, duration, aim values for various parameters, and contingency plans.

- Perform the field test at several levels of natural gas injection using aim values developed for the field test to achieve the desired objective (productivity increase, coke consumption decrease, etc.).
- Monitor the test work with the host site and provide real-time, in-process technical support.
- Collect operating data for several steady-state conditions for subsequent analysis and interpretation.

B. OPERATING HISTORY AND TEST OBJECTIVES AT NATIONAL GRANITE CITY

National Steel Company has injected natural gas at rates of about 90 lb/THM on its A and B furnaces at the Granite City Division since early 1993. National embarked on a program to reduce coke consumption and costs by reducing the fuel rate in the furnaces through increased natural gas injection. Hot metal production was capped at the time, and the major incentive was to reduce the purchases of merchant coke. Minor upgrades were performed on the natural gas delivery system and the injection rate was increased to about 120 lb/THM on both furnaces later in 1993. Additional upgrades and modifications permitted increased injection levels, and both furnaces were injecting at levels of about 150 lb/THM by late 1994, with the injection rate limited by oxygen availability.

In planning for the scheduled reline of the B furnace during the second quarter of 1995, National sought to define a practice that would maximize the hot metal production from the A furnace. Because the supplemental oxygen normally consumed by the B furnace could be redirected to the A furnace during the reline, it was recognized that increasing the natural gas injection level offered a means to substantially increase the A furnace productivity. Because hoisting capacity was limited, additional scrap would have to be put on the burden to make the targeted production.

In the fall of 1994, National Steel Granite City Division entered into an agreement with GRI to conduct a test on its A furnace to demonstrate the advantages of natural gas injection at higher-than-average rates to achieve productivity gains and decreases in coke consumption. The results of the test work were to be organized into a technical data package that would be provided to the steel industry as a baseline manual for this practice.

The natural gas injection test at National was to be carried out in four phases:

Phase A: Injection tests at a baseline rate of 150 lb/THM

Phase B: Injection tests at rates above 150 lb/THM, up to 250 lb/THM

Phase C: Facilities upgrade

Phase D: Injection tests at rates above 250 lb/THM up to 300 lb/THM

The baseline tests and upgrades were carried out over the winter and early spring in 1994/1995, and Phase B tests were carried out during the second quarter reline. The Phase D testing has not been initiated yet.

3
Test Site Description and Operating Practices

This chapter describes the equipment in the blast furnace area, National's standard operating procedures, and the data collection procedures used in the tests. First, the blast furnace itself is described, followed by description of the auxiliary systems that support the blast furnace operations. Then a description of the upgrades made in conjunction with the test is presented, and the normal operational procedures and the changes implemented with the test plan are described.

A. FURNACE DESCRIPTION

National's 'A' furnace is located in the Granite City plant. The furnace is a two bell top type with a two skip loading system. There is a single tap hole with outlets for three torpedo cars. The hot metal is delivered by rail car to the nearby basic oxygen furnace where it is weighed.

Furnace Details

- Furnace Name: 'A'
- Hearth Diameter: 27 ft 3 in
- Working Height: 79 ft 3 in
- Number of Tuyeres: 18
- Normal Top Pressure: 6 psig
- Top Type: Two Bell System
- Pressurizing Gas: Clean BF Gas
- Top Gas Analyzer: Daniels Model 2500 gas chromatograph
- Working Volume: 50,659 ft^3
- Trough Design: Fixed
- Bosh Cooling: Plates
- Type of Burden Distribution: Revolving Distributor, Fixed Armor
- Date of Last Blow-in: October 1992

Test Site Description and Operating Practices

Natural Gas Injection System

Natural gas is delivered to the Granite City plant at 175 psig through a 10-inch high-pressure line. After a pressure reduction at a 6-inch metering station, the natural gas is delivered through a 6-inch supply line to the 4-inch circle pipe at the blast furnace. The circle pipe delivers gas to 16 one-inch flexible hoses. The two tuyeres over the taphole are blanked for thermal control. The flexible hoses connect to 1 1/4-inch retractable lances made of Inconel. The maximum gas injection rate with this configuration is about 9,000 cfm.

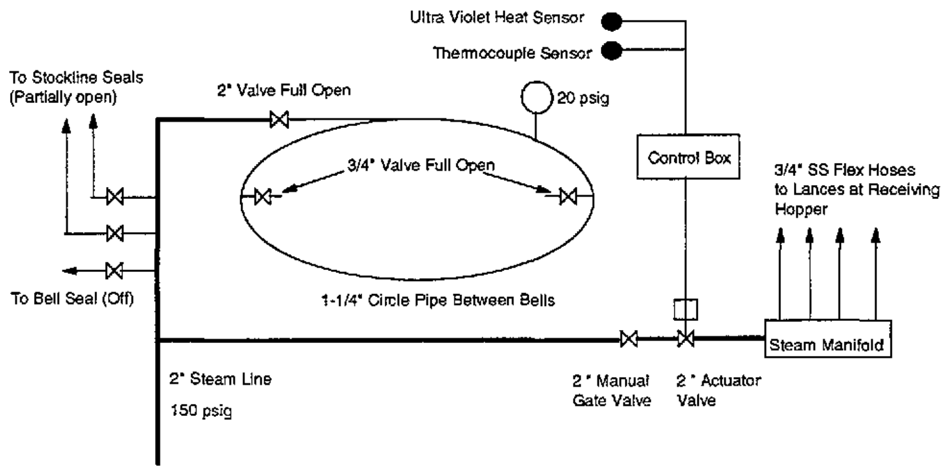
There are shutoff valves at each lance as well as a main shutoff at the circle pipe feed. The lances are four feet long and enter the side of the blowpipe horizontally. The angle of entry is 14° from the center line. The tip of the lance is normally positioned about two feet back from the nose of the tuyere.

Fire Detection/Suppression System

National's original top fire detection and suppression system operated automatically, but was equipped with a manual override. The system consisted of an ultraviolet heat sensor, on/off control valve, and a manifold that directed steam to three lances that were directed downward toward the small bell. Intermediate pressure (IP) steam was supplied by a 2-inch line. The steam was normally off, but once a fire had been detected and extinguished the steam remained on for an additional five minutes.

As natural gas injection rates were increased above 150 lb/THM (top gas hydrogen contents above about 7 percent), top fires became more frequent and the performance of the system became unsatisfactory. A modified system was installed and is shown schematically in Figure 3-1.

Figure 3.1. Steam Injection System between Bells at National GCS A Furnace



SOURCE: National Granite City Steel,

A fourth steam lance was installed and all lances were repositioned toward the bottom of the receiving hopper. Also, a thermocouple was installed as a back-up device for the UV detector. The steam main was extended and a circle pipe was installed supplying two lances to inject steam between the bells. Continuous steam flow between the bells was initiated and, based on the circle pipe pressure, the rate was estimated to be about 1,700 PPH, or about 10 lb/THM. When the fire suppression system was activated, the flow of steam to the bells and the hopper is estimated to be about 4,000 PPH.

When a top fire alarm is sounded the operators cease injection of natural gas and supplemental oxygen. Steam sparging is continued for 5 minutes after the fire is extinguished, and the gas and oxygen are then reset to their previous flow rates. This modified system proved to be satisfactory in suppressing the top fires that occurred at the higher injection rates.

Top Gas Analysis

The top gas is sampled from the clean gas main downstream of the Bishoff scrubber via a foot-long probe with a single sample opening at the tip. The gas sample passes through a 1-inch line to the analyzer room, where a drip leg is installed to remove bulk moisture and flow is controlled manually with a low-flow alarmed rotameter. The sample is conditioned by passing it through two coalescing filters for dust and moisture removal.

The analysis is carried out in a Daniels Model 2500 gas chromatograph system. The analyzer reports CO, CO_2, H_2, and N_2 and is calibrated to report absolute — not argon and moisture-free — values. The system is recalibrated weekly by passing a series of standard calibration gases through it, or more frequently if a problem is detected. Calibration gas flow is initiated automatically if wind is pulled and the top pressure falls below a set point.

B. AUXILIARIES DESCRIPTION

National operates a coke plant adjacent to the blast furnace area, and purchases additional coke to supply its needs when both furnaces are operating. A boiler house produces the steam required for the turbo blowers and other plant uses. Coke oven gas, cleaned blast furnace gas, and natural gas fuel the burners in the boiler house and the stoves. Oxygen is supplied from an Air Products plant on site while natural gas is acquired from the Mississippi River Transmission line. The oxygen delivery system, stoves, stock house, data collection system, and wind delivery system are described below.

Oxygen Supply

High-purity, high-pressure oxygen is delivered via a 6-inch main, passed through a 6-inch metering station, and then passed to 4-inch lines connected to the cold blast mains. The metering was done by a 6-inch orifice meter.

Test Site Description and Operating Practices

Stoves

A description of National's blast heating stoves is presented below.

- Number: 3
- Total Heating Surface: 188,952 ft^2
- Stove Burner Capacity: 40,000 cfm
- Burner Stove Isolation: Shutout door
- Hot Blast Valve Type: 42-inch mushroom
- Stove Gas: Clean Blast Furnace Gas enriched with coke oven gas
- Target HHV for combustion gas: 105 Btu/SCF

The stoves are controlled at dome and stack temperatures of 2,200 and 600°F, respectively, and the normal hot blast temperature is 1,800°F. Typically, the stove cycle is 30 minutes from on gas to on blast.

Stock House

Plant-produced coke and required merchant coke are retrieved from the coke yard by front end loader and charged to a common bin before being loaded to rail cars and transported to the stock house via the highline. Metallic-bearing burden is also retrieved from the ore field by front end loaders and transported to the highline via conveyors. No mixing or blending of coke or scrap from various sources is attempted. Consequently, the type and quality of the coke charge varies randomly. Pellets are screened at the highline.

Burden materials are withdrawn from the various bins through hydraulic gates and weighed by a scale car. The required burden recipe is computed by a blast furnace burden model. The coke is withdrawn, screened, and weighed as required, with a nuclear moisture on-line analyzer (MOLA) gauge used to correct the charge to a dry weight basis. An accumulator system is used to assist the scale-car operator in setting target weights to compensate for over or underdraws.

Each skip has a volume of 270 ft^3 and the skip motor can lift a maximum weight of 30,000 lbs. The normal number of charges per day is 110 to 120, with 130 being the maximum sustainable charging practice.

Wind Delivery System

Two turbo blowers supply the wind to the A and B furnaces through a common header. During the reline (Phase B) one blower was under repair, and the nominal maximum capacity of the one operating was 100 mscfm at 28 to 29 psig. The flow rate is measured by a venturi meter located on the suction side, and flow is controlled by varying the flow of steam to the turbine.

Data Acquisition System

Furnace conditions are monitored and controlled by a Rosemont computer system, and data analysis, averaging, and reporting are carried out through a Digital VAX system. Data on blast pressure, moisture, and temperature and top gas temperature, pressure, and composition are recorded each minute, averaged hourly and averaged daily for reporting. Blast volume is recorded on charts and averaged manually. Flows of natural gas and oxygen are indicated, but daily flows are taken from totalizing meters to compute the average flow.

Burden charge is computed manually from the recorded number of skips per day and the pounds per skip. The coke is assayed once per day and iron-bearing burden is assayed once per shift (except for chips); dust, scraps, and cold briquetted iron were assayed only occasionally. Both hot metal and slag were assayed once per cast, with the hot metal weighed at the BOF shop.

C. UPGRADES

The upgrades carried out at Granite City to support the high rate injection tests on the A furnace are described below.

Natural Gas Delivery System

The delivery capacity for natural gas was increased to about 20,000 cfm by removing line restrictions. The 4-inch control and shut-off valves and orifice plate were replaced with 6-inch units and a vortex meter, respectively. Also, redundant check values and constriction plates in the circle pipe were removed.

Oxygen Delivery System

Oxygen delivery capacity was increased by replacing the existing 4-inch supply line from the oxygen plant with a 6-inch line, replacing 4-inch meter runs with 6-inch ones and replacing the orifice plate with a vortex meter, upsizing the pressure reducing station and resetting the reliefs up to 250 psig. In addition, a 4-inch line was installed to bypass the B furnace to maximize the flow of oxygen to the A furnace for these tests.

D. NATIONAL OPERATING PRACTICES

Furnace charging and operating practices used at National are described below. Both were changed to accommodate the natural gas tests, and the original procedures and the changes made to them are described.

Charging Practice

The charging practice throughout the tests was to keep the amount of coke in the coke skips constant while varying the amount of ore in the ore skips to change the ore-to-coke ratio. A constant coke slit of about 12 inches was maintained. Prior to the tests, achieving furnace production of about 3,600 TPD required the addition of 120 lb/THM of scrap to the charge.

The charging sequence used throughout the tests was OOCC/OSCC/. The first two ore skips contained Minntac self-fluxing pellets and nut coke, and the third ore skip contained National acid pellets. The addition of nut coke was believe to enhance furnace performance by improving burden permeability and reducing the extent of the solution loss reaction. The stone skip contained pellet chips, BOF slag, fines, gravel, ilmenite, and metallics. The metallics included pit scrap, crusher scrap (B-Scrap) and cold briquetted iron.

The ratio of merchant coke to home coke charged and the ratio of pit scrap to B-Scrap to cold briquetted iron charged depended on the availability of the various materials and operator practice. The ratios varied significantly from day to day, and even from month to month.

The coke skips were filled to contain a maximum of about 6,500 lb, and the maximum load that the ore skips could contain (at 96 percent capacity) was 28,800 lb. It was recognized prior to the tests that, while the number of charges could be increased somewhat, ore skip capacity constraints would limit hot metal production. Therefore, increasing productivity would require charging additional metallics to the burden. It was also recognized that the practice of maintaining a constant coke slit under these circumstances limited the maximum "ore"-to-coke ratio that could be charged unless large amounts of scrap were put on.

During the tests, a number of changes were made to this practice, including removal of chips and reduction of nut coke. These are described in the following chapter presenting the experimental results.

Typical burden analyses are shown in Table 3-1, while Table 3-2 shows a typical natural gas assay. The assay shown for pit and crusher (B) scrap is an average value. Scrap compositions can vary significantly, depending on the origin of the raw material and the performance of the separation process.

Table 3-1. Typical Burden Analyses

	%, Dry Basis									
Material	Fe	SiO_2	Al_2O_3	CaO	MgO	Mn	C	S	P	H_2O
Coke	1.38	3.96	2.20	0.45	0.28		90.00	0.62	0.007	10.6
Acid Pellet	65.92	4.69	0.31	0.89	0.55	0.09		0.004	0.013	2.4
Self-Flux Pellet	64.43	4.00	0.29	3.26	1.25	0.10		0.004	0.014	2.77
Pellet Chip	34.89	4.28	0.30	2.58	1.05	0.10		0.006	0.015	6.22
CBI	78 (1)	5.05	1.33	2.15	2.79	0.36	2.6	0.03	0.21	1.8
Pit/Crusher Scrap	66.5 (2)	6.42	1.43	9.67	2.60	0.9		0.2	0.12	1.5
BOF Slag	19.82	13.23	1.28	41.62	11.71	3.96		0.071	0.44	1.77
BF Fines	54.02	7.53	1.79	20.99	4.31	1.89		0.033	0.207	1.65
Ilmenite	40.88	18.23	3.95	0.96	2.03	0.08		0.35	0.014	2
Gravel	4.64	87.37	1.6	0.97	0.39	0.33		0.013		3.12

(1) Total iron. Metallic iron is 73 percent of the total.
(2) Total iron. Metallic iron is 46 percent of the total.

Table 3-2. Typical Natural Gas Analysis

	Percent by Volume						
Natural Gas	CO_2	N_2	CH_4	Butanes	Pentanes	C_2H_6	C_3H_8
Horseshoe Lake (1)	1.34	0.78	95.17	0.11	.04	2.13	.38

(1) HHV = 1,020 Btu/SCF at 14.65 psia, 60 OF, and dry.

Furnace Standard Operating Procedures

National sets aim values for furnace operation to achieve the desired production and hot metal chemistry by following a heat level control system. The coke, wind, and supplemental oxygen rates are fixed, and the prioritized set of control

Table 3-3. Standard Operating Procedures at National Granite City

HEAT LEVEL CONTROL MATRIX

NOTE: All temperatures in °F

Emergency Below 2581	Lower Red 2581-2630	Lower Yellow 2631-2660	Green 2661-2730	Upper Yellow 2731-2780	Upper Red Above 2780	
1st Cast	+1/2 % NG	No Change	No Change	No Change	-1/2 % NG	1st Cast
2nd Cast	No Change	+1/4 % NG	No Change	1/4 % NG	-1/4 % NG	2nd Cast
3rd Cast	+1/2 % NG	No Change	No Change	No Change	-1/4 % NG	3rd Cast
4th Cast	No Change	+1/4 % NG	No Change	1/4 % NG	-1/4 % NG	4th Cast
5th Cast	+1/2 % NG	No Change	No Change	-1/4 % NG	-1/4 % NG	5th Cast

Emergency Heat Level Control Action

A 2580 - 2541	B 2540 - 2501	C Below 2500
1) Cut Wind 10% * 2) 2X Coke/Hr 3) Contact Mgr. B.F. Opns. or person on call 4) Continue until temp. trends above 2,630, then go to heat level matrix	1) Cut Wind 10% * 2) 2X Coke/Chg 3) Contact Mgr. B.F. Opns. or person on call 4) Continue until temp. trends above 2,541, then go to Emer Action "A"	1) Cut Wind 10% * 2) 4X Coke/Chg 3) Drain trough 4) Contact Mgr. B.F. Opns. or person on call 4) Continue until temp. trends above 2,500, then go to Emer Action "B"

*Wind will only be cut once

Natural Gas Guidelines

"A" Fce: TARGET % +/- variation %
"B" Fce: TARGET % +/- variation %

NOTE: If natural gas is not available or heat level control matrix calls for change outside parameters defined above, then:

	SUBSTITUTION
For every +1/4% NG	Add 5 lb coke rate
For every -1/4% NG	Add 2 gr moisture

Double substitution quantity for 1/2% changes

Extra Coke Guidelines

Condition	Action	Duration
FCE top temp 120°F or below for >2 hrs (Refer to SOP#NSCS-C-O-1616-06-11) →	2 X C per hour	Until T.T. more than 120°F
Stove Problems Resulting in Loss of H.B.T. → HMT: 2,700°F or Above, HBT: 1,750-1,799 →	No Action	
HMT: 2,700°F or Above, HBT: 1,601-1,749 →	Remove 3 gr moisture*	Until HBT 1,750 or greater
HMT: 2,700°F or Above, HBT: 1,600 or Below →	Remove all moisture*, wait 3 hours, then 1 X C every 2 hours	Until HBT 1,750 or greater
HMT: Below 2,700°F, HBT: 1,750-1,799 →	No Action	
HMT: Below 2,700°F, HBT: 1,601-1,749 →	Remove 3 gr moisture*, wait 3 hours, then 1 X C every 2 hours	Until HBT 1,750 or greater
HMT: Below 2,700°F, HBT:1,600 or Below → (Refer to SOP#NSCS-C-O-1616-06-10)	Remove all moisture*, 1 X C every hour * If moisture is being used	Until HBT 1,750 or greater
Off rods (>16 ft) for greater than 1 hour (Refer to SOP#NSCS-C-O-1616-06-01) →	1 X C per hour	Until on rods (<16 ft)

actions shown in Table 3-3 is used to respond to changes in hot metal temperature. Under normal circumstances the furnace runs with ambient moisture and the flow rate of supplemental oxygen is not charged: the natural gas injection rate is used to achieve trim control of hot metal temperature outside the range of 2,660 to 2,730°F.

Lower and upper operating limits around the natural gas aim value are set by the operators. Within these limits, the gas injection rate is increased if the hot metal temperature is low and vice versa. If changes in the gas injection rate within these limits do not restore the hot metal temperature, a change is made in the coke rate. Emergency actions, which include pulling wind and adding extra skips of coke, are taken if the temperature drops below 2,580°F. Standard operating procedures also exist for reacting to such events as low top gas temperature, loss of rod, and stove problems.

Hot Metal Production

Prior to these tests, the furnace was typically tapped about 10 to 11 casts per day. At the highest production rate, the frequency was increased to up to 14 casts per day of some 300 tons. The cast time was typically about an hour, with 30 to 40 minutes between casts. Each cast normally filled two to three bottles, and partially filled bottles were usually held for the next cast. During Phase A, some bottles were used for hot metal produced in both the A and B furnaces, and proper accounting was difficult.

The operators entered an estimate of the amount cast in the logs based on the estimated volume of the bottle filled. For accounting purposes, however, furnace hot metal production was determined by the poured weight from each bottle recorded at the BOF shop, with a 1 percent correction applied for the estimated slag content. Incomplete draining of the bottles, changing numbers of bottles in inventory on the tracks, and filling of bottles from both furnaces made the accounting chore an interesting exercise.

E. TEST PLAN OUTLINE — AIM VALUES AND DATA ACQUISITION

Test Plan

The objectives of Phase A testing were to obtain baseline data at a natural gas injection rate of 150 lb/THM while meeting "normal" hot metal production requirements (since the B furnace was still in operation), and obtain data that would be used to project aim values at higher productivities and injection rates in Phase B.

Phase C involved the installation of the upgrades needed to achieve the higher rates of gas injection and was completed during the course of Phase A testing.

Phase B involved ramping up to 250 lb/THM in increments of 25 to 50 lb/THM, starting from a level of 150 lb/THM, while maximizing production. Maximizing coke savings was a collateral priority for the tests.

Aim Values

Aim values for key furnace set points and test length for each injection period were provided to National as guidance in setting desired operating conditions. The aim values were determined by the predictive model using the most recent available A furnace data that could be rationalized by the analytical blast furnace model.

Because National already injected gas at levels close to 150 lb/THM before Phase A testing was initiated, it was not necessary to develop aim values for this practice. Phase B aim values, shown in Table 3-4 below, were estimated based on the results of the Phase A tests. The hot metal production targets of 3,800-4,200 TPD were set by National.

Table 3-4. Phase B Aim Values

Process Parameters	Units	First Ramp	Second Ramp	200 lb/ THM	Third Ramp	250 lb/ THM
Test Duration	Days	10	10	30	10	30
Hot Metal Production	TPD	3,800	3,900	4,000	4,100	4,200
Natural Gas Injection	lb/THM	166	183	200	225	250
Supplemental Oxygen	lb/THM	140	157	185	230	279
Blast Moisture	gr/SCF	6	6	6	6	6
Blast Temperature	°F	1,791	1,791	1,791	1,791	1,791
Delivered Wind	scfm	93,300	93,300	91,200	88,800	85,000
AISI RAFT	°F	3,317	3,242	3,174	3,094	3,011
Thermal and Chemical Energy above 2,700 °F	MMBTU/hr	0.67	0.65	0.63	0.64	0.66
Dry Coke Rate	lb/THM	756	732	207	684	659
Scrap Change	lb/THM	122	152	183	213	244

RAFT is a derived parameter, not an input parameter in setting these aim values. The wind and supplemental oxygen rates are chosen to maintain the desired thermal plus chemical energy in the hearth zone while limiting the flow of bosh gases to control the pressure drop at the desired value. As in the case with RAFT, the coke rate is a derived parameter. Charging a different amount of coke will change the hot metal temperature, the top gas temperature and composition, or both.

Data Acquisition

Ramp-up schedules were set up assuming five- to ten-day periods would be necessary for increasing natural gas injection levels in increments of 25 to 50 lb/THM. This amount of time was set in consideration of the experience at the Armco Steel natural gas trials during 1992. Ten-day periods were allowed at each targeted natural gas injection level (200 and 250 lb/THM) for stabilization and 20 days were allowed for subsequent data collection. The 20-day period was assumed to be enough time for realization of at least three steady-state periods of four to five days each. The schedule of Phase B was developed to coincide with the reline schedule planned for the B furnace.

4
Data Analysis Procedures

This chapter describes the data analysis procedures used to analyze the information collected from the A furnace at National. First, a summary description of the blast furnace computational procedures is given. Then, a summary of the data-screening rationale is presented with a description of the procedures that were used to screen the data obtained during these tests.

A. DESCRIPTION OF COMPUTATIONAL PROCEDURES

These blast furnace computational procedures provide a tool to analyze and predict blast furnace performance in support of operational and economic decision making. The main features of the procedures have been described previously[8] and are only summarized here.

The blast furnace model operates in two modes: an analysis mode that evaluates real-time furnace operating data, and a predictive mode that projects furnace performance under new conditions. In the analysis mode, at least four consecutive days of "steady-state" furnace operation are required for the model to perform material and energy balances under conditions in which the statistical uncertainties in the rationalized results are reduced to acceptable levels. Three component material balances are made around the blast furnace (on iron, carbon, and oxygen) to initiate the procedure, with the hydrogen balance closed by calculating reaction water production "by difference." Errors are closed to zero by correcting burden material charge rates, composition, and blast volume.

There are sufficient degrees of freedom in this procedure that many different solutions are possible that satisfy the three balances. Burden material charge and blast rate adjustments are constrained so that the corrections required are within the likely ranges of measuring errors at the furnace. The hierarchy of choosing the best values for the corrections is to adjust the iron-bearing constituents first, then the coke, and then the wind. After these corrections are made, the slag rate is fixed by forced closure of the acid constituents (SiO_2 + Al_2O_3) and closure is

[8] *Injection of Natural Gas in the Blast Furnace at High Rates: Field Experiments at Armco Steel Company.* Gas Research Institute (GRI-92/0353), April 1993.

sought on the alkali (CaO + MgO) constituents. The alkali balance may be closed in two ways: the first option is to adjust the flux rate within the allowed correction limit, and if this does not produce closure, the acidic and alkali compositions of the major iron-bearing constituent (pellets or sinter) are adjusted in equal but opposite amounts to achieve closure.

Once the overall material balances are closed, an overall energy balance is performed to obtain the overall furnace heat loss. The calculated overall loss is assigned to five zones in the furnace (hearth, bosh, lower, middle, and upper stack), and material and energy balances are performed for each zone. As mentioned above, no unique solution to the overall balances can be obtained, and such factors as analytical errors, reporting errors, unknown operating problems (e.g., stave leakage), or unsteady state conditions may produce an unacceptable result even though the overall material balances close.

Unacceptable results include heat losses that are physically unreasonable, the calculation of thermodynamically infeasible conditions in the zonal balances (e.g., gas temperatures below burden temperatures or compositions beyond their equilibrium limits), or correction factors for the burden that exceed the likely errors in measurement. If any of these conditions are found to occur, they can be removed (within limits) by adjusting the top gas composition. Changes of up to ±1 percent in N_2, CO, and CO_2 are allowed (the reported H_2 content is retained) with the hierarchy of changes being to adjust the N_2 content first at a constant CO:CO_2 ratio, and then to adjust the CO:CO_2 ratio only if closure cannot be obtained on the carbon balance.

Closure of the furnace balance is acceptable if the following criteria are met:

- Iron, carbon, and acid/alkali balances are closed with correction factors or assay changes that are within the likely range of measuring errors.

- The correction factor applied to the wind rate is consistent from period to period.

- Changes in top gas composition are within ±1 percent of the reported value.

- The zonal balances do not show pinches (gas temperature minus burden temperature) of less than 20°F.
- The calculated furnace heat loss is within about ±50 percent of the value estimated from wall heat flux measurements.

The latter constraint is actually a rather stringent test of the data quality, because furnace heat loss is calculated as the difference between very large input and output enthalpy flows. For example, a typical mid-sized furnace would have blast plus burden enthalpies of about minus 1,100 MMBTU/hr and hot metal, slag, plus top gas enthalpies of about minus 1,180 MMBTU/hr, so that the furnace heat loss is about 80 MMBTU/hr. Changes of 40 MMBTU/hr or more can be induced by very small changes in burden assays or moisture contents or top gas assays — particularly CO_2 content.

Data sets that have met the above criteria are considered "rationalized" and, unless otherwise noted, are the results of a series of good days at the furnace and are reported here.

B. DATA SCREENING PROCEDURE AND RATIONALE

Previous analyses of the errors in material balance closure have shown that a period of about 100 hours (four days) of continuous, steady-state operation is required to reduce the errors to acceptable limits given the capability of typical data acquisition systems. As a practical matter, a minimum of three consecutive delay-free days or a run of four consecutive days with delays less than one hour are needed as the minimum periods required to obtain reliable closure. A day with excessive down or delay time "breaks" the continuity, and requires re-indexing the period of time that can be included for analysis at a given level of gas injection. Also, events such as recalibration of the top gas analyzer or a significant shift in the composition of the burden also would require re-indexing of the period.

The Phase A tests, acquiring baseline data at 150 lb/THM, lasted four months. During this period considerable effort was expended in analyzing the data according to the procedures described above, but rationalized data could be obtained for only about one-quarter of the time. Iron balances only rarely closed with corrections that were within the likely range of measuring uncertainty. Wind rate corrections were reasonably consistent (and usually small) but large coke rate corrections or large adjustments to the top gas assay were often required to close the carbon balance. The problems were tentatively ascribed to the hot metal accounting uncertainties described earlier and to the uneven quality of the mixture of plant-produced and purchased coke used in the blast furnace.

It was anticipated that both of these problems would be resolved in Phase B when only plant-produced coke would be used and only one furnace would be operating. Unfortunately, this was not the case. To resolve these problems, and produce sufficient data for these analyses, the following conventions were adopted:

- Hot metal production is calculated based on a 98 percent yield of the iron-bearing charge to the burden, not on the hot metal consumption reported at the BOF.

- If one day in a sequence of otherwise acceptable days showed an upset condition (e.g., delay > 1 hour) that day would be excluded from the material balance calculations, but the time period would not be reindexed.

5
Experimental Results

This chapter presents the results of the natural gas injection tests at National Steel's Granite City Plant. The first section of the chapter describes the chronology of events during the tests and the results of the screening of the operating data. The second section presents the evaluation of the rationalized data for each data point selected at the various injection levels.

A. CHRONOLOGY OF TESTS

Phase A

Baseline data collection in Phase A was initiated at a time when the A furnace target production was about 3,600 TPD. Daily average injection rates for gas and oxygen were about 8,800 and 3,900 scfm, respectively, when there were no delays. The burden contained acid and self-fluxing pellets and chips, various scraps, and mixtures of home and various merchant cokes. This practice was in effect for the entire period, with changes made only in response to the normal planned and unplanned maintenance events and to furnace upsets according to standard operating procedures.

The data points chosen for analysis during Phase A of the National tests are shown in Table 5-1. Major external events, such as down time and maintenance delays, are noted to show the reason for exclusion of certain days from analysis, and the natural gas consumption is listed to show changes in injection rate. A total of about five weeks' worth of data from this period were rationalized. Note, however, that there were three periods during this phase in which furnace operations apparently were steady, but the data could not be rationalized according to the criteria described in the previous chapter. That is, large adjustments were required to top gas compositions or to the reported coke rate to close the balances, or balance closure violated a thermodynamic constraint in one of the zones.

Table 5-1. National Granite City Test Data Selection for Phase A

Period Description	Dates	Natural Gas Consumption (scfm)	Notes
Begin Phase A	12/1/94	8,900	
Data Point 1	**12/1-12/6/94**	**8,800**	**162 lb/THM**
	12/7-12/8/94	4,500	Scheduled outage, burnt tuyeres
	12/9-12/11/94	7,,500	Filling problems
Data Point 2	**12/12-12/18/94**	**8,400**	**151 lb/THM**
	12/19-12/22/94	7,000	Scheduled outage, mud gun problem
	12/23-12/31/94	7,900	Reasonably steady period, but data can't be rationalized
	1/1-1/6/95	6,100	Scheduled outage and restart
	1/7-1/10/95	7,000	Steady period but data can't be rationalized
Data Point 3	**1/11-1/16/95**	**7,900**	**142 lb/THM**
Data Point 4	**1/17-1/23/95**	**7,500**	**132 lb/THM**
	1/24-1/25/95	5,400	Stove problems
	1/26-1/31/95	7,800	Reasonably steady period, but data can't be rationalized
Data Point 5	**3/1-3/5/95**	**8,700**	**154 lb/THM**
	3/6-3/11/95	7,100	Scheduled outage, BOF problems, restart
	3/12-3/15/95	6,800	Stove problems, restart
Data Point 6	**3/16-3/20/95**	**8,000**	**139 lb/THM**
	3/21/95	6,700	Bishoff problems
End Phase A	3/22/95	9,100	

System Upgrades (Phase C)

Upgrades to the oxygen and gas delivery systems were underway during the course of Phase A testing, and were completed in mid-March with the installation of an oxygen bypass line around the B furnace. Use of this line to divert oxygen from the B to the A furnace marked the termination of Phase A and the initiation of Phase B.

Phase B

The data points chosen for analysis in Phase B are shown in Table 5-2. Natural gas injection rates and hot metal production on the A furnace were ramped up as soon as the oxygen diverted from the B furnace became available. The ramp-up holding point (nominally 175 lb/THM) was reached within two weeks and held for about two weeks before continuing the ramp-up to a 200 lb/THM injection point. This ramp-up was accomplished within a week, and the 200 lb/THM condition was held for about a month. Injection rates were then ramped up quickly to the next holding point (nominally 225 lb/THM), and were held there for a month. The reline of the B furnace was completed and the oxygen supply to the A furnace was decreased before the gas injection rate could be increased to the 250 lb/THM target. A total of about six weeks' worth of data from this period were rationalized, and there were two periods of apparently steady furnace performance that could not be rationalized.

B. EVALUATION OF RATIONALIZED DATA

Rationalized data from four periods are evaluated in detail in this section. The periods are: the base case (150 lb/THM) and periods with targeted gas injection levels of 175, 200, and 225 lb/THM.

The dates selected for each data point and the corrections required to rationalize the burden and wind rates and top gas compositions to force material balance closure are shown for each period. The rationalized operating parameters, thermal and energy parameters, and hot metal and top gas compositions are shown as well as data describing the dynamic behavior of the furnace. A narrative chronology of the significant events in each period is presented in the appendix.

The terms used to describe furnace performance are defined in Table 5-3.

Table 5-2. National Granite City Test Data Selection for Phase B

Period Description	Dates	Natural Gas Consumption (scfm)	Notes
Begin Phase B	3/22/95	9,100	
	3/23-3/28/95	10,500	Ramping up gas and oxygen injection
	3/29-3/31/95	5,700	Scheduled outage, restart
	4/1-4/5/95	10,100	Steady period, ramping up
Data Point 7	**4/6-4/11/95**	**11,000**	**170 lb/THM**
Data Point 8	**4/12-4/17/95**	**11,300**	**178 lb/THM**
	4/18-4/23/95	12,400	Minor delays, ramping up gas and oxygen
Data Point 9	**4/24-4/30/95**	**12,800**	**193 lb/THM**
	5/1-5/2/95	10,000	Tap hole, mud gun problems
	5/3-5/7/95	6,000	Scheduled outage, mud gun problems, restart
Data Point 10	**5/8-5/13/95**	**11,900**	**185 lb/THM**
	5/14-5/17/95	11,800	Scheduled outage, restart
	5/18-5/22/95	12,000	Reasonably steady period, but data can't be rationalized
Data Point 11	**5/23-5/29/95**	**13,600**	**199 lb/THM**
	5/30-5/31/95	13,000	Top fire, delays
Data Point 12	**6/1-6/6/95**	**14,300**	**213 lb/THM**
	6/7-6/16/95	11,100	Scheduled outage, Bishoff problem, burnt tuyere, minor delays, restart
	6/17-6/21/95	14,700	Steady period, but data can't be rationalized
	6/22/95	12,200	Ladle derailment delay
Data Point 13	**6/23-6/26/95**	**15,700**	**228 lb/THM**
	6/27/95	10,000	Scheduled outage
	6/28-7/2/95	14,000	Off rod delays each day
	7/2-7/6/95	15,700	Major burden changes

Table 5-3. Definitions of Process Parameter Terms

Parameter	Definition
Bosh Hydrogen	The total flow of hydrogen gas, in pound moles per ton of hot metal or as a percentage of the total gases in the bosh. It is calculated from the blast and supplemental fuel and oxygen rates.
Rho V^2 term, or Bosh Kinetic Energy	The ratio of the value of the kinetic energy of the bosh gases, ρV^2, to the average density of the burden constituents. The average burden density is calculated from the burden ratio, and the ρV^2 term is calculated from the flow rate, temperature, and composition of the bosh gases, which are determined by material and energy balances. Values below the maximum limit indicate that smooth burden descent should be expected. Analogous to the K value normally reported.
EGC	The extent of the endothermic gasification of carbon, also called the solution loss or Boudard reaction. The amount of carbon, in moles per ton of hot metal, consumed by the reaction is calculated by overall material balance when analyzing furnace performance, or established based on bosh gas composition.
Energy Balance RAFT	The Raceway Adiabatic Flame Temperature, in °F, calculated by a rigorous energy balance. Gases consist only of N_2, Ar, CO, and H_2. Coke temperature is assumed to be either 2,900°F or 50°F below the hearth gas temperature, whichever is higher.
Energy Above 2,700°F	The total thermal energy content of the hearth gases above the reference temperature of 2,700°F, in units of millions of Btu per ton of hot metal. The flow rate of the gases is calculated for the blast and supplemental fuel and oxygen rates, and their temperature is calculated by an energy balance on the hearth zone assuming the burden constituents enter the zone at 2,700°F.
Hearth Zone Gas Temperature Difference	The difference in temperature, in °F, between the gases leaving the hearth zone and the hot metal. The gas temperature is calculated by material and energy balance on the hearth zone based on blast conditions and supplemental fuel and oxygen rates, and hot metal and slag production rates. Burden constituents are assumed to enter the zone at 2,700°F.

Table 5-3 (continued)

Parameter	Definition
Reduction Zone Duty	The amount of energy, in billions of Btu per hour, required for direct and indirect reduction of iron and for heating burden constituents in the reduction zone. It is calculated by material and energy balance with the solids temperatures entering and leaving the zone normally set at 1,800°F and 2,700°F, respectively.
Reduction Zone "Pinch" Temperature	The difference in temperature, in °F, between the gases leaving the reduction zone and the solids entering the zone. The limit of this zone is usually defined as the location at which the solids temperature is 1,800°F, and the gas temperature is calculated by material and energy balance based on the temperature of the gases leaving the hearth and the known or estimated extent of the solution loss reaction. Corresponds to the temperature difference in the thermal reserve zone.
Thermal-plus-Chemical Energy Above 2,700°F	The sum of the thermal energy above 2,700°F leaving the hearth zone (see "Energy Above 2,700°F") and the energy-equivalent of the hydrogen content of the hearth gases. The latter is calculated by estimating, based on the bosh gas hydrogen content, the extent to which the hydrogen in the gases will reduce iron, thus decreasing the extent of the solution loss reaction. The decreased thermal energy requirements arising from the decreased extent of direct reduction are then added to the thermal energy of the rising gases to calculate their thermal-plus-chemical (i.e., due to H_2) energy content.
Total Energy Released	The amount of energy, in millions of Btu per hour, required for heat losses and metallurgical reactions in the hearth zone, and to heat the gases leaving the hearth. It is calculated by material and energy balance from the production rate and blast rate, assuming that burden constituents enter the hearth zone at 2,700°F. It is analogous to the driving rate.
Pressure Drop-to-Burden Density Ratio	The dimensionless ratio of the gas pressure drop per unit height of the furnace to the average burden density. The pressure drop is estimated from the reported blast pressure minus reported top gas pressure less a correction of 3 psi for losses through the tuyere. The height difference is taken from the tuyere line to the normal stock line, and average burden density is calculated from the burden charge composition.

Table 5-3 (continued)

Parameter	Definition
Cast-to-Cast Variation in the Thermal State of the Hearth, dQ/dt	The change in the amount of energy required, in millions of Btu, to produce successive casts with different temperatures and compositions divided by the time between casts. It is calculated from the amount of hot metal and slag produced in each cast, their temperatures, the hot metal silicon and manganese contents, and the estimated material inventory in the hearth zone that also responds to the changes. It is a measure of the variability of the burden descent to the hearth.

Base Cases

Data acquisition in the Phase A baseline period covered a time span of almost four months in which the A furnace was run strictly for commercial production of hot metal. Early in the period there were difficulties obtaining a consistent mix of plant-produced and merchant coke and, because the merchant coke was of poor quality, this led to episodes in which the hot metal temperature and chemistry varied greatly. Aim values were changed frequently to restore control. Better-quality merchant coke became available later in the period and furnace operation became somewhat smoother. Over this period, the scrap charge (121 lb/THM) averaged about 50 percent cold briquetted iron and 50 percent pit and crusher scrap.

The correction factors used to rationalize the base-case data are shown in Table 5-4. As discussed earlier, the iron balance is based on 98 percent yield of the iron-bearing constituents charged. While the carbon balance closure required a consistently positive adjustment applied to the reported coke rate, it is within the expected range of measurement error. Relatively large adjustments were made to the top gas nitrogen content (three were at the maximum 1 percent allowed) to avoid a thermodynamic infeasibility in zonal balances, but the corresponding wind rate corrections were lower than most we have seen on other furnaces.

Table 5-4. Correction Factors Used for Rationalizing the Base-Case Period

	Units	Data Points						
		1	2	3	4	5	6	Wt. Avg.
Start Date		12/1/94	12/12/94	1/11/95	1/17/95	3/1/95	3/16/95	
No. of Days		5	7	5	6	4	5	
Iron-Bearing Burden	%	-2	-2	-2	-2	-2	-2	-2
Minntac Pellet (SiO_2+Al_2O3)	%	0.36	-0.02	0.55	-0.35	-0.03	-0.25	0.03
Coke Rate	%	2.36	2.35	1.52	1.40	0.73	2.00	1.79
Wind	%	-1.70	0.20	1.68	0.77	4.05	0.55	0.78
Top Gas								
CO	%	-0.25	-0.3	-0.5	-0.5	-0.5	-0.4	-0.4
CO_2	%	-0.25	-0.3	-0.5	-0.5	-0.5	-0.4	-0.4
N_2	%	0.5	0.6	1.0	1.0	1.0	0.8	0.80

The rationalized operating parameters shown in Table 5-5 suggest that, while the burden composition was not changed, there were small but noticeable increases in both total oxygen consumption in the furnace and the production of hot metal over the period. The increases were not, in general, achieved by making significant changes in aim value, but through smoother furnace operation that led to fewer delays. Wind and supplemental oxygen set points were unchanged except for data point 6, in which the oxygen enrichment was increased from 2.8 to 3.3 percent. The production increases were the result of dumping an additional 5 to 8 charges/day.

Table 5-5. Rationalized Operating Parameters for Base-Case Period

Parameter	Units	Data Points						
		1	2	3	4	5	6	Wt. Avg.
Productivity								
Production	TPD	3,512	3,600	3,620	3,689	3,654	3,750	3,635
% Increase								
Production	TPD/100cfwv	6.9	7.1	7.2	7.3	7.2	7.4	7.2
Burden (dry)								
Coke	lb/THM	807	820	815	807	806	798	810
Acid Pellets	lb/THM	829	835	835	833	828	836	833
Self-Fluxing Pellets	lb/THM	1,657	1,660	1,665	1,654	1,668	1,662	1,661
BOF Slag	lb/THM	151	149	147	138	167	160	151
BF Fines	lb/THM	91	91	91	90	92	92	91
Pellet Chips	lb/THM	119	118	117	117	119	119	118
Ilmenite	lb/THM	34	30	30	30	37	46	34
Gravel	lb/THM	30	27	26	25	26	26	27
Scrap	lb/THM	121	121	121	121	122	123	121
Wind								
Wind, delivered	mscfm	95.6	98.3	98.5	97.3	100.8	97.3	97.9
Wind	MSCF/THM	39.2	39.3	39.2	38.0	39.8	37.4	38.8
Blast Moisture	gr/SCF	7.3	8.6	4.9	4.1	3.0	5.4	5.8
Supplemental O_2	lb/THM	127	126	125	121	126	139	127
Supplemental O_2	TPD	224	226	226	223	229	261	231
Total O_2	TPD	1,441	1,478	1,480	1,462	1,513	1,500	1,476
Total O_2	TPD/100cfwv	2.8	2.9	2.9	2.9	3.0	3.0	2.9
Natural Gas	lb/THM	162	151	142	132	154	139	146
Others								
Fuel Rate	lb/THM	969	971	957	939	960	937	956
Slag Production	lb/THM	393	400	397	376	424	428	401
dP/B. Density		0.43	0.42	0.43	0.43	0.42	0.43	0.43
Top Gas Production	MSCF/THM, dry	58.6	58.3	58.1	56.1	59.0	56.1	57.6
Top Gas H_2	%	7.18	6.52	6.46	5.86	7.00	6.61	6.56
Top Gas CO	%	21.21	21.09	20.70	20.41	20.52	20.38	20.74
Top Gas CO_2	%	19.32	19.67	20.11	20.81	19.76	20.96	20.11
Top Gas N_2	%	52.29	52.72	52.73	52.91	52.72	52.05	52.59

Table 5-6. Thermal/Energy Parameters for Base-Case Period

Parameter	Units	Data Points						
		1	2	3	4	5	6	Wt. Avg.
Blast Temp.	°F	1,794	1,793	1,791	1,777	1,791	1,775	1,787
H.M. Temp.	°F	2,684	2,704	2,701	2,704	2,688	2,706	2,699
AISI RAFT	°F	3,353	3,386	3,515	3,558	3,501	3,511	3,467
Rho V^2		22.60	24.05	24.10	23.31	25.25	23.69	23.79
Hearth Zone Gas	°F	2,826	2,812	2,925	2,952	2,941	2,938	2,894
dT Hearth	°F	142	108	224	248	253	232	195
Bosh H_2	lbmol/THM	21.3	20.3	18.2	16.6	19.1	18.0	18.9
T+C Energy	MMBTU/THM	0.61	0.58	0.67	0.66	0.71	0.68	0.65
EGC	lbmol/THM	7.4	6.9	8.4	8.7	8.6	8.2	7.9
dT Bosh	°F	20	20	25	20	27	21	22
Top Gas Temp.	°F	352	313	273	240	287	265	288
HHV	Btu/SCF	92	89	88	85	89	87	88
Top CO/CO_2		1.10	1.07	1.03	0.98	1.04	0.97	1.03
H_2 Util. Eff.	%	47.8	50.6	45.5	47.8	42.8	45.7	47.1
Heat Loss	MMBTU/hr	107	117	128	120	141	125	122

As would be expected, the thermal state of the furnace and the zonal balance did not change greatly either, as shown in Table 5-6, except for data points 4 and 6. These points show higher-than-average hot metal temperatures, lower-than-average wind rates, top temperatures, and CO/CO_2 ratios, and lower-than-average coke rates. The fuel rates for these data points are also significantly lower than the average for the base-case period because the natural gas injection rates were lower than average. The variability in hot metal chemistry and temperature was lower than average for these data points, as shown in Table 5-7, although the values for the cast-to-cast thermal variability were close to average. Clearly, the furnace was operating more efficiently than usual during these times.

Table 5-7. Summary of Hot Metal Chemistry for Base Case Period

Parameter	Units	Data Points						
		1	2	3	4	5	6	Wt. Avg.
Average Silicon	%	0.85	0.97	0.78	0.77	0.62	0.61	0.78
Std. Deviation	%	0.13	0.16	0.14	0.07	0.05	0.06	0.11
Average Sulfur	%	0.020	0.022	0.031	0.029	0.025	0.022	0.025
Std. Deviation	%	0.001	0.005	0.006	0.004	0.006	0.003	0.004
Average Temp.	°F	2,684	2,704	2,701	2,704	2,688	2,706	2,699
Std. Deviation	°F	9	23	27	10	19	3	15
dQ/dt Avg. Variability	MMBTU/hr	15.1	26.3	26.7	22.5	13.8	17.9	21.0
dQ/dt Avg. Var. Std. Deviation	MMBTU/hr	11.3	25.9	25.6	19.1	13.5	13.1	18.7
Average Cast Amount	Tons/Cast	338	265	312	335	340	361	321

The most likely reasons for these episodic increases in efficiency are the variability in coke quality and scrap mix. Very little coke mixing can take place in the holding bin at the coke yard, and obtaining even roughly uniform amounts of plant-produced and merchant coke requires that the front end loader operators follow a consistent pattern when retrieving coke from the various sources for transfer to the holding bin. The same consideration applies to the mixture of pit and crusher scrap. It is possible that the high-efficiency data points correspond to times in which the required discipline broke down and abnormally large amounts of better-quality coke and scrap were charged.

Ramp-Up Data: 175 lb/THM

The ramp-up to the 200 lb/THM injection rate was initiated in late March when the total amount of oxygen available increased as a result of the upgrades. Oxygen enrichment was increased from about 3.5 percent to 4 percent and then

5 percent, and the natural gas flow rate was increased in corresponding steps from 8.2 percent to 10.5 percent to 11.5 percent of the wind.

The highest values mentioned were set when the B furnace was taken down for reline on April 1. At that point, maximizing productivity gains became the key objective of the tests, and more scrap was put on the burden. The ratio of cold briquetted iron to pit plus crusher scrap remained the same as it had been in the base case at about 1:1. Also, the charging frequency was increased, the amount of time the hopper gates were allowed to remain open was decreased, and some self-fluxing pellets were added to the stone skip to increase hot metal production. The A furnace was now charged solely with plant-produced coke.

The test plan allowed for a relatively short period of time to be spent in ramp-up, because the desire was to increase natural gas and oxygen injection rates as quickly as possible. The correction factors required to rationalize data from two relatively steady times are shown in Table 5-8. The magnitude of the correction factors is close to that required in the base-case period, except that no corrections were required to the top gas nitrogen content to achieve closure for these data points.

Table 5-8. Correction Factors Used for Rationalizing Ramp-Up to 175 lb/THM Gas Injection Rate

	Units	Data Points		
		7	8	Wt. Avg.
Start Date		4/6/95	4/12/95	
No. of Days		6	5	
Iron-Bearing Burden	%	-2	-2	-2
Minntac Pellet (SiO_2+Al_2O3)	%	-0.25	-0.11	-0.19
Coke Rate	%	2.35	1.19	1.82
Wind	%	0.10	-1.25	-0.51
Top Gas				
CO	%	-0.1	0	-0.05
CO_2	%	0.1	0	0.05
N_2	%	0	0	0

The rationalized operating parameters and the thermal and energy balance parameters for these data points are summarized in Tables 5-9 and 5-10, respectively. Production was increased by almost 15 percent from the average base-case value, and both the coke rate and the total fuel rate decreased significantly. Some of these benefits are attributable to the increased metallization of the burden: the total pellet charge was decreased by almost 90 lb/THM, while the scrap charge was increased by more than 60 lb/THM, which increased the amount of metallic iron charged by about 27 lb/THM. The reduced thermal load of the more highly metallized burden permitted the productivity gains to be achieved at a relatively low increase in the total amount of oxygen required by the furnace, but all of the increase was obtained from the additional supplemental oxygen that became available. The furnace pressure drop also increased noticeably during this period, although this did not lead to an increase in reported slips or problems in the burden descent.

Table 5-9. Rationalized Operating Parameters for Ramp-Up to 175 lb/THM Gas Injection Rate

Parameter	Units	Data Points		
		7	8	Wt. Avg.
Productivity				
Production	TPD	4,208	4,108	4,162
% Increase	@3,635	15.8	13.0	14.5
Production	TPD/100cfwv	8.3	8.1	8.2
Burden (dry)				
Coke	lb/THM	754	747	751
Acid Pellets	lb/THM	797	771	785
Self-Fluxing Pellets	lb/THM	1,608	1,636	1,621
BOF Slag	lb/THM	138	135	137
BF Fines	lb/THM	122	122	122
Pellet Chips	lb/THM	121	120	121
Ilmenite	lb/THM	45	45	45
Gravel	lb/THM	26	26	26
Scrap	lb/THM	183	183	183
Wind				
Wind, delivered	mscfm	96.7	93.9	95.4
Wind	MSCF/THM	33.1	32.9	33.0
Blast Moisture	gr/SCF	5.7	4.9	5.3
Supplemental O_2	lb/THM	205	212	209
Supplemental O_2	TPD	432	436	434
Total O_2	TPD	1,663	1,632	1,649
Total O_2	TPD/100cfwv	3.3	3.2	3.3
Natural Gas	lb/THM	170	178	174
Others				
Fuel Rate	lb/THM	924	925	925
Slag Production	lb/THM	420	417	419
dP/B. Density		0.45	0.46	0.45
Top Gas Production	MSCF/THM, dry	52.9	52.9	52.9
Top Gas H_2	%	8.34	8.61	8.46
Top Gas CO	%	22.00	22.12	22.05
Top Gas CO_2	%	20.80	20.65	20.73
Top Gas N_2	%	48.86	48.62	48.75

The amount of oxygen injected increased from less than 0.9 lb O_2/lb natural gas in the base case to over 1.2 lb/lb during the ramp-up, and the RAFT did not decrease significantly as a consequence. The bosh hydrogen increased by almost 3 lb mole/THM as expected at the higher injection level, but the extent of the solution loss reaction decreased by only 0.4 mole/THM. This is an unexpectedly small decrease in EGC, since the hydrogen utilization efficiency remained reasonably high and a substantial amount of additional scrap had been charged. The top gas heating value increased to almost 100 Btu/SCF, and the operators discontinued the use of enriching coke oven gas for stove firing.

Table 5-10. Thermal/Energy Parameters for Ramp-Up to 175 lb/THM Gas Injection Rate

Parameter	Units	Data Points		
		7	8	Wt. Avg.
Blast Temp.	°F	1,789	1,789	1,789
H.M. Temp.	°F	2,703	2,701	2,702
AISI RAFT	°F	3,437	3,424	3,431
Rho V^2		25.29	23.74	24.59
Hearth Zone Gas	°F	2,902	2,900	2,901
dT Hearth	°F	199	199	199
Bosh H_2	lbmol/THM	21.4	22.1	21.7
T+C Energy	MMBTU/THM	0.70	0.71	0.70
EGC	lbmol/THM	7.5	7.4	7.5
dT Bosh	°F	20	22	21
Top Gas Temp.	°F	289	301	294
HHV	Btu/SCF	98	99	98
Top CO/CO_2		1.06	1.07	1.06
H_2 Util. Eff.	%	45.7	45.6	45.7
Heat Loss	MMBTU/hr	112	106	109

The control of the hot metal chemistry, as measured by the standard deviations of the hot metal temperature, composition, and cast-to-cast thermal variability, was improved slightly or at worst was unchanged compared to the base case, as shown in Table 5-11. This is consistent with the reports of smooth burden descent at the higher pressure drop. Also, there were a number of incidents during this period in which supplemental oxygen was lost for about an hour. The gas injection rate was usually left unchanged — resulting in temporary decreases in RAFT of about 500°F, and normal operations were resumed when the oxygen supply was restored. The only consequence of these occurrences was a decrease in hot metal temperature for one or two casts following the event.

Table 5-11. Summary of Hot Metal Chemistry for Ramp-Up to 175 lb/THM Gas Injection Rate

Parameter	Units	Data Points		
		7	8	Wt. Avg.
Average Silicon	%	0.60	0.60	0.60
Std. Deviation	%	0.05	0.06	0.05
Average Sulfur	%	0.024	0.024	0.024
Std. Deviation	%	0.003	0.003	0.003
Average Temp.	°F	2,703	2,701	2,702
Std. Deviation	°F	14	10	12
dQ/dt Avg. Variability	MMBTU/hr	18.9	21.3	20.0
dQ/dt Avg. Var. Std. Deviation	MMBTU/hr	16.0	17.4	16.6
Average Cast Amount	Tons/cast	328	326	327

200 lb/THM Period

The supplemental oxygen and natural gas injection rates were increased in concert following the completion of the ramp-up tests at 175 lb/THM, but the burden was initially unchanged with productivity increases sought by increasing the number of skips charged. The gains achieved were not sufficient, so the amount of scrap charged and the oxygen enrichment were increased again. The amount of higher-quality cold briquetted iron in the scrap mix was increased to 63 percent of the total.

The pressure drop remained high, and wind had to be pulled by 3 mcfm on occasion to allow smooth burden descent. In addition, coke handling procedures were modified to increase screening time to reject more undersize and increase the average coke size. Any benefits achieved from this practice may have been lost, however, because the B furnace reline activities resulted in a blockage of the highline and forced use of a bypass conveyor system. The double handling of the coke and loss of the highline screening station may have actually increased the amount of fines charged. Continued high blast pressure led the operators to remove pellet chips from the burden in an attempt to improve permeability, and to put on additional scrap to improve productivity. The correction factors used to rationalize the data from this period are shown in Table 5-12.

Table 5-12. Correction Factors Used for Rationalizing 200 lb/THM Gas Injection Rate

		Data Points			
	Units	9	10	11	Wt. Avg.
Start Date		04/24/95	5/8/95	5/23/95	
No. of Days		7	6	6	
Iron-Bearing Burden	%	-2	-2	-2	-2
Minntac Pellet (SiO_2+Al_2O3)	%	-0.26	0.26	0.02	-0.01
Coke Rate	%	0.52	2.38	2.02	1.58
Wind	%	0.86	-0.83	-2.58	-0.76
Top Gas					
CO	%	0	-0.1	0.5	0.13
CO_2	%	0	0.1	0.5	0.19
N_2	%	0	0	-1	-0.32

There were two scheduled outages and a number of delays in this period that were not related to the tests (e.g., mud gun problems, trough problems, etc.) that made it difficult to obtain prolonged stretches of steady operation for data rationalization. In addition, there was one apparently steady period (from 5/18-5/22) in which the data could not be rationalized within the allowed range of corrections. The correction factors shown in Table 5-12 for the data points rationalized are consistent with those acquired in the previous periods. A small adjustment was required in the top gas CO/CO_2 ratio to close the carbon balance for data point 10, and nitrogen corrections at the allowed limit were required to close data point 11. The rationalized operating parameters and thermal profile for these points are shown in Tables 5-13 and 5-14.

Additional productivity gains, to 8.5 TPD/CCF, were achieved compared to the ramp-up condition through increased use of scrap, oxygen, and natural gas. The scrap charge was increased by about 30 lb/THM to a total of 214 lb/THM, but the metallic iron content only increased by about 20 lb/THM. Again, all of the additional oxygen was supplied via enrichment, with the ratio of oxygen-to-gas injection increasing from about 1.2 to almost 1.4 lb O_2/lb natural gas. Also, the marginal increase in productivity was obtained with a higher increase in oxygen consumption than had been required previously, the ratio being about 1.3 tons of hot metal produced/ton of total oxygen consumed.

The bosh gas hydrogen content increased as expected, hydrogen utilization increased somewhat, and the extent of the solution loss reaction decreased significantly compared to the previous period. The decrease in the solution loss reaction, about 18 lb/THM, exceeded the 10 lb/THM decrease achieved in coke consumption, so that more coke was being consumed in the raceway and hearth reactions than had been the case in the previous period. This increased coke consumption, in turn, is reflected in the higher values for the thermal-plus-chemical energy in the hearth and in the hearth and bosh zone thermal pinches when compared to those values obtained in the ramp-up period. The furnace was run hotter at the hearth even though this did not show up in higher hot metal temperature or higher top gas temperature. The top gas temperature actually

Table 5-13. Rationalized Operating Parameters for 200 lb/THM Gas Injection Rate

Parameter	Units	Data Points			
		9	10	11	Wt. Avg.
Productivity					
Production	TPD	4,279	4,185	4,448	4,303
% Increase	@ 3,635	17.7	15.1	22.4	18.4
Production	TPD/100cfwv	8.5	8.3	8.8	8.5
Burden (dry)					
Coke	lb/THM	734	761	729	741
Acid Pellets	lb/THM	768	759	767	765
Self-Fluxing Pellets	lb/THM	1,632	1,618	1,709	1,652
BOF Slag	lb/THM	139	150	152	147
BF Fines	lb/THM	122	123	123	123
Pellet Chips	lb/THM	119	118	0	81
Ilmenite	lb/THM	45	27	31	35
Gravel	lb/THM	26	26	26	26
Scrap	lb/THM	182	220	246	214
Wind					
Wind, delivered	mscfm	94.6	92.1	92.3	93.1
Wind	MSCF/THM	31.8	31.7	29.9	31.2
Blast Moisture	gr/SCF	3.8	6.9	6.4	5.6
Supplemental O_2	lb/THM	244	274	283	266
Supplemental O_2	TPD	521	574	628	572
Total O_2	TPD	1,727	1,748	1,804	1,758
Total O_2	TPD/100cfwv	3.4	3.5	3.6	3.5
Natural Gas	lb/THM	193	185	199	192
Others					
Fuel Rate	lb/THM	927	946	928	933
Slag Production	lb/THM	410	434	437	426
dP/B. Density		0.44	0.46	0.46	0.45
Top Gas Production	MSCF/THM, dry	52.3	52.7	50.7	51.9
Top Gas H_2	%	9.08	8.98	9.73	9.25
Top Gas CO	%	22.67	23.17	23.54	23.10
Top Gas CO_2	%	20.60	20.81	20.61	20.67
Top Gas N_2	%	47.65	47.04	46.12	46.97

Table 5-14. Thermal/Energy Parameters for 200 lb/THM Gas Injection Rate

Parameter	Units	Data Points			
		9	10	11	Wt. Avg.
Blast Temp.	°F	1,791	1,792	1,790	1,791
H.M. Temp.	°F	2,687	2,701	2,702	2,696
AISI RAFT	°F	3,418	3,481	3,386	3,428
Rho V^2		25.51	25.28	25.83	25.54
Hearth Zone Gas	°F	2,899	2,918	2,883	2,900
dT Hearth	°F	212	217	181	204
Bosh H_2	lbmol/THM	23.6	23.4	24.9	23.9
T+C Energy	MMBTU/THM	0.73	0.77	0.74	0.75
EGC	lbmol/THM	6.9	5.8	5.6	6.1
dT Bosh	°F	35	80	55	56
Top Gas Temp.	°F	273	264	232	257
HHV	Btu/SCF	103	104	108	105
Top CO/CO_2		1.10	1.11	1.14	1.12
H_2 Util. Eff.	%	46.9	46.6	47.8	47.1
Heat Loss	MMBTU/hr	119	140	130	129

decreased by almost 40°F, and while the hydrogen utilization efficiency increased, the carbon utilization efficiency decreased. This is shown by the increase in CO/CO_2 ratio from 1.06 at a gas injection level of 174 lb/THM during the ramp-up to a ratio of 1.14 during the 200 lb/THM level period.

If normalized to the increase in gas consumption, this decrease in carbon utilization efficiency when compared with the previous conditions would result in a rather poor marginal replacement ratio of less than 0.6 lb coke/lb natural gas, even though the decrease in the solution loss reaction amounted to 1 lb coke/lb natural gas. The reason for this poor performance is not clear, but it may be the result of the burdening practice used. Since National chose to run a constant coke slit, the amount of coke charged stayed essentially the same from period to period.

The only way the coke rate could be reduced, then, was to increase the amount of ore charged. But the ore skips were loaded to their design capacity, and production increases were only obtained by increasing the amount of scrap charged. Thus, the increases in the "ore"-to-coke ratio that could be achieved were limited, and this limited the decrease in coke rate achievable, independent of the amount of gas that could be injected.

Furthermore, the decreased burden permeability, possibly resulting from poor scrap properties or excessive coke fines, limited the amount of wind that the furnace could accept, which increased the amount of oxygen that had to be supplied by enrichment, thus holding the heat level at the hearth at higher-than-necessary levels: note that the RAFT was essentially unchanged. The aim values set for this period were chosen to maintain the hot metal chemistry in the desired range, and this was achieved as shown in Table 5-15. The difficulties with burden descent described above did result in slight increases in the variability, and constrained the operators' ability to change to more cost-efficient set points.

Table 5-15. Summary of Hot Metal Chemistry for 200 lb/THM Gas Injection Rate

		Data Points			
Parameter	**Units**	**9**	**10**	**11**	**Wt. Avg.**
Average Silicon	%	0.60	0.64	0.48	0.57
Std. Deviation	%	0.07	0.13	0.05	0.08
Average Sulfur	%	0.027	0.023	0.021	0.024
Std. Deviation	%	0.005	0.007	0.004	0.005
Average Temp.	°F	2,687	2,701	2,702	2,696
Std. Deviation	°F	14	18	13	15
dQ/dt Avg. Variability	MMBTU/hr	17.5	22.6	16.4	18.8
dQ/dt Avg. Var. Std. Deviation	MMBTU/hr	13.8	17.6	14.2	15.1
Average Cast Amount	Tons/Cast	326	306	307	314

Experimental Results

Ramp-Up Data: 225 lb/THM

The ramp-up to higher gas and oxygen injection rates was initiated in late May 1995, together with a series of moves aimed at increasing burden permeability as a means to increase productivity further. The pellet chips were removed during the previous period, the amount of BOF slag and gravel was reduced by some 20 lb/THM, the amount of BF fines was held constant, and the amount of scrap charged was increased by almost 30 lb/THM. However, supply limitations forced a reduction in the fraction of cold briquetted iron in the scrap mix to less than 40 percent of the total, and the amount of metallic iron charged did not change. The amount of nut coke charged with the pellets was reduced from 50 to 20 lb/THM, and the maintenance activities on the highline were completed so that pellet screening was reinitiated and double handling of the coke was eliminated. While it appeared that these moves resulted in some improvement in permeability, the furnace continued to be driven for productivity, and the burden pressure drop did not decrease.

There were two scheduled outages and a number of maintenance-related curtailments (e.g., Bishoff problems, tuyere burnt, slag backup to blow pipes, etc.) that resulted in excessive delays in this period. Also, a prolonged period of heavy rains and loss of the MOLA instrument on occasion made it difficult to achieve steady operation. The operators were forced to make numerous changes in gas injection and ore-to-coke set points in an attempt to control hot metal temperature and chemistry, and they apparently overcorrected on occasion. The unsteady operation resulted in the ramp-up period being prolonged beyond that called for in the test plan. The correction factors used in rationalizing the data points in this period are shown in Table 5-16.

Table 5-16. Correction Factors Used for Rationalizing Ramp-Up to 225 lb/THM Gas Injection Rate

	Units	Data Points 12	13	Wt. Avg.
Start Date		6/1/95	6/23/95	
No. of Days		6	4	
Iron-Bearing Burden	%	-2	-2	-2
Minntac Pellet (SiO_2+Al_2O3)	%	0.12	0.13	0.12
Coke Rate	%	1.45	0.51	1.07
Wind	%	-2.28	-6	-3.77
Top Gas				
CO	%	0.4	0.5	0.44
CO_2	%	0.4	0.5	0.44
N_2	%	-0.8	-1	-0.88

While the corrections required to force the coke and acid/alkali balances are the same as for the previous periods, large corrections to the wind rate and to the top gas nitrogen were required to force closure of the oxygen balance. In addition, there was a time of steady furnace operation between data points 12 and 13 that could not be rationalized within the expected limits of measurement error, so less than two weeks' worth of data could be rationalized from more than a month's operation at this condition. The operating parameters and furnace thermal/energy profile calculated from the rationalized data are shown in Tables 5-17 and 5-18, respectively.

Table 5-17. Rationalized Operating Parameters for Ramp-Up to 225 lb/THM Gas Injection Rate

Parameter	Units	Data Points		
		12	13	Wt. Avg.
Productivity				
Production	TPD	4,343	4,461	4,396
% Increase		19.5	22.7	20.9
Production	TPD/100cfwv	8.6	8.8	8.7
Burden (dry)				
Coke	lb/THM	729	714	723
Acid Pellets	lb/THM	761	762	761
Self-Fluxing Pellets	lb/THM	1,702	1,708	1,704
BOF Slag	lb/THM	132	136	134
BF Fines	lb/THM	121	120	121
Pellet Chips	lb/THM	0	0	0
Ilmenite	lb/THM	30	30	30
Gravel	lb/THM	20	18	19
Scrap	lb/THM	243	241	242
Wind				
Wind, delivered	mscfm	94.0	90.9	92.7
Wind	MSCF/THM	31.1	29.3	30.4
Blast Moisture	gr/SCF	7.1	6.3	6.8
Supplemental O_2	lb/THM	290	336	308
Supplemental O_2	TPD	630	750	678
Total O_2	TPD	1,827	1,908	1,859
Total O_2	TPD/100cfwv	3.6	3.8	3.7
Natural Gas	lb/THM	213	228	219
Others				
Fuel Rate	lb/THM	942	942	942
Slag Production	lb/THM	413	410	412
dP/B. Density		0.45	0.45	0.45
Top Gas Production	MSCF/THM, dry	52.3	51.0	51.8
Top Gas H_2	%	9.98	10.17	10.06
Top Gas CO	%	23.58	24.86	24.09
Top Gas CO_2	%	19.97	19.96	19.97
Top Gas N_2	%	46.47	45.01	45.89

Table 5-18. Thermal/Energy Parameters for Ramp-Up to 225 lb/THM Gas Injection Rate

Parameter	Units	Data Points		
		12	13	Wt. Avg.
Blast Temp.	°F	1,792	1,797	1,794
H.M. Temp.	°F	2,699	2,691	2,696
AISI RAFT	°F	3,317	3,346	3,329
Rho V^2		26.96	27.06	27.00
Hearth Zone Gas	°F	2,844	2,850	2,846
dT Hearth	°F	145	159	151
Bosh H_2	lbmol/THM	26.8	28.2	27.4
T+C Energy	MMBTU/THM	0.75	0.79	0.77
EGC	lbmol/THM	4.6	3.9	4.3
dT Bosh	°F	88	119	100
Top Gas Temp.	°F	293	361	320
HHV	BTU/SCF	109	113	111
Top CO/CO_2		1.18	1.25	1.21
H_2 Util. Eff.	%	48.7	51.4	49.8
Heat Loss	MMBTU/hr	140	141	140

Since no more metallic iron was added to the burden, the increases in productivity were due solely to the increased number of charges made. As was the case in the previous two periods (ramp-up at 175 lb/THM and 200 lb/THM gas injection), the furnace accepted additional oxygen solely from increased enrichment, and while the ratio of supplemental oxygen to natural gas injected remained at about 1.4 lb O_2/lb natural gas, the marginal productivity achieved by the additional oxygen decreased to less than 1 ton hot metal/ton oxygen.

The bosh hydrogen increased when compared to the previous period, as expected, by 3.5 lb mole/THM. Overall hydrogen utilization efficiency actually increased somewhat, and the extent of the solution loss reaction decreased by 1.8 lb mole, equivalent to about 35 lb coke/THM. Again, however, the total fuel rate increased, because the coke rate only decreased by 18 lb/THM while the gas injection rate increase by 27 lb/THM. This was the result of higher-than-expected carbon consumption at the hearth, which shows up as an increase in the amount of thermal-plus-chemical energy released. Since the "ore"-to-coke ratio could not be increased because of the constant coke slit and skip capacity limitations, the high coke rate simply led to increases in the top gas temperature and CO/CO_2 ratio.

The marginal improvements in burden permeability made in this period compared to those in the previous two periods did lead to closer control of hot metal chemistry. This is reflected in the slightly decreased values of the standard deviations shown in Table 5-19.

Table 5-19. Summary of Hot Metal Chemistry for Ramp-Up to 225 lb/THM Gas Injection Rate

Parameter	Units	Data Points		
		12	13	Wt. Avg.
Average Silicon	%	0.51	0.63	0.56
Std. Deviation	%	0.02	0.04	0.03
Average Sulfur	%	0.017	0.019	0.018
Std. Deviation	%	0.003	0.003	0.003
Average Temp.	°F	2,699	2,691	2,696
Std. Deviation	°F	5	16	9
dQ/dt Avg. Variability	MMBTU/hr	14.2	16.4	15.1
dQ/dt Avg. Var. Std. Deviation	MMBTU/hr	10.9	14.5	12.3
Average Cast Amount	Tons/Cast	326	357	338

Experimental Results

Conclusion of Phase B

At the end of data point 13, the operators began preparations for the anticipated restart of the B furnace. However, slippages in the reline schedule resulted in a continued need for high rates of hot metal production from the A furnace. The oxygen enrichment set point was increased to 9.5 to 10 percent, the natural gas set point was increased to 16 to 17 percent of the wind, and the aim value for the coke rate was decreased to 675 lb/THM. While a period of steady operation sufficient for data rationalization could not be obtained, these conditions correspond to oxygen and natural gas injection rates of about 350 and 240 lb/THM, respectively, at a production rate of 4,400 TPD, or 8.8 TPD/CCF.

Operations continued at these conditions for about two weeks until the reline was completed and the B furnace was blown in. Then oxygen, gas, and burden set points were returned to those in place during the baseline period as production in the B furnace was resumed.

6
EFFECT OF NATURAL GAS INJECTION ON FURNACE PERFORMANCE

This chapter presents an analysis of the performance of National's A furnace at the various injection levels and compares it with the performance of other furnaces.

A. BACKGROUND

Injection of natural gas (or any other supplemental fuel) and oxygen at the tuyeres not only changes the material and energy balances in the raceway and hearth, but also affects the chemical and thermal balances and burden physical properties in the bosh and stack. The net results of the changed chemical and physical processes are observed as changes in furnace performance: productivity, hot metal chemistry, burden descent or pressure drop, coke consumption, and top gas composition.

Natural gas differs from all other supplemental fuels except coke oven gas in its high ratio of hydrogen to carbon, and in the strongly endothermic nature of its combustion under raceway conditions. These properties of natural gas dictate the ways in which gas injection changes furnace performance, and they must be understood to take full advantage of the benefits offered by gas injection. In this chapter of the report we will show the changes that natural gas injection had on the performance of National's A furnace, and describe the reasons for these changes and the implications for optimizing the practice.

B. TUYERE AND HEARTH LEVEL CONTROL — WIND AND OXYGEN REQUIREMENTS

A central question in setting aim values for natural gas injection is: how much wind and supplemental oxygen must be supplied to drive the furnace and maintain control of hot metal temperature (and chemistry) and provide an adequate thermal reserve? Injecting excessive amounts of oxygen brings a double economic penalty, since not only do oxygen costs increase but the excess oxygen burns more coke, which also increases costs. Older practice with natural gas, and current practice with coal injection, is to maintain the RAFT at a high value by injecting large amounts of supplemental oxygen. This high RAFT practice was not followed during these tests, as shown in Figure 6-1, and has not been followed on other furnaces injecting natural gas, as shown in Figure 6-2.

Figure 6-1.
AISI RAFT vs. Natural Gas Injection Rate, National GCS A Furnace

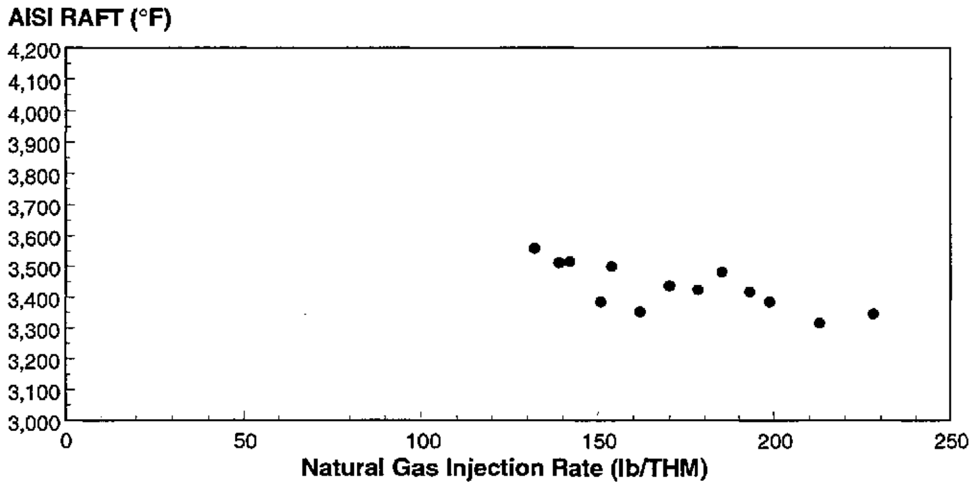
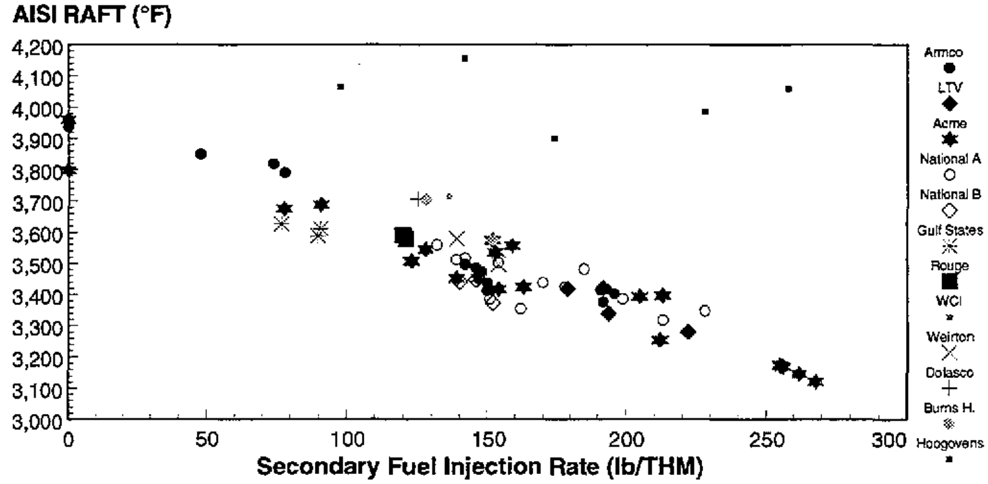


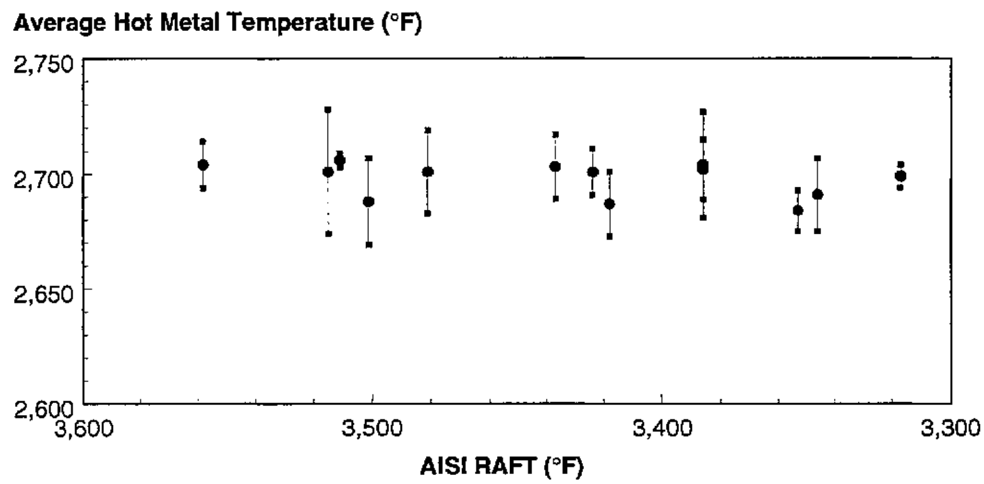
Figure 6-2.
AISI RAFT vs. Secondary Fuel Injection Rate



At National, the RAFT was decreased by some 190°F to about 3,350°F, while the injection rate was increased from about 130 lb/THM to 230 lb/THM gas. The data appear to lie in the middle range of other furnaces, as shown in Figure 6-2, but the spread in the data for the other furnaces is quite large: more than 200°F at some conditions. The "best fit" through all of the data show that, for all of these furnaces, a reduction in RAFT of about 290°F should be targeted for a 100 lb/THM increase in the level of gas injection. This has significant economic effects since, at typical conditions, running a RAFT 100°F higher than necessary by excess oxygen injection entails a cost increase of about $1.5/THM.

Some operators have been concerned that low RAFT practice will lead to low hot metal temperature and a cold furnace condition. The data in Figure 6-3 show that, if the furnace is properly balanced, hot metal temperatures are maintained even as RAFT decreases. National achieves the tight control of hot metal temperature shown in Figure 6-3 by using the level of gas injection as a control tool. The moves made to minimize the excursions in hot metal temperature are described in Table 3-3.

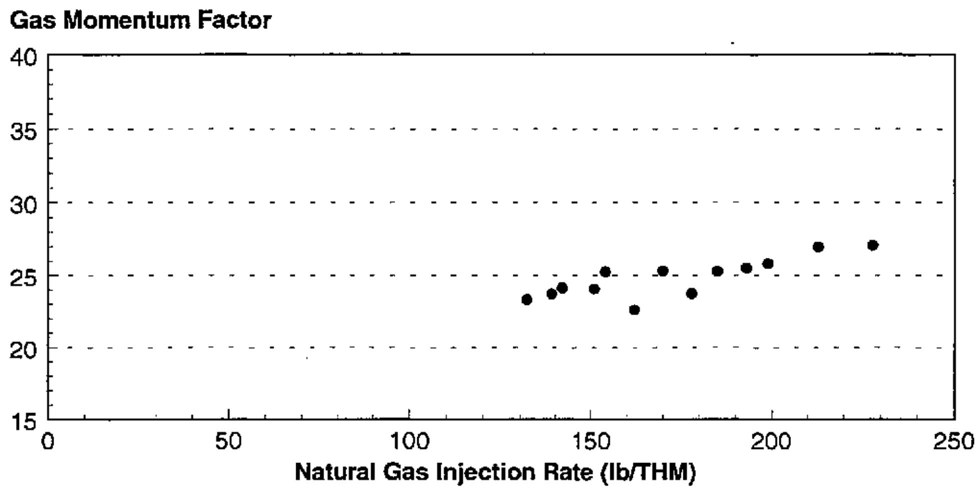
Figure 6-3.
Average Hot Metal Temperature vs. AISI RAFT, National GCS A Furnace



Balancing the furnace properly requires that the total amount of oxygen from the wind and the supplemental oxygen supplied at the tuyeres be sufficient to burn both the injected gas and enough coke to provide the high temperature thermal energy at the hearth and bosh zones. Since wind is less costly than supplemental oxygen, maximizing its consumption has economic advantages and the heated nitrogen is available to carry sensible energy up the furnace that otherwise would have to be generated by combustion of coke. The maximum amount of wind that the furnace can accept is limited by the burden permeability and the maximum pressure drop that can be taken to assure smooth burden descent. These parameters are practice-specific and are not easily predicted, but can be obtained from an analysis of furnace performance.

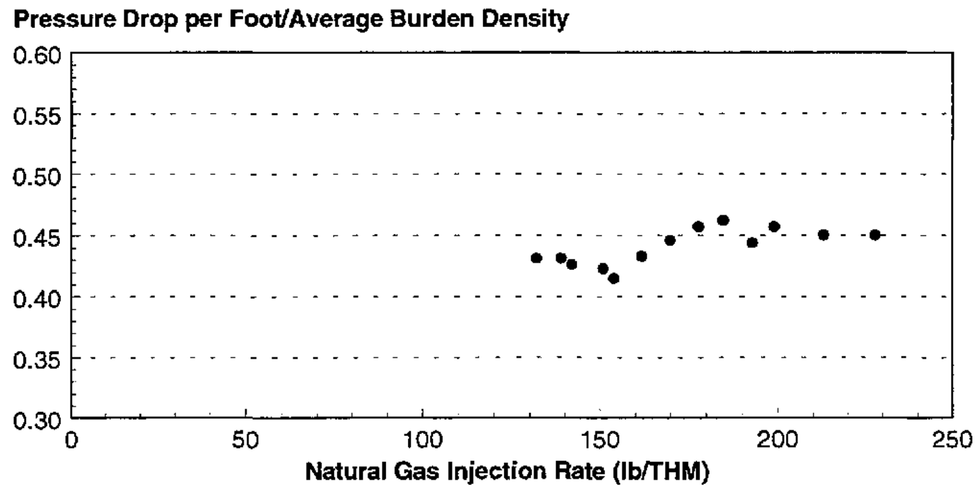
A parameter, the "rho V squared term," is a measure of the bosh gas kinetic energy that determines pressure drop (see Table 5-3 for a complete definition of this parameter). As long as major changes are not made in the burdening practice (for example, putting on different types of scrap, changing the coke source, or changing the ratio of iron-bearing materials) and the parameter value is not exceeded, the furnace should accept an amount of wind that will not result in increased pressure drop. The value of this parameter, and the furnace pressure drop per unit of active height divided by the average burden density, are shown in Figures 6-4 and 6-5.

Figure 6-4.
Gas Momentum Factor vs. Natural Gas Injection Rate, National GCS A Furnace



Under base-case conditions, ρV^2 had a value of about 23.8 ±1.4, and as the gas, oxygen, and production rates were increased throughout the tests, the period average values increased to 24.6, 25.5, and then 27. Without changes in burden composition, these increases would not be sufficient to cause problems with burden descent, especially the small increase in the 175 lb/THM ramp-up period. However, as described above, the amount of scrap in the burden was increased substantially in the first ramp-up, and was increased further at higher injection rates to increase productivity.

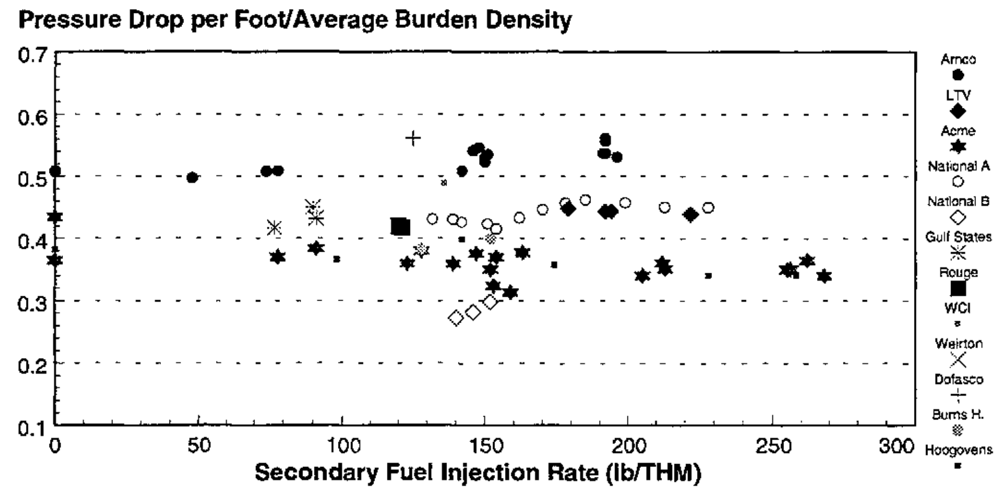
Figure 6-5.
Ratio of Operating Pressure Drop to the Average Burden Density vs. Natural Gas Injection Rate, National GCS A Furnace



An immediate increase was noted in the pressure drop, as shown in Figure 6-5: the ratio of pressure drop per foot to average burden density increased from 0.43 in the base case to 0.45 in the first ramp-up and following periods. (The actual pressure drops increased from 22.8 to 24.5 psi.)

As shown in Figure 6-6, the pressure drop in the National furnace was within the range of other furnaces injecting supplemental fuels at comparable rates. However, the decrease in burden permeability that was observed as more scrap was put on the burden limited the furnace's ability to accept more wind, forcing the operators to use supplemental oxygen to drive it to obtain the desired productivity.

Figure 6-6.
Ratio of Operating Pressure Drop to the Average Burden Density vs. Secondary Fuel Injection Rate



C. TUYERE AND HEARTH LEVEL CONTROL — ENERGY REQUIREMENTS

Sufficient oxygen must be supplied to provide the high temperature energy required for the tuyere and hearth zone reactions and to provide the energy required for burden heating and reduction in the bosh and stack at the target production rate. The combustion energy liberated in the raceway is transferred as sensible heat from cooling gases and the key question is: how much energy must be supplied? The amount of energy required for burden heating and hot metal and slag production is reasonably well defined, but a major issue is the amount of energy that must be supplied to satisfy the highly endothermic solution loss reaction, or EGC.

The high hydrogen content of natural gas has a major influence on the solution loss reaction since it is available to "prereduce" iron oxides in the stack and therefore decrease the amount that will be reduced directly in the bosh. The efficiency of hydrogen utilization increased slightly over the range of injection rates tested at National, as shown in Figure 6-7. In fact, the overall hydrogen utilization efficiency was in the high range of efficiencies obtained in other furnaces, as shown in Figure 6-8.

Figure 6-7.
Overall Hydrogen Utilization Efficiency vs. Natural Gas Injection Rate, National GCS A Furnace

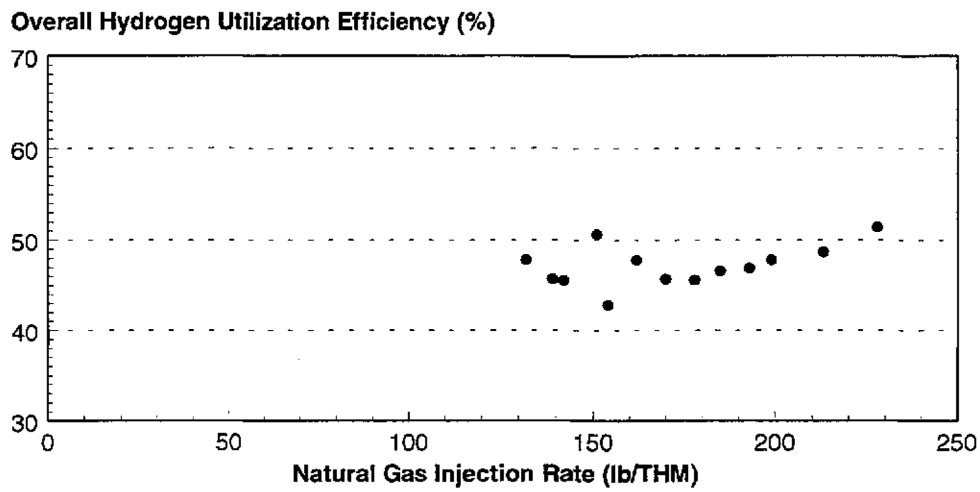
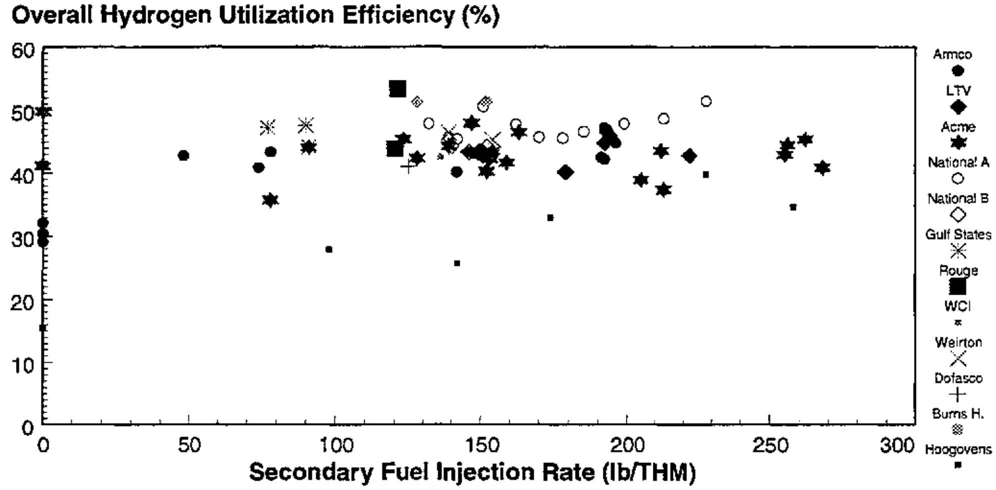


Figure 6-8.
Overall Hydrogen Utilization Efficiency vs. Secondary Fuel Injection Rate



Since increasing amounts of hydrogen are being used at constant or increasing efficiency, the extent of indirect reduction must increase and the extent of the solution loss reaction must decrease at higher gas injection rates. This is found to be the case, as shown in Figure 6-9 and 6-10, for the National A and other furnaces. The slope of the curve of the extent of the solution loss reaction versus bosh hydrogen content at National is about 0.42, that is, each additional mole of hydrogen introduced was associated with a reduction in the extent of the solution loss reaction by 0.42 mole.

This slope is somewhat higher than the average of about 0.35 for all of the other furnaces shown in Figure 6-10, and the extents of the solution loss reaction in the National A furnace are lower than found in other furnaces of comparable bosh hydrogen content. Some of this decrease is attributable to the high scrap content of the burden: the solution loss reaction cannot occur if the charge is completely metallic, after all.

Since the amount of scrap charged was increased by about 120 lb/THM from the base case to the 250 lb/THM ramp-up period, the burden oxygen content was reduced by about 1.5 atoms of oxygen per ton. Over these ranges of hydrogen contents, only about 20 percent of the reduction of iron is done by the solution loss reaction, so the benefit of the higher scrap content should have been of the order of 0.3 moles per ton reduction in the EGC. If this "credit" were applied to the data shown in Figure 6-9, the slope of the curve for the National A furnace would still be higher than average (at about 0.39), and the conclusion remains that the furnace was using hydrogen rather efficiently.

Figure 6-9.
Direct and Indirect Reductions vs. Bosh Gas Hydrogen Content, National GCS A Furnace

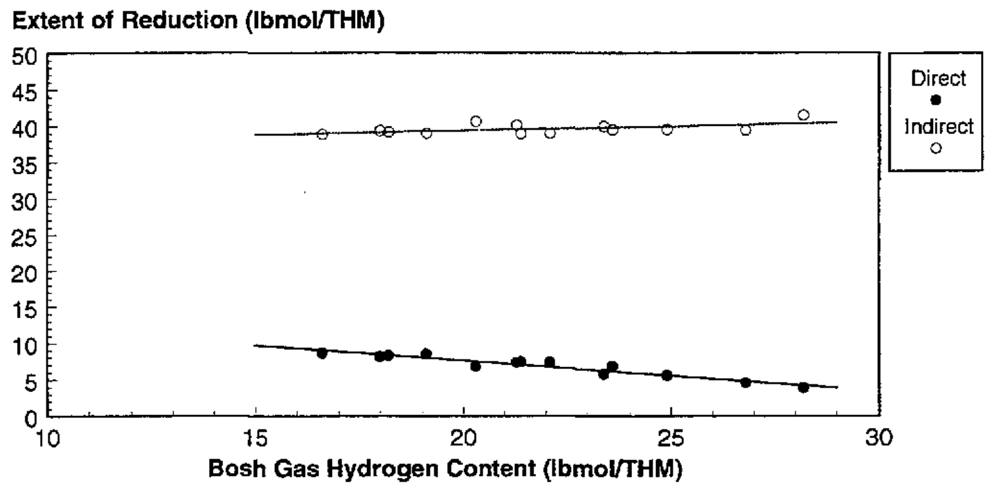
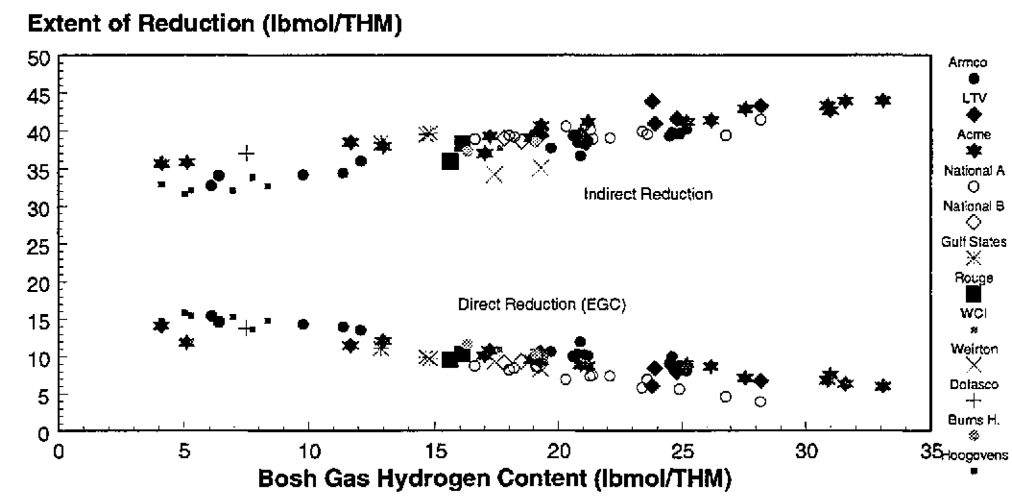


Figure 6-10.
Direct and Indirect Reduction vs. Bosh Gas Hydrogen Content



Since the extent of the solution loss reaction is decreasing, less carbon needs to be burned at the hearth to provide energy for it, and the total amount of carbon burned can be reduced, as shown in Figures 6-11 and 6-12, for the National A and other furnaces. The large amount of scatter in the data in Figure 6-12 results from the differences in operating practices among the furnaces. Those with higher hot blast temperatures, better-quality coke or better control of burden distribution, and more reduced burdens will require less carbon combustion than furnaces that do not have these advantages. Also, those that operate at lower RAFTs (all else equal) will burn less carbon at the hearth and so be more efficient. The conditions and practice at National during these tests were such that carbon combustion in the hearth decreased by about 0.035 lb mole, or about 0.45 lb of coke, per pound of gas injected. This is about the same as the average value of the furnaces shown in Figure 6-12.

Figure 6-11.
Carbon Burned in the Hearth vs. Natural Gas Injection Rate, National GCS A Furnace

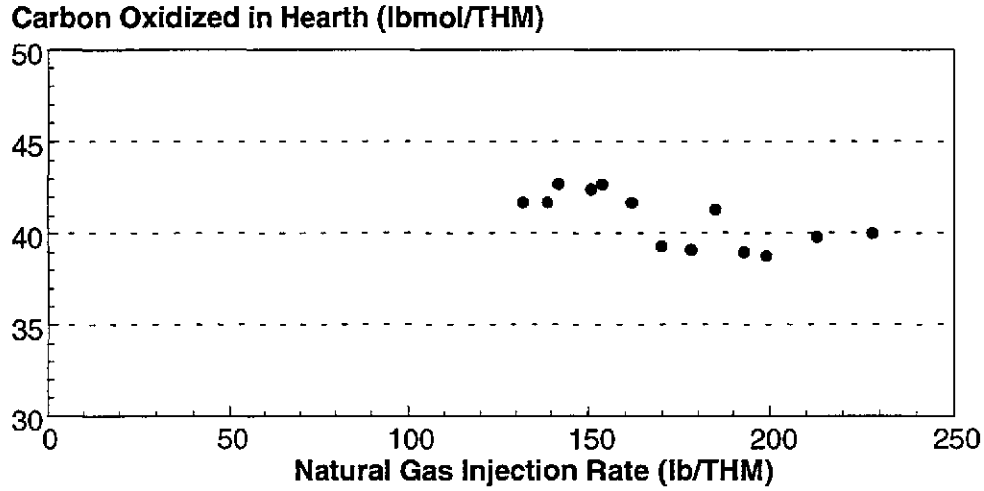
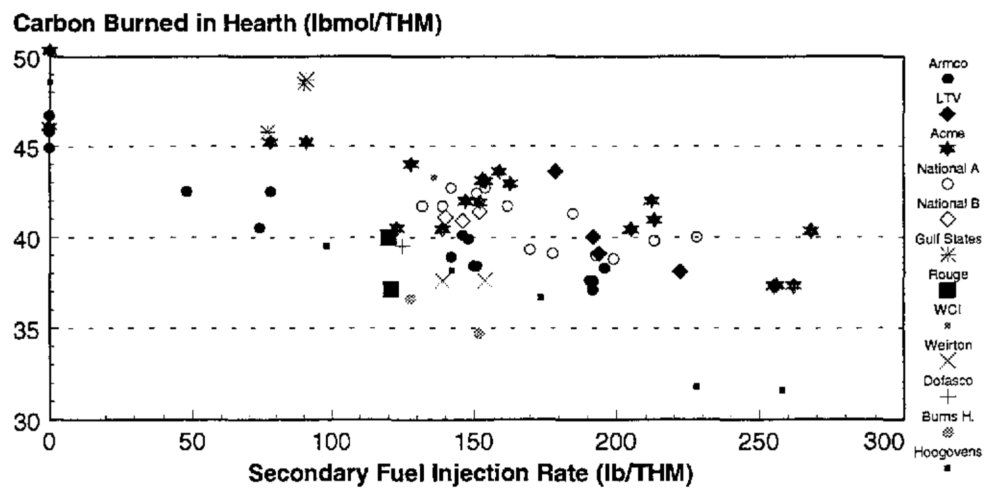
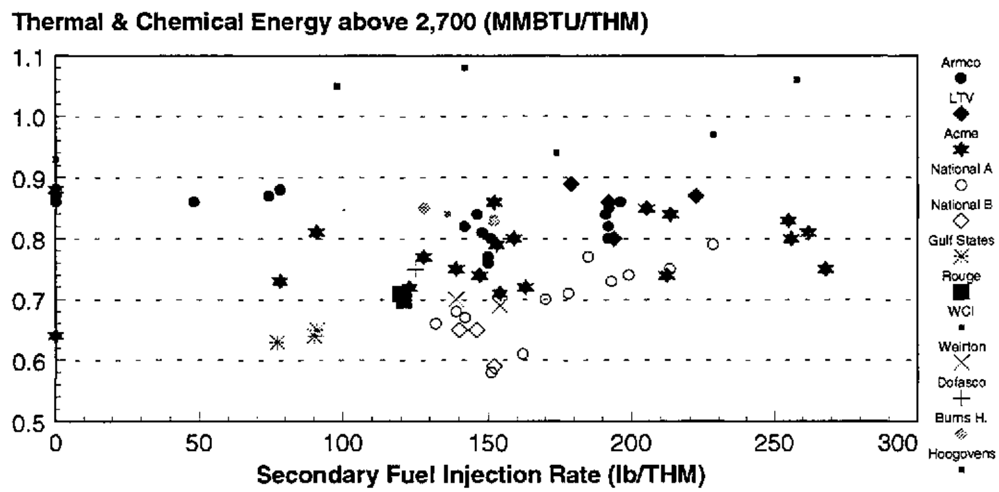


Figure 6-12.
Carbon Burned in the Hearth vs. Secondary Fuel Injection Rate



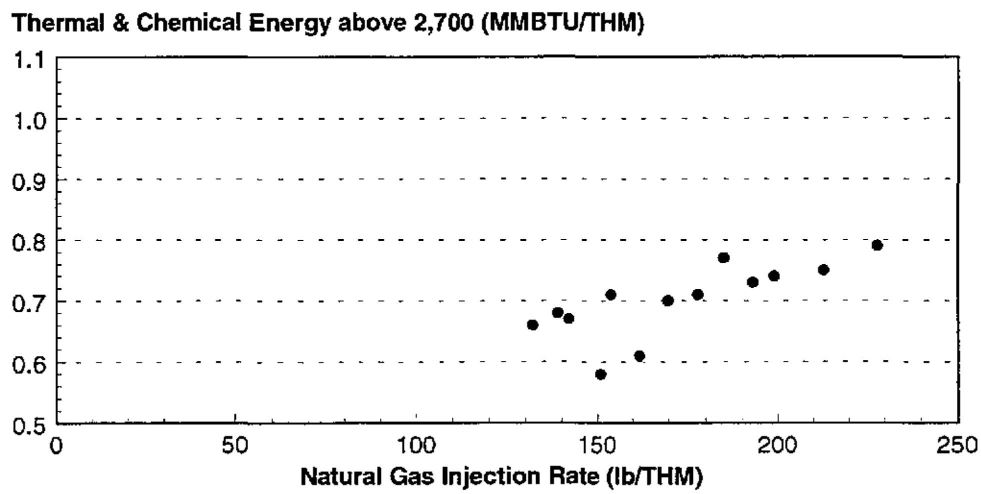
As shown in Figure 6-3, this practice will not result in a decrease in hot metal temperature as long as the furnace is properly balanced. While RAFT is not a usable parameter in setting aim values (see Figures 6-1 and 6-2), a new parameter can be used to fix the high temperature energy requirements — the total thermal-plus-chemical energy of the hearth gases generated per ton of hot metal produced (see Table 5-3 for a complete definition of this parameter). The appropriate value of the parameter is practice-specific, but it can be obtained from an analysis of existing furnace performance. Holding this parameter essentially constant over the range of gas injection levels contemplated will provide sufficient energy to the furnace, as shown in Figure 6-13.

Figure 6-13.
Thermal Condition of Various Furnaces vs. Secondary Fuel Injection Rates



The thermal condition of the National A furnace was not held constant during these tests, but increased as the natural gas injection level increased, as shown in Figure 6-14. Since the extent of the solution loss reaction was lower than expected, this increase in energy could not be used efficiently, and the extra carbon burned to produce the energy resulted in a steadily increasing top gas CO/CO_2 ratio.

Figure 6-14.
Thermal Condition of National GCS A Furnace vs. Natural Gas Injection Rate



D. FURNACE PRODUCTIVITY AND COKE CONSUMPTION

Increases in furnace productivity can be achieved by driving the furnace harder, i.e., supplying more oxygen, or reducing the specific furnace energy requirement by putting metallics in the burden, or both, as was practiced by National during these tests. The A furnace achieved productivities that were comparable to other furnaces injecting high levels of supplemental fuels and using burden metallics, as shown in Figure 6-15.

Over the range of natural gas injection rates tested, the furnace achieved high average marginal productivities of about 2.1 tons of hot metal per ton of oxygen consumed, as shown in Figure 6-16. Most of this gain, however, was obtained in moving from the base-case practice to the first ramp-up conditions in which half of the total additional scrap was added and high gains would be expected. The marginal gains were lower at the higher injection rates, about 1.2 tons hot metal/ton of oxygen, and were largely achieved by injecting increasing amounts of supplemental oxygen because the decreased burden permeability limited the amount of wind that the furnace could accept.

Figure 6-15.
Hot Metal Production vs. Total Delivered Oxygen

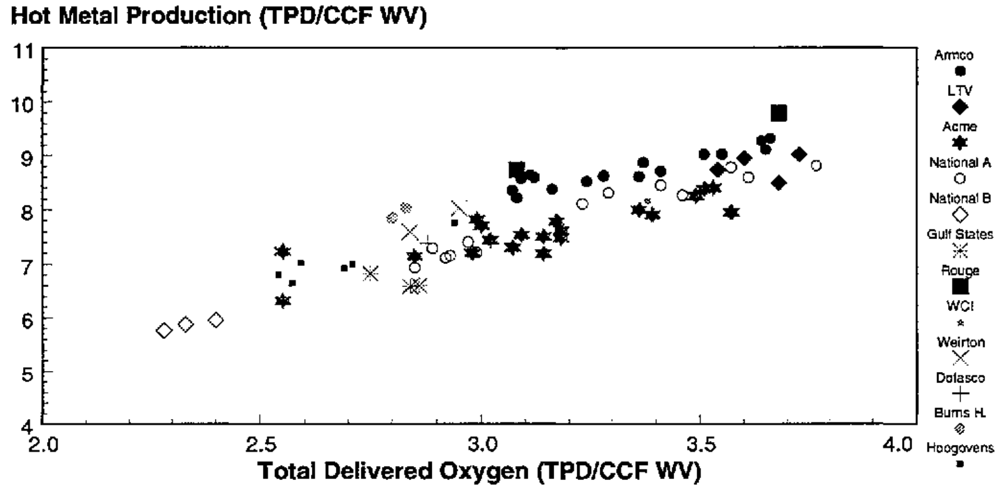
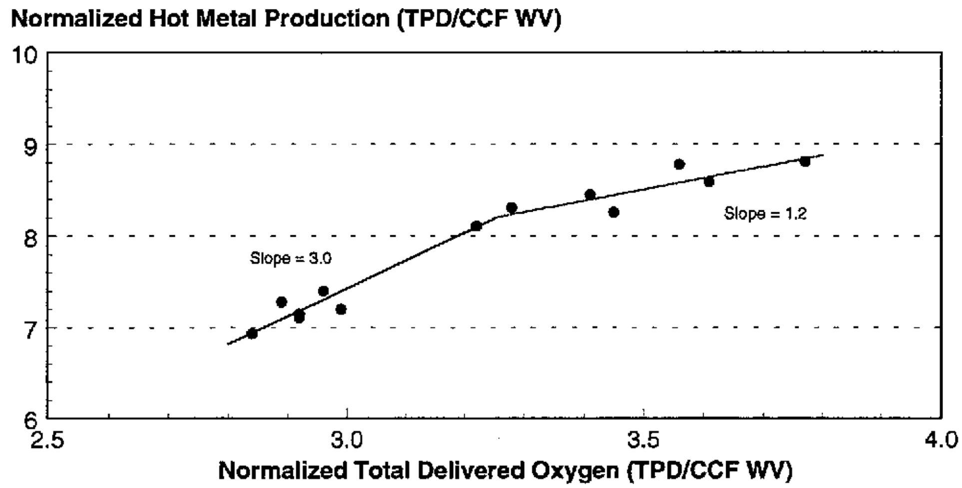


Figure 6-16.
Hot Metal Production vs. Total Delivered Oxygen, National GCS A Furnace



Because injection of natural gas results in a decrease in the extent of the solution loss reaction (see Figures 6-9 and 6-10) and permits the furnace to be thermally balanced with less coke consumption in the hearth (see Figures 6-11 and 6-12), injection of gas reduces coke consumption. Since additional scrap was put on the burden in these tests, the decrease in reduction energy requirements should lead to additional coke savings when compared to an all-pellet practice. The furnace coke requirements for National's A furnace and for other furnaces injecting natural gas are shown in Figures 6-17 and 6-18, respectively.

The data in Figure 6-18 show that the coke rates in National's A furnace were as low or lower than other furnaces injecting natural gas at levels above about 150 lb/THM. This is to be expected since scrap was being charged at 180 to 240 lb/THM. The overall coke replacement ratio obtained during these tests was about 1.2 lb coke/lb natural gas, which is as high as has been found in other furnaces in this range of injection rates. However, the replacement ratio was much higher in moving from baseline conditions to the first ramp-up period than it was in moving to higher injection rates as shown in Figure 6-17. The increase in burden metallic iron charge of about 27 lb/THM and the decrease in wind rate and blast humidity that occurred between the base case and ramp-up conditions to

174 lb/THM would account for reductions in coke consumption of about 6.8 and 5.2 lb/THM, respectively. Together, these would appear as a "credit" for natural gas injection of more than 0.4 lb coke/lb gas, so that a higher-than-average replacement ratio in this range is understandable. However, from this ramp-up condition to the highest injection level (219 lb/THM), the increased metallic iron charge of 18 lb/THM would be expected to reduce coke consumption by only about 4.5 lb/THM. However, the simultaneous increase in blast humidity increased coke consumption by about 3.3 lb/THM, so the net "credit" to gas injection was less than 0.03 lb/lb.

Some decreases in marginal replacement rate have been found in other furnaces operating at injection rates this high. While there may be many factors involved, including burdening practices and less-than-optimum assignment of set point values, some of the decrease in replacement results simply from the increasing use of supplemental oxygen at higher injection rates. Increasing blast enrichment decreases the amount of nitrogen that enters the furnace per unit of fuel burned, there is less sensible heat available to preheat the burden, and more fuel must be combusted to provide the energy. As described earlier, burden permeability limitations resulted in a requirement for unusually high oxygen enrichments in the A furnace.

The primary objective of furnace operation during the test periods after the base case was to maximize production during the B furnace reline, and this was achieved by putting on additional scrap and maximizing the driving rate by increasing oxygen enrichment. But skip capacity was limited, and National's practice was to run a constant coke slit, so that the increase in the "ore"-to-coke ratio that could be achieved was constrained. This charging practice, in effect, forced the furnace to accept more coke than it might have if the coke slit had been allowed to decrease. The "extra" coke charged was burned at relatively low efficiency, as shown by the increase in top gas CO/CO_2 ratio from 1.06 at a gas injection rate of 174 lb/THM to 1.21 at an injection rate of 219 lb/THM, even though the hydrogen utilization efficiency increased throughout the tests.

Figure 6-17.
Rationalized Dry Coke Rate vs. Natural Gas Injection Rate, National GCS A Furnace

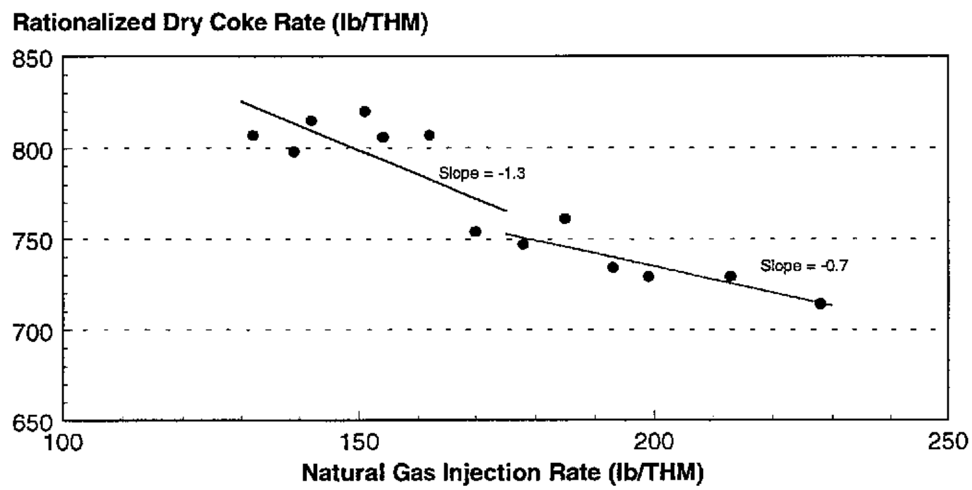
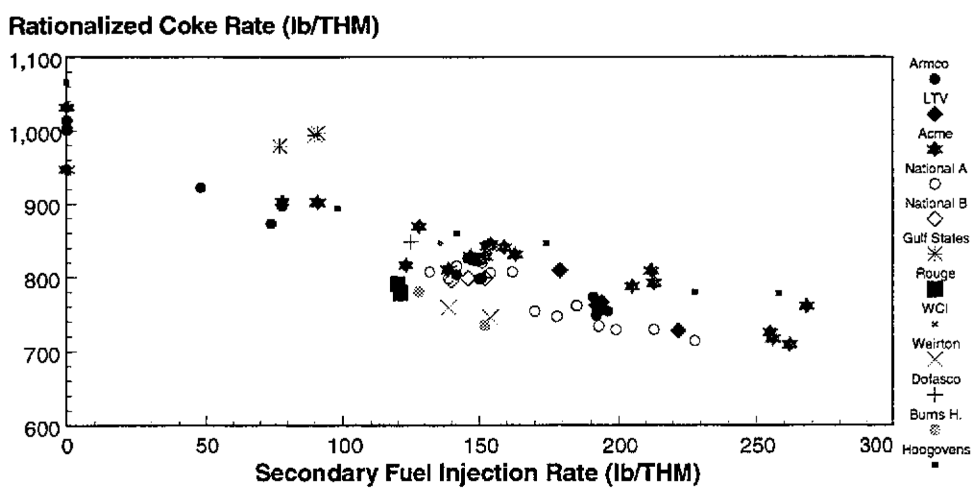


Figure 6-18.
Rationalized Coke Rate vs. Secondary Fuel Injection Rate



If the burden permeability were not adversely affected by decreasing the coke slit, it is possible that production and hot metal temperature targets could have been met with less coke being consumed at higher efficiency, and the marginal replacement ratio obtained would have been closer to the values found in other furnaces.

E. HOT METAL QUALITY

It has already been shown (see Figure 6-3) that the hot metal temperature and its variability (standard deviation of the average) do not depend on the gas injection rate. The same conclusion can be drawn with respect to the hot metal chemistry, as shown in Figures 6-19 and 6-20.

The high hot metal silicon contents and the high variability in the base case were attributed to the problems in obtaining a consistent coke mixture mentioned earlier: some of the merchant coke had an extremely high ash content. Even though the coke rate was decreased by almost 90 lb/THM and the scrap addition rate was increased by 120 lb/THM in these tests, the burdening practice was controlled so that the slag rate actually increased by 10 to 20 lb/THM, and the basicity was held at about 1.0. This resulted in a decrease in hot metal sulfur content of more than 0.005 percent, which provided economic benefits in desulfurization since National produces significant amounts of low-sulfur steel products.

Figure 6-19
Hot Metal Silicon Content and Standard Deviation vs. Natural Gas Injection Rate, National GCS A Furnace

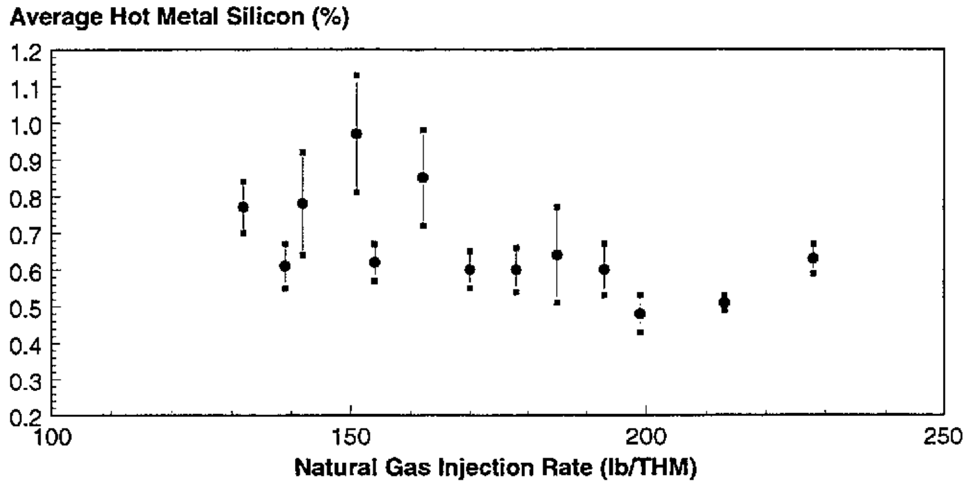
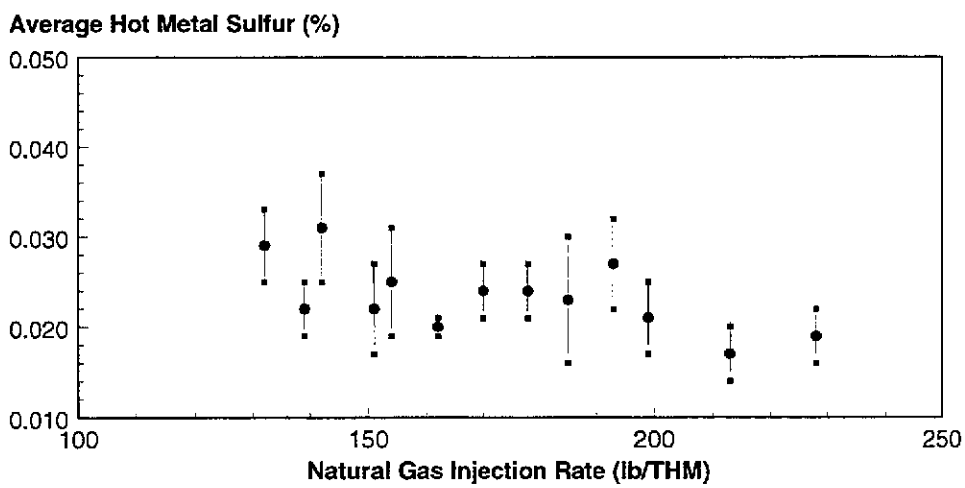
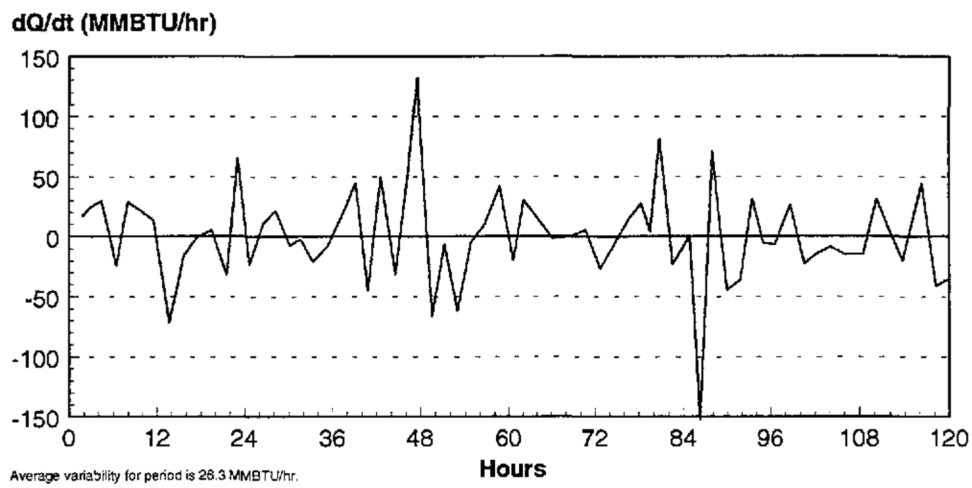


Figure 6-20.
Hot Metal Sulfur Content and Standard Deviation vs. Natural Gas Injection Rate, National GCS A Furnace



An additional measure of the variability in furnace performance is the cast-to-cast thermal variation in the hearth (see Table 5-3 for a complete definition of this parameter). This parameter estimates the changes in energy that have occurred in the hearth between successive casts to heat (or cool) the hot metal and increase (or decrease) the silicon and manganese contents, and then divides the energy change by the time between casts to derive an estimate of the rate of change. Records of the cast-to-cast variability for two base-case data sets are shown in Figures 6-21 and 6-22, respectively. Average values (with the standard deviations) for all of the data points in these tests are shown in Figure 6-23.

Figure 6-21.
Cast-to-Cast Variability for National GCS A Furnace — Base Period Data Point 2, 151 lb/THM Natural Gas Injection Rate



Average variability for period is 26.3 MMBTU/hr.
Standard deviation is 25.9 MMBTU/hr.

Figure 6-22.
Cast-to-Cast Variability for National GCS A Furnace — Base Period Data Point 6, 139 lb/THM Natural Gas Injection Rate

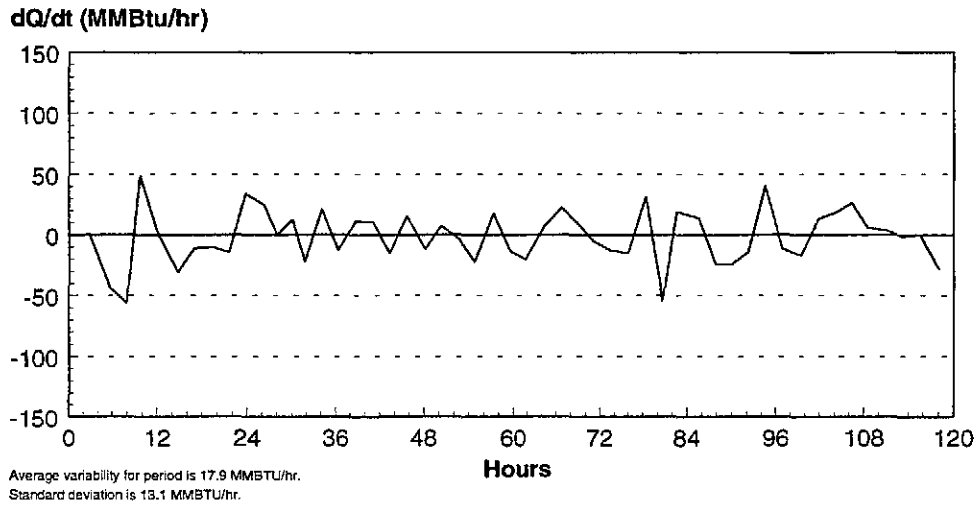
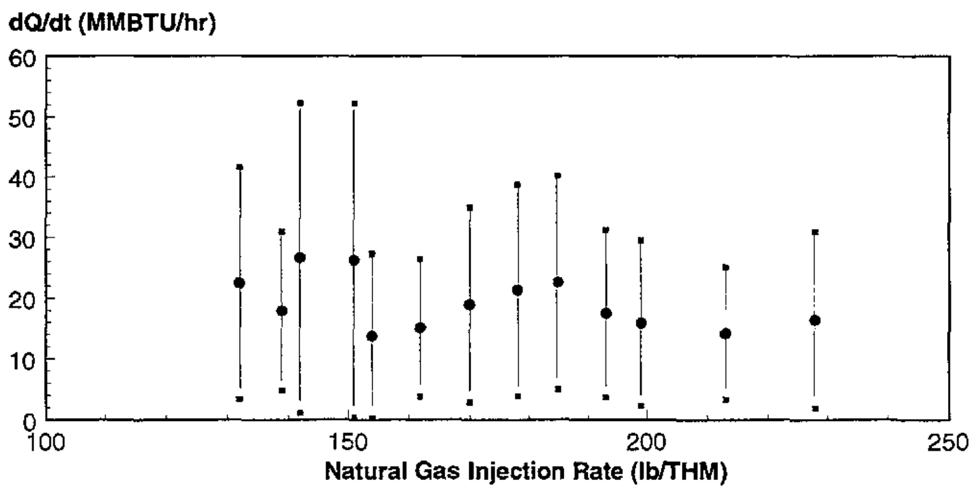


Figure 6-23.
Cast-to-Cast Variability in the Hearth vs. Natural Gas Injection Rate, National GCS A Furnace



If hot metal temperature and chemistry were unchanged from cast-to-cast, the value of this parameter would be zero. When successive casts have higher temperatures and silicon contents, the value is positive, and vice versa. Over long periods, the parameter will show equal average variations above and below the zero point as the hot metal temperature and chemistry fluctuate around the aim values. For shorter periods, the parameter defines the unsteady-state response of the furnace quantitatively.

Referring to Figure 6-21, for example, the cast taken about 36 hours into the period was nearly unchanged from the previous one (dQ/dt about zero). The temperature/silicon content of the next cast was significantly higher (dQ/dt +50), but on the successive three casts the temperature/silicon content went significantly lower, higher, and then lower again (dQ/dt –, +, –50). Then, there was a large positive excursion in temperature/silicon content in the cast taken at 48 hours (dQ/dt > +100), which was followed by decreases in the temperature/silicon contents on the following four casts (all dQ/dt's negative).

The average value and standard deviation in the cast-to-cast variability for data point 2 exceed the averages for the baseline period, as do the standard deviations in hot metal temperature and silicon contents. These data were taken at a time in which large amounts of low-quality merchant coke were being charged to the furnace, and the operators were having difficulty holding hot metal aim values. The data shown in Figure 6-22 were taken at a comparable injection rate and higher production rate, but during a period in which coke quality was better. The smoother furnace operation is shown in the significantly reduced values of the cast-to-cast variability.

As shown in Figure 6-23, there appears to be a trend toward decreasing values of both the average cast-to-cast variability and its standard deviation at the higher injection rates, even though the furnace was driven for production and burden permeability was decreasing. Our interpretation of this parameter is that it reflects mainly the effects of irregular burden descent through the bosh, and the major cause for large decreases is the rapid descent of some unreduced iron into the hearth. (Large decreases would normally be followed by large increases if the next cast temperature and composition return to the aim values). Decreasing the extent of the solution loss reaction through gas injection may be a contributor to smoother burden descent.

Since the average steady-state heat release from the blast reactions in the raceway/hearth was about 310 MMBTU/hr throughout these tests, the average cast-to-cast fluctuations were of the order of 5 percent of the steady value, with maximum fluctuations usually in the range of 10 to 15 percent of the average. The stability of furnace operation shown at high gas injection rates provides a measure of safety to the operators.

APPENDIX A
Narrative of Events

DESCRIPTION OF EVENTS IN BASE-CASE PERIOD

12/1/94	Recovered from cold furnace. Increased coke aim value by 5 lb/THM (to 775 lb/THM) and increased natural gas aim value to 9 percent.
12/2/94	Down for about 2.5 hours for runner repair.
12/3/94	Coke aim value decreased by 5 lb/THM.
12/4/94	Cast temperatures in lower yellow. Increased coke aim value by 15 lb/THM.
12/6/94	Coke aim value increased by 10 lb/THM as cast temperatures in lower yellow. Four extra skips of coke at midnight in preparation for shutdown.
12/7/94	Scheduled eight-hour outage. Burnt tuyere after start-up.
12/8/94	Changed two tuyeres. Emergency Action B taken when subsequent cast temperature was 2,515°F. Wind was cut to 90 mscfm. As temperature recovered, Emergency Action A was followed. Natural gas and oxygen aim values set at 8 percent and 3 percent, respectively, during emergency response. Hot metal temperature excursion possibly caused by increased amount of low-quality coke charged to furnace.
12/9/94	Increased moisture to 20 gr/SCF as furnace becomes hot. Natural gas aim value cut to 7.5 percent. Decrease coke aim value by 5 lb/THM.
12/11/94	Down for 3.5 hours due to skip derailment and off-rod condition. Coke aim value increased by 10 lb/THM.

Narrative of Events

12/13/94	Coke aim value increased by 10 lb/THM. Slip detected.
12/15/94	Furnace running hot. Coke aim value decreased by 25 lb/THM and moisture increased to 17 gr/SCF. Natural gas aim value decreased to 7.5 percent.
12/16/94	Coke aim value decreased by 10 lb/THM. Natural gas aim value increased to 7.75 percent six hours later as moisture gradually reduced.
12/18/94	Coke aim value increased by 5 lb/THM and natural gas aim value increased to 9 percent as furnace appeared to run cold.
12/19/94	Coke aim value increased by 10 lb/THM. Furnace placed on check for about three hours due to mud gun problems.
12/20/94	Four extra skips of coke charged to furnace in preparation for scheduled shutdown.
12/21/94	Scheduled shutdown for eleven hours.
12/22/94	Coke aim value decreased by 10 lb/THM because furnace was running hot coming back on-line from shutdown.
12/23/94	Coke aim value decreased by 10 lb/THM.
12/24/94	Two extra skips of coke for shutdown. Three blowpipes changed.
12/26/94	Furnace placed on check for about half an hour because of loose shaft on cold blast valve on No. 3 stove. Coke aim value increased by 10 lb/THM.
12/27/94	Low blast temperature because of problems with cold blast valve on No. 1 stove. Charged one extra skip of coke every two hours.

Narrative of Events

12/28/94	Furnace on twenty-minute check due to off-rod condition. Blast temperature depressed for about 2.5 hours due to switching problems with cold blast valve on No. 1 stove.
12/29/94	Low blast temperature because of problems at No. 1 stove. One extra skip of coke per hour charged to furnace for six hours.
1/2/95	Coke aim value increased by 30 lb/THM in preparation for extended scheduled shutdown. Natural gas aim value decreased by 1 percent seven hours later. Wind cut to 90 mscfm.
1/3/95	Furnace shutdown commenced at 7:35 P.M.
1/4/94	Furnace shutdown for 24 hours. Main objective is trough work. Six-inch vortex flow meter installed on natural gas pipeline.
1/5/95	Furnace comes back on-line at 12:45 p.m. After start-up, furnace placed on check several times due to filling trouble and problem with bootleg hanger. Furnace is shutdown for about 1.5 hours to repair bootleg hanger and skip.
1/6/95	Coke aim value decreased by 10 lb/THM (to 800 lb/THM) because furnace was running hot. Natural gas aim value decreased to 6.75 percent. Moisture increased to 14 gr/SCF. Wind rate returned to 100 mscfm.
1/7/95	Natural gas aim value increased to 7 percent.
1/8/95	Coke aim value decreased by 10 lb/THM.
1/9/95	Coke aim value decreased by 10 lb/THM.
1/10/95	Natural gas aim value increased to 8 percent because furnace was running cold.
1/11/95	Natural gas aim value increased to 9 percent. Later, coke aim value increased by 10 lb/THM to increase hot metal temperature.

Narrative of Events

1/12/95	Furnace on one-hour check due to coke car trouble. Coke aim value increased by 10 lb/THM.
1/13/95	Cast temperatures in upper red. Natural gas aim value decreased to 7.5 percent and coke aim value decreased by 10 lb/THM. Increased moisture to 13 gr/SCF.
1/14/95	Furnace down for about 4.5 hours to repair mud gun and tap hole.
1/17/95	Furnace on check for one hour because of BOF slow down.
1/18/95	Furnace on check for about two hours due to filling trouble. Two extra skips of coke charged due to off-rod conditions. Coke aim value decreased by 5 lb/THM.
1/19/95	Two extra skips of coke charged due to operator error. Low blast temperature due to cold blast valve problems on No. 2 stove. One extra skip of coke per hour for six hours.
1/20/95	Coke aim value decreased by 5 lb/THM.
1/21/95	One extra skip of coke charged because of problem with coke moisture analyzer.
1/22/95	One extra skip of coke charged because of problem with coke moisture analyzer.
1/23/95	One extra skip of coke charged because of problem with coke moisture analyzer. Low blast temperature for about three hours due to burner door packing on No. 2 stove. No action taken.
1/24/95	Furnace on check several times due to problems at BOF. One extra skip of coke per hour for three hours in preparation for shutdown. Shutdown for about 13 hours to repair gas valve on No. 2 stove.

Narrative of Events

1/25/95	Continued shutdown for about 1.5 hours. Furnace back on-line at about 1:30 A.M. Four extra skips of coke charged. First cast temperature was 2,575°F. Natural gas aim value increased to 9 percent. One extra skip of coke per hour for three hours was charged due to problems with No. 3 stove.
1/26/95	Increased moisture to 8 gr/SCF and decreased natural gas aim value to 8 percent because of runner build-up. Primary coke screening was not performed.
1/27/95	Coke aim value decreased by 10 lb/THM. Furnace on check for about half an hour due to power failure.
1/28/95	Furnace shutdown for about two hours to change blowpipe.
1/30/95	Furnace on check for 14 minutes due to off-rod condition.
1/31/95	Cast temperatures in upper yellow. Natural gas aim value decreased to 8 percent. Coke aim value decreased by 10 lb/THM. Furnace shutdown at 6:50 P.M. because of BOF. Shutdown duration is about 4.5 hours as a natural gas check valve is replaced.
3/1/95	Ilmenite increased to 1.25 percent.
3/2/95	Fan problem on No. 2 stove lowered the blast temperature. Natural gas aim value increased to 9 percent to compensate. Coke aim value increased by 10 lb/THM (to 785 lb/THM). Natural gas aim value was further increased to 9.25 percent and oxygen enrichment increased to 3.5 percent in response to decreasing cast temperatures.
3/3/95	Coke aim value increased by 5 lb/THM. A top fire extinguished by smothering with pellet dump. Six extra skips of coke charged to furnace in preparation for shutdown due to BOF. Shutdown duration was about six hours.

Narrative of Events

3/5/95	Coke aim value increased by 10 lb/THM. Furnace on check for 18 minutes because of off-rod condition.
3/6/95	Coke aim value decreased by 10 lb/THM.
3/7/95	Low blast temperature due to problem with hot blast valve on No. 3 stove. Furnace shutdown for 3.5 hours because of BOF. Four extra skips of coke charged in preparation for scheduled shutdown.
3/8/95	Four extra skips of coke charged in preparation for scheduled shutdown. One extra skip of coke charged because of drop in blast temperature due to fan fire in No. 2 stove. Furnace on check for 15 minutes because of runner problem. Furnace shutdown at 9:40 A.M. for about eleven hours.
3/9/95	Cast temperatures in upper red. Natural gas aim value decreased to 7.25 percent. About five hours later, coke aim value decreased by 10 lb/THM.
3/10/95	Coke aim value decreased by 10 lb/THM. Natural gas aim value increased to 7.5 percent.
3/11/95	Coke aim value decreased by 10 lb/THM.
3/12/95	Coke aim value decreased by 10 lb/THM. Four extra skips of coke charged in preparation for shutdown. Furnace down at 6:20 P.M. because of hot blast valve on No. 3 stove.
3/13/95	Shutdown until 8 A.M. Five extra skips of coke charged because of trouble raising blast temperature. Natural gas aim value maintained at 7.75 percent during start-up.
3/14/95	Cast temperatures in lower yellow. Increase natural gas aim value to 9 percent. Coke aim value increased by 10 lb/THM. Natural gas increased to 9.25 percent. Thirteen extra skips of coke charged. Coke aim value increased by 5 lb/THM.

3/15/95	Cast temperatures in upper yellow. Gradual decrease in natural gas aim values to 8 percent.
3/16/95	Cast temperatures in upper red. Natural gas aim value at minimum of 7.5 percent. Moisture increased to 11 gr/SCF. When stabilized, blast temperature decreased due to faulty cold blast valve on No. 3 stove. One extra skip of coke per hour charged for seven hours. Natural gas aim value increased to 8.25 percent
3/17/95	Furnace put on twelve-minute check because of top fire.
3/20/95	Furnace put on twenty-minute check because of top fire. Coke aim value increased by 10 lb/THM.
3/21/95	Furnace shutdown for about 5.5 hours because of a hole in Bishoff.

DESCRIPTION OF EVENTS IN RAMP-UP TO 200 LB/THM PERIOD

3/22/95	Coke aim value decreased by 20 lb/THM (to 755 lb/THM) in preparation for increasing the natural gas operating range and aim value. New range is between 9.75 to 11.25 percent. Oxygen enrichment increased to 4 percent. Natural gas aim value increased to 11 percent 4.5 hours later.
3/23/95	Coke aim value decreased by 10 lb/THM.
3/24/95	Furnace put on eight-minute check because of top fire.
3/25/95	Furnace put on 21-minute check because of top fire.
3/27/95	Cast temperatures in lower yellow. Natural gas aim value increased to 11.25 percent and coke aim value increased by 10 lb/THM.
3/28/95	Furnace put on six-minute check because of top fire. Coke aim value increased by 5 lb/THM. Four extra skips of coke charged in

	preparation for extended scheduled shutdown. Furnace shutdown at 11:10 P.M.
3/29/95	24-hour shutdown. Scheduled work included a complete trough rebuild and upgrade of the supplemental oxygen injection system. Top fire detection and suppression system installed.
3/30/95	Furnace back on-line at 8:30 A.M. Furnace on check for one hour due to off-rod condition. Decrease in blast temperature due to gas valve problem on No. 2 stove. One extra skip of coke per hour for seven hours. Burden changes on the B furnace in preparation for blow down.
3/31/95	Cast temperatures in upper red. Natural gas aim value gradually decreased to 9.75 percent and coke aim value decreased by 5 lb/THM. Moisture increased to 12 gr/SCF. Scrap removed from the B furnace to stockpile for the A furnace.
4/1/95	Moisture gradually reduced. Cast temperatures steadily dropped. Two extra skips of coke charged. Natural gas aim value maintained at 9.75 percent. Scrap increased by 1 percent (to 5 percent). Incremental reduction in the natural gas injection rate on the B furnace is initiated. Oxygen enrichment on the B furnace is decreased by 1 percent.
4/2/95	Coke aim value decreased by 10 lb/THM. Scrap increased to 6 percent.
4/3/94	Blast furnace (BF) fines increased to 4 percent.
4/4/95	Coke aim value decreased by 15 lb/THM. Oxygen enrichment increased to 4.5 percent. Natural gas and oxygen taken off the B furnace.
4/5/95	Furnace on check for 46 minutes because of filling trouble and off-rod condition. One extra skip of coke charged because of off-rod condition.

Narrative of Events

4/6/95	Oxygen enrichment increased to 5 percent.
4/7/95	Oxygen enrichment increased to 6 percent. B furnace blown down at 10:45 P.M.
4/8/95	Top fire detected. Natural gas and oxygen shutoff for three minutes. Furnace on check for 22 minutes because large bell hung open. Burden movement in furnace is faster since the addition of more oxygen.
4/9/95	Difficulty in maintaining stockline. Four extra skips of coke charged because of off-rod condition. Record production of over 4,600 tons of hot metal from 132 charges.
4/10/95	Low blast temperature due to fan problem on No. 3 stove. 5,000 lbs of self-flux pellets included with stone skip.
4/13/95	Loss of oxygen for about 1.5 hours. Natural gas aim value maintained at 12 percent.
4/14/95	Loss of oxygen for about 4.5 hours. Natural gas aim value maintained at 11.5 percent. Slip occurred causing excessive high top gas temperature. Blast pressure increased to between 29 and 32 psi. Coke screening time increased.
4/15/95	Furnace down for about 4.5 hours because of ore car problem.
4/16/95	Loss of oxygen on two occasions, each lasting about one hour. Natural gas was shut off during each event.
4/17/95	Coke aim value decreased by 10 lb/THM (to 710 lb/THM).
4/18/95	Oxygen enrichment increased to 6.5 percent. Coke oven gas removed from stove firing. Clean blast furnace gas is the only source.

DESCRIPTION OF EVENTS IN 200 LB/THM PERIOD

4/25/95	Coke aim value increased by 5 lb/THM (to 715 lb/THM).
4/26/95	Oxygen enrichment increased to 7 percent. Natural gas operating range increased to between 12.5 and 14 percent. Coke aim value decreased by 5 lb/THM. Wind at 97 mscfm to avoid high blast pressure.
4/27/95	Coke plant produced low-stability coke.
4/28/95	Coke aim value decreased by 5 lb/THM. Cast temperatures drifted toward lower yellow. Natural gas aim value increased to 14 percent. Coke aim value increased by 10 lb/THM.
4/29/95	Coke aim value increased by 5 lb/THM. Eight extra skips of coke charged because of low cast temperatures.
5/1/95	Work on the rail bridge at the coke-plant side of the highline forced coke to be transported by truck to the ore field and retrieved by front end loader to a conveyor. At the same time, bin work at the B furnace highline side prevents the use of the screener-in-the-sky for pellet screening.
5/2/95	Coke aim value increased by 70 lb/THM in preparation for extended scheduled shutdown on 5/3. Reduction in the natural gas aim value commenced about five hours later. Furnace down for four hours because of mud gun.
5/3/95	Furnace shut down at 6:50 A.M.
5/4/95	Attempted to restarted furnace at 11:15 A.M. Runner build-up and a burnt tuyere forced furnace to shut down again. Restarted at 10:35 P.M. Coke aim value decreased by 35 lb/THM (to 755 lb/THM).

Narrative of Events

5/5/95	Furnace shutdown for five hours for runner clean-up. Furnace on check numerous occasions because of runner build-up.
5/6/95	Emergency Action A taken. Ten extra skips of coke charged.
5/7/95	Coke aim value decreased by 10 lb/THM. Furnace on numerous check time because of maintenance related work.
5/9/95	Scrap increased to 7 percent. Oxygen enrichment increased to 7.5 percent. Coke aim value decreased by 10 lb/THM.
5/10/95	Coke aim value decreased by 10 lb/THM.
5/11/95	Coke aim value decreased by 15 lb/THM. Scrap increased to 8 percent. Oxygen enrichment increased to 8 percent. Wind rate at 94 mscfm due to high blast pressure. Two top fires detected.
5/12/95	Coke aim value decreased by 10 lb/THM to 700 lb/THM, which is a record low.
5/13/95	Cast temperatures in lower yellow. Natural gas aim value gradually increased from 12.75 to 13.75 percent.
5/14/95	Pellet chips removed from burden due to concern with continued high blast pressure. Coke aim value increased by 20 lb/THM because of depressed cast temperatures.
5/17/95	Twelve extra skips of coke charged in preparation for scheduled eight-hour shutdown. Furnace shut down at 10:15 A.M. for about 9.5 hours.
5/19/95	Coke aim value decreased by 10 lb/THM. Numerous furnace checks due to off-rod conditions. Top fire detected.
5/20/95	Coke aim value decreased by 10 lb/THM. 30,000 lbs of pellet chips dumped to extinguish top fire. Furnace on check for 36 minutes due to filling trouble.

Narrative of Events

5/21/95	Coke aim value decreased by 10 lb/THM to 690 lb/THM, which is a new record low. Coke screening problems increased blast pressure. Wind rate cut to 95 mscfm. Line pressure in the natural gas supply line increased to 175 psig.
5/22/95	Cast temperatures in lower yellow. Natural gas aim value steadily increased from 12.5 to 14.25 percent, which is new maximum.
5/23/95	Problems with stove fan on No. 1 stove drop blast temperature. Extra skips of coke charged to compensate for low blast temperature and for off-rod condition. Coke aim value increased by 5 lb/THM.
5/24/95	Two top fires detected.
5/25/95	Furnace down for about one hour to repair bell rod. Coke aim value decreased by 5 lb/THM. Problems with coke moisture analyzer detected.
5/26/95	Top fire detected.
5/27/95	Coke aim value decreased by 5 lb/THM to 685 lb/THM, which is a new low. One extra skip of coke charged due to low top temperature. Heavy rain during late afternoon.
5/29/95	Coke aim value decreased by 5 lb/THM to 680 lb/THM, which is a new low. Cast temperatures trend downward. Natural gas aim value increased to 15 percent. Top fire detected.
5/30/95	Cast temperatures in lower yellow. Coke aim value increased by 10 lb/THM. Emergency Action A taken. Two extra skips of coke per hour charged for nine hours. Natural gas aim value increased to 15.5 percent. Oxygen enrichment increased to 8.5 percent. Coke moisture analyzer went down at 3 P.M. Coke weight on wet basis.

5/31/95	Coke moisture analyzer repaired at 10:30 A.M. Numerous top fires throughout day. Natural gas aim value cut to 7 percent to halt top fire at 5:55 P.M. Two steam lines burnt. Furnace shutdown at 6:40 P.M. to replace steam lines to furnace top. Natural gas returned to previous aim value at 7:50 P.M.

DESCRIPTION OF EVENTS IN RAMP-UP TO 250 LB/THM PERIOD

6/1/95	Gravel reduced by 100 lb per charge. Coke aim value increased by 5 lb/THM. Top fire detected.
6/2/95	Coke aim value increased by 5 lb/THM. Top fire detected.
6/4/95	Top fire detected.
6/5/95	Nut coke decreased from 50 to 20 lb/THM to improve burden permeability.
6/7/95	Eight extra skips of coke charged in preparation for scheduled shutdown. Wind curtailed too fast and as a result, slag was backfilled into blow pipes. Scheduled outage extended to clean and change blow pipes. Blast temperature slow to come back up. Four extra skips of coke charged. Natural gas aim value increased to 14.75 percent and oxygen enrichment increased to 8 percent. Frequent top fires detected after start-up.
6/8/95	Cast temperatures in lower yellow. Coke aim value increased by 10 lb/THM. Two extra skips of coke charged per hour for six hours as preventive measure. Numerous top fires occurred. Cut natural gas aim value to 7.5 percent and oxygen enrichment to 4 percent. High top pressure. Furnace shutdown at 4:15 P.M. to repair Bishoff and change one tuyere. Top fire prevention system modified. Steam continuously on between bells. Thermocouple sensor added. Repositioned steam lances in receiving hopper and steam injected only in the presence of fire.

Narrative of Events

6/9/95	One extra skip of coke charged per hour for eleven hours as preventive measure. Furnace down to change natural gas injection lance and versa valve. Natural gas aim value increased to 13 percent and oxygen enrichment increased to 8 percent. Coke aim value increased by 25 lb/THM. Nut coke increased to 50 lb/THM.
6/10/95	Coke aim value decreased by 20 lb/THM. Nut coke reduced to 20 lb/THM. Oxygen enrichment increased to 8.5 percent.
6/11/95	Coke aim value decreased by 10 lb/THM. Oxygen enrichment increased to 9 percent.
6/12/95	Coke aim value decreased by 5 lb/THM at 12 A.M. Cast temperatures trended downward. Natural gas aim value maximized at 13.75 percent. Emergency Action A taken and natural gas aim value further increased to 14.75 percent. Wind cut to 88 mscfm. Coke aim value increased by 10 lb/THM. Highline work completed. Double handling of coke eliminated and pellet screening resumed.
6/14/95	Furnace on check on several occasions due to off-rod conditions. Furnace shutdown for one hour to change burnt tuyere. Natural gas aim value increased to 15 percent.
6/15/95	Cast temperatures in upper red. Coke aim value decreased by 15 lb/THM. Natural gas injection operating range increased to between 13 and 16 percent. Natural gas aim value gradually decreased to 14 percent.
6/16/95	Oxygen enrichment dropped to 4 percent at 12:15 A.M. for ten minutes. Natural gas aim value cut to 7 percent for duration. Reset aim values at 12:30 A.M. Coke aim value decreased by 5 lb/THM. Furnace on check for twenty minutes because of off-rod and hanging conditions. Furnace shutdown for about 1.5 hours to grease line to bell rod.

6/20/95	Natural gas and oxygen turned off at 1:15 A.M. for one hour to slow furnace down because of tap hole drill problem.
6/21/95	Cast temperatures trend upward to upper red. Natural gas aim value decreased to 14.75 percent and coke aim value decreased by 5 lb/THM. Moisture maintained at 6 gr/SCF.
6/22/95	Furnace shutdown for about 4.5 hours due to a iron ladle derailment. Cast temperatures trended downward to lower red. Natural gas aim value increased to 16 percent.
6/23/95	Cast temperatures in lower yellow. Coke aim value increased by 5 lb/THM. Natural gas aim value increased to 16.25 percent and oxygen enrichment increased to 9.5 percent. Six extra skips of coke charged as insurance. Coke aim value increased by another 5 lb/THM.
6/24/95	Natural gas aim value increased to 16.5 percent as cast temperature trended downward.
6/26/95	Furnace on check for about one hour due to mud gun trouble.
6/27/95	Furnace shutdown for scheduled trough work at 9 A.M. Shutdown duration is about 7.5 hours.
6/28/95	Furnace on check for about 1.5 hours due to off-rod condition. Minor slip and hang detected.
6/29/95	Switched to No. 5 turbo blower because of bearing maintenance work on No. 4 turbo blower. Excessive vibrations on No. 5 turbo blower and wind rate limited to 83 mscfm. Switched back to No. 4 turbo blower 6.5 hours later. Cast temperatures trended downward to lower yellow and no movement was made.
6/30/95	Cast temperatures in upper yellow. Coke aim value decreased by 10 lb/THM. Natural gas aim value gradually decreased to

15.5 percent. Furnace on check for about one hour due to fill trouble and off-rod condition. Top fire detected.

7/1/95 Cast temperatures in upper red. Coke aim value decreased by 10 lb/THM to 675 lb/THM, which is a new low. Natural gas aim value gradually decreased to 14 percent. Furnace on check for about one hour due to fill trouble, hanging, and off-rod conditions.

7/2/95 Cast temperatures trend downward and stay in lower yellow. Natural gas aim value is steadily increased to 16.75 percent. Natural gas and oxygen shut off at 7 P.M. for two hours.

7/3/95 First cast temperature in lower red. Wind cut to 90 mscfm to slow down furnace. Furnace running "tight," indicating a low fuel rate. Natural gas aim value increased to 17 percent. Coke aim value increased by 15 lb/THM. Oxygen enrichment increased to 10 percent. Blast temperature drops at 9:45 A.M. because of burner door problem on No. 2 stove. At 3:30 P.M., scrap is reduced to 4 percent and the coke aim value is increased by 40 lb/THM. Blast temperature drops to 1,675°F and eventually to 1,550°F. One extra skip of coke per hour is initiated. Natural gas aim value increased to 18 percent and oxygen enrichment increased to 10.5 percent.

7/4/95 Wind cut to 81 mscfm. Coke aim value increased by 10 lb/THM. Emergency Action A taken as the blast temperature begins to recover. Cast temperature recovers. Natural gas aim value reduced to 17 percent and oxygen enrichment decreased to 10 percent. Wind back to 95 mscfm at 3:35 P.M.

7/5/95 Blast temperature dropped to 1,600°F because of crack in dome in No. 1 stove. Blast temperature recovered at 12:40 P.M. No moves made to natural gas or oxygen. Three extra skips of coke charged. Wind increased to 98 mscfm.

Narrative of Events

7/6/95	Cast temperatures in upper yellow. Natural gas aim value gradually decreased to 15 percent. Oxygen enrichment maintained at 10 percent. Top fire detected.
7/7/95	Cast temperatures in upper yellow. Natural gas aim value decreased to 14.25 percent. Coke aim value decreased by 10 lb/THM.
7/11/95	B furnace blown in at 2:30 A.M.
7/14/95	B furnace tapped.
7/16/95	Natural gas decreased to nominal rate of 150 lb/THM on A furnace.

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