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LABILITY OF MINING WASTES AND THEIR NTIAL FOR USE AS HIGHWAY MATERIAL

Vol. I. Classification and Technical and Environmental Analysis

May 1976

Final Report

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16. Abstract

This study was performed to determine the availability of mining and metallurgical wastes in the United States and to assess their potential for use in various aspects of highway construction. A comprehensive literature survey was performed to develop information on locations, amounts, compositions, and uses of various mining and metallurgical wastes. Knowledgeable personnel in the mining industry, governmental agencies, trade associations, and universities were contacted to obtain additional unpublished information. The information was used to inventory, classify, and evaluate these wastes.

Over 1.6 billion tons of mining and metallurgical wastes are produced each year. Although a small percentage of all this material is actually being used, a number of mining and metallurgical wastes have been successfully utilized as highway construction material. A number of other mineral wastes are potentially useful with some degree of processing. Materials most highly recommended for use in highway construction are gold gravels, steel slag, lead-zinc chat, phosphate slag, taconite tailings, copper slag, and waste rock from the mining of copper, fluorspar, gold, and iron ore.

This is the first of three volumes. Volume II, published as FHWA-RD-76-107, is subtitled "Location of Mining and Metallurgical Wastes and Mining Industry Trends." Volume III, published as FHWA-RD-76-108, is subtitled "Annotated Bibliography."

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PREFACE

This is the first volume 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 Messrs. Robert J. Collins and Richard H. Miller. The investigation was accomplished under the supervision of Mr. Robert J. Collins.

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. Dr. Dean also furnished useful information pertaining to the technical and environmental properties of specific mineral wastes.

The mapping and tabulation of mining and metallurgical wastes on a state by state basis was accomplished with the assistance of Messrs. George T. Kraus and Marc J. Steinbring. The maps and figures in this volume of the report were prepared by Mr. Jeff Amerine.

Evaluation of waste samples was performed by Drs. Stanley K. Ciesielski, William B. Fergusson, and Edward M. Wallo and Messrs. Robert J. Collins, Richard Hollinger, and Richard H. Miller. A 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. BACKGROUND

Mining operations represent one of the largest sources of solid waste in our society. For the most part, these wastes are found in huge, unsightly heaps which are barren of plant life. Because they are essentially rock-like or earthen in nature, they represent material having potential for use in highway construction.

Although some of these wastes have been used in embankments and base courses, they have commonly been avoided in favor of conventional soils and aggregate materials. Because of the increasing scarcity of conventional materials in certain sections of the country and the overall abundance of mining wastes, a need exists to survey the kinds, locations, quantities, and general nature of mining and metallurgical wastes and to assess their potential for possible highway engineering use.

A concerted effort is needed to provide the highway engineer with practical information concerning these materials before any extensive use of them is possible. In some cases, certain mining and metallurgical wastes may be a better material to use in a specific application than conventional materials. There are also instances where use of these materials may result in cost savings.

Furthermore, the use of such solid wastes will reduce the degree of pollution, improve the general aesthetic character of the landscape, and make land available for more natural or profitable uses.

2. OBJECTIVES

The objectives of this project were to:

1. Determine the types, locations, amounts, and compositions of mining and metallurgical wastes in the contiguous United States.

2. Determine the extent of current and past usage of these wastes in highway construction.

3. Evaluate the potential for use of these wastes in various aspects of highway construction.

3. RESEARCH APPROACH

To achieve the objectives of this study, the work was conducted in four distinct tasks:

Task A - Review Literature Pertaining to Mining and Metallurgical Wastes

Task B - Collect Unpublished Information From Mining Experts and Highway Engineers

Task C - Inventory, Classify, and Evaluate Mining and Metallurgical Wastes

Task D - Recommend Further Research and Utilization of Mining and Metallurgical Wastes in Highway Construction

The general procedures used in the performance of each of the above tasks are described in this section. Successive sections of the report will discuss the findings, conclusions, and recommendations resulting from this work.

Task A - REVIEW LITERATURE PERTAINING TO MINING AND METALLURGICAL WASTES

A thorough review was made of available domestic and foreign literature pertaining to mining, mineral processing, metallurgy, ceramics, aggregate production, highway construction, and highway research. This review focused on published information pertaining to:

1. Types, locations, and quantities of various mining and metallurgical waste materials.

2. Prior uses of these waste materials in highway construction.

3. Additional uses of mining and metallurgical wastes.

4. Research and development efforts aimed at converting these wastes into useful products.

Information sources that were consulted during this and other phases of the study included:

Information Retrieval Services

Highway Research Information Service (HRIS)

National Technical Information Service (NTIS)

Solid Waste Information Retrieval Service (SWIRS)

<u>Government and Industry-Related Publications</u>

Keystone Coal Industry Manual (McGraw-Hill)

Mineral Facts and Problems (U.S. Bureau of Mines)

Minerals Yearbook, 1972 - Volumes I and II (U.S. Bureau of Mines)

Proceedings of the First International Tailing Symposium

Proceedings of First through Fourth Mineral Waste Utilization Symposia (U.S. Bureau of Mines and Illinois Institute of Technology Research Institute)

Proceedings of the First Technical Conference on Coal and the Environment (National Coal Association)

Skillings Mining Review

Transportation Research Board Records and Bulletins

U.S. Bureau of Mines Information Circulars and Reports of Investigations

U.S. Department of Health, Education, and Welfare reports

U.S. Environmental Protection Agency reports

<u>Technical and Industrial Periodicals</u>

American Ceramic Society Bulletin

Brick and Clay Record

Chemical Engineering

Chemistry and Industry

Civil Engineering

Coal Age

Construction Methods and Equipment

Engineering and Mining Journal

Engineering News-Record

Highway Research News

Iron Age

Mine and Quarry

Mining Congress Journal

Mining Engineering

Pit and Quarry

Roads and Streets

Rock Products

Related Miscellaneous Reports

A number of reports pertaining to mining and metallurgical wastes were prepared by private consultants or study commissions for mining companies or governmental agencies, such as the Appalachian Regional Commission, National Academy of Sciences, and the National Commission on Materials Policy.

Reports such as these were received at different times during this project from a variety of sources. These reports involved a wide range of subjects, from detailed marketing analysis of specific waste uses to broad studies of potential alternatives for mineral waste disposal. All applicable published material from the above sources was reviewed and evaluated. The end result of this phase of the work was the compilation of an annotated bibliography, containing a summary of eighty of the most pertinent of the publications reviewed. This bibliography will be published as a separate report in connection with this project.

Task B - COLLECT UNPUBLISHED INFORMATION FROM MINING EXPERTS AND HIGHWAY ENGINEERS

Besides reviewing the published information previously cited, a great deal of additional unpublished information on mining and metallurgical wastes was also obtained from knowledgeable sources. These sources included, but were not necessarily limited to, the following:

1. All major metal, non-metal, and coal mining companies.

2. All major steel companies and slag processors.

3. State highway officials and materials engineers in thirty-five states having significant mining activity.

4. State geologists, environmental, and mining officials in thirty-five states having significant mining activity.

5. U.S. Bureau of Mines State liaison officers in thirty-five states having significant mining activity.

6. Universities having mining engineering, civil engineering, or environmental engineering schools.

7. Trade associations, such as the National Slag Association and the National Coal Association.

8. Members of the Mineral Waste Stabilization Committee, comprised of a cross-section of government and industry representatives whose aim is to reduce the impact of mining wastes on the environment.

All of the above sources were initially contacted by letter in order to obtain some or all of the following information:

1. Locations and estimated quantities of mining and/or metallurgical wastes accumulated or produced annually.

2. Description of specific waste materials, including physical properties and chemical compositions.

3. Known current or previous uses of these waste materials in highway construction.

4. Unpublished data on the performance of these waste materials in specific highway construction applications.

5. Other possible uses for these wastes.

6. Information on the probable cost of retrieving, processing, and transporting mining and/or metallurgical wastes.

Material samples were requested from the largest mining and slag producing operations, representing a cross-section of the basic types of available mining and metallurgical wastes. A total of 85 samples were received and evaluated later in the study.

Responses were catalogued according to source and state. Follow-up letters were sent when no response was received or when additional contacts were suggested. A number of respondents were further contacted by telephone.

Several mining and slag-producing operations were visited during the course of the study. Responsible individuals at these locations were contacted personally in order to obtain a first-hand industry perspective on the generation, disposal, and possible uses of the waste materials. In several instances, these personal contacts were initiated by industries having a particular interest in the utilization of their solid wastes. Visits were made to the following locations:

1. Anthracite coal refuse - Louis Beltrami & Associates, Eckley, Pennsylvania

2. Bituminous coal refuse - Consolidation Coal Corporation, Osage, West Virginia

3. Bituminous coal refuse - U.S. Steel Corporation, New Eagle, Pennsylvania

4. Copper mill tailings - Cities Service, Inc., Miami, Arizona

5. Iron ore tailing - Bethlehem Mines, Morgantown, Pennsylvania

6. Steel slag - Jones & Laughlin Steel Company, Aliquippa, Pennsylvania

7. Zinc mill tailings - New Jersey Zinc Company Center Valley, Pennsylvania

8. Zinc smelter residue - New Jersey Zinc Company, Palmerton, Pennsylvania

Contacts were also made with a number of contractors whose business includes the processing and marketing of by-products, such as blast furnace slag, steel slag, iron ore waste rock, copper smelter slag, and zinc smelter residue. Much useful information was obtained from these contacts concerning the processing techniques used, quantities sold, predominant uses, and problems associated with marketing and transportation.

Task C - INVENTORY, CLASSIFY, AND EVALUATE MINING AND METALLURGICAL WASTES

The work performed in this task was aimed at:

1. Organizing the information received in the previous tasks into a systematic classification system of mining and metallurgical wastes.

2. Using all information at hand to evaluate the use potential of these wastes according to the technical, economic, and environmental factors involved.

The waste materials identified in this study were classified according to their industrial source and physical state. A complete description of this classification system is made in Chapter 4 of this report.

In most cases, the physical properties of a particular material generated from different industrial sources were found to be quite similar, due to the fact that the basic mineral processing techniques involved are essentially the same throughout the mining industry. Where information was available, the geologic source of the waste material was also included in the classification process.

An inventory of mining and metallurgical wastes was conducted and is presented in separate sections of this report. Much of the input in this phase of the study was provided by responses from the producers of the wastes themselves, supplemented by known information provided by our geologist and mining consultant.

In Chapter 4, an inventory is made of the total estimated quantities of mining and metallurgical wastes according to industrial source and physical state. In Volume II of this report, a more detailed presentation is made on an individual State basis of the occurrence of specific accumulations of mining and metallurgical wastes. A total of thirty-five states are included in this inventory. These states were judged to be the states having significant levels of mining and/or metallurgical activity.

The evaluation of mining and metallurgical waste materials for use in highway construction was performed in three quite distinct, but coordinated, phases. These three evaluative phases involved a consideration of the technical, environmental, and economic aspects of utilizing each of these materials in some phase of highway construction.

A technical evaluation of the physical, chemical, and engineering properties of specific waste materials was performed by an evaluation team which consisted of two soils engineers, a geologist, an asphalt paving specialist, and a Portland cement concrete specialist. Individual materials were evaluated for particular uses in highway construction by physical inspection of material samples, records of past performance, and consideration of known physical and chemical properties as determined in the previous tasks. The potential usefulness of each material for embankments, base or sub-base, asphalt paving, or Portland cement concrete was determined.

The Franklin Institute Research Laboratories was primarily responsible for conducting an evaluation of the environmental factors involved in the present disposal and potential highway use of specific mining and metallurgical wastes. The overall approach first involved an identification of current environmental problems associated with disposal of certain mining and metallurgical wastes. The principal focus of the environmental evaluation was a determination of possible or actual air and ground water effects resulting from use of specific materials in highway applications.

An evaluation was made of the economic feasibility of utilizing mining and metallurgical wastes in highway construction. The evaluation consisted of determining the probable value of such materials, and the cost of transporting these materials by various modes, as determined by a transportation economist. Available information regarding the cost of processing such materials was also analyzed. This evaluation served to determine the economic feasibility for the use of a specific material within a certain area.

Task D - RECOMMEND FURTHER RESEARCH AND UTILIZATION OF MINING AND METALLURGICAL WASTES IN HIGHWAY CONSTRUCTION.

The results of the work performed in the three preceding tasks were reviewed and analyzed. A number of conclusions and recommendations resulting from these findings are discussed in the final chapter of this report. This chapter recommends the use of specific mining and metallurgical wastes in various highway construction applications. It also proposes areas where further research is needed in order to better identify the possible usefulness of other mining and metallurgical wastes for highway construction purposes.

4. CLASSIFICATION, INVENTORY, AND DESCRIPTION OF MINING AND METALLURGICAL WASTES

The extraction and production of metals, minerals, and coal involve one or more steps within the general sphere of mining and metallurgical operations. Normally, these steps include the mining, milling, smelting, and refining of ores or minerals and the mining and preparation of coal. The number of steps involved in obtaining value from these materials is determined by the nature of the deposit and the finished form in which the mineral substance is desired. For example, copper ores must be mined, milled, smelted, and refined, while feldspar needs only to be mined and milled.

This chapter of the report will describe in some detail the nature of various types of mining and metallurgical wastes, the quantities of these materials, their sources and locations, their physical and chemical properties, and some general comments on their availability.

4.1 CLASSIFICATION OF MINING AND METALLURGICAL WASTES

Mining and metallurgical wastes evaluated during this study have been classified into five general categories as follows:

1. Waste rock is the coarse material which is broken and removed during metal and non-metal mining operations to expose the ore. Waste rock is more or less homogeneous at each mining operation, but can vary widely in nature from one mine to another. The size of the rock is also variable, but individual pieces are normally twelve inches (305 mm) or less in size.

2. Mill tailings are the finely divided materials which are discarded from the concentration and recovery of mineral values from metallic and nonmetallic ores. These tailings are characterized by fine particle sizes and a widely varying chemical and mineralogical composition from one mill location to another. The finer fractions are normally disposed into impoundments in a slurry form. The relative quantity and physical characteristics of mill tailings are dependent on the percentage of mineral value contained in the ore and the mineral processing techniques employed in separating the mineral from the parent rock.

3. Coal refuse refers to the reject material produced during the preparation and washing of coal. This reject material ranges in particle size from four inches (101.6 mm) down to finer than 200 mesh (.074 mm) and is composed principally of shale, slate, clay, and variable amounts of coal. Coal refuse is found primarily in a solid form, although the finer fractions are disposed of as a slurry.

4. Smelter slags are the molten by-products from the smelting or sintering of metallic ores, principally iron and steel, copper, lead, nickel, phosphate, and zinc. These materials exhibit a high degree of hardness and porosity and vary in unit weight and chemical composition. Included among these materials are the slags from iron blast furnaces, various types of steel furnaces, and the slags from the smelting of metallic ores such as copper, lead, zinc, phosphate, and nickel.

5. Washery rejects refer to the large quantities of muds, sludges, and/or slimes produced during the refining of crude bauxite and pebble phosphate ores. These wastes are disposed of in a slurry form at very low solids contents and, even after prolonged drying periods, still generally exist in a semi-solid state.

4.2 INVENTORY OF MINING AND METALLURGICAL WASTES

The volume of wastes produced each year by the mining and metallurgical processing industries is staggering. It is estimated that over 1.6 billion tons (1,450 Mtonne) of mineral wastes are being generated annually in the United States. In addition, there are literally mountains of solid wastes which have accumulated in various parts of the country from many years of past disposal from the mining industry.

As our demand grows for products derived from mining and metallurgical activity, so also will the amount of solid waste produced by these industries. Because of the gradual depletion of higher grade ores and increased material handling requirements for mining suitable deposits, the future amount of mining wastes generated per ton of finished product will also increase. Therefore, an increase in the rate of future production of mineral wastes in the United States is anticipated.

The location and amounts of various categories of mining and metallurgical wastes are extremely important in determining their potential for use as construction material. Figure 1 shows the locations of the most significant deposits of mining and processing wastes. Coal refuse locations are shown in Figure 2. Figure 3 indicates the locations of major producers of iron and steel slag. Figure 4 shows the locations of primary metal smelting facilities.

It is useful to determine in which basic mineral industries and in which states the most significant quantities of these wastes are produced. This data will indicate where the most sizeable amounts of materials that should be considered for further evaluation as highway construction material are most likely to be found. Specifically excluded from this analysis of mining and metallurgical wastes are the wastes produced by the crushed stone and clay industries.

Table 1 is a tabulation of the estimated amounts of material handled and marketable product for basic mineral industries producing the largest annual waste volumes. Table 2 is an inventory of the estimated amounts of specific mining and metallurgical wastes produced by these industries. The tables are based upon information published by the United States Bureau of Mines in its 1972 Minerals Yearbook, supplemented by information derived from the literature review and responses received from numerous mining firms throughout the country.

Because of the gross quantities involved, it must be remembered that these figures are simply estimates which are intended to illustrate the relative amounts of solid wastes produced by each basic industry. It should not be assumed that the accumulated and annually produced tonnages of materials indicated in these tables are all presently available for potential use.

Table 3 summarizes the present rate at which various mining and metallurgical wastes are currently being generated in terms of the amount of waste produced per ton of finished product. This information is helpful in attempting to project the future generation of solid waste from each mineral industry. These generation rates represent industry-wide averages. Because of substantial variations in the type of ore, its mineral content, and the degree of processing employed at different locations, waste generation characteristics at any particular mining location may deviate somewhat from the average figures shown.

Figure 1. Locations of Mining and Processing Wastes

Figure 2. Location of Coal Refuse

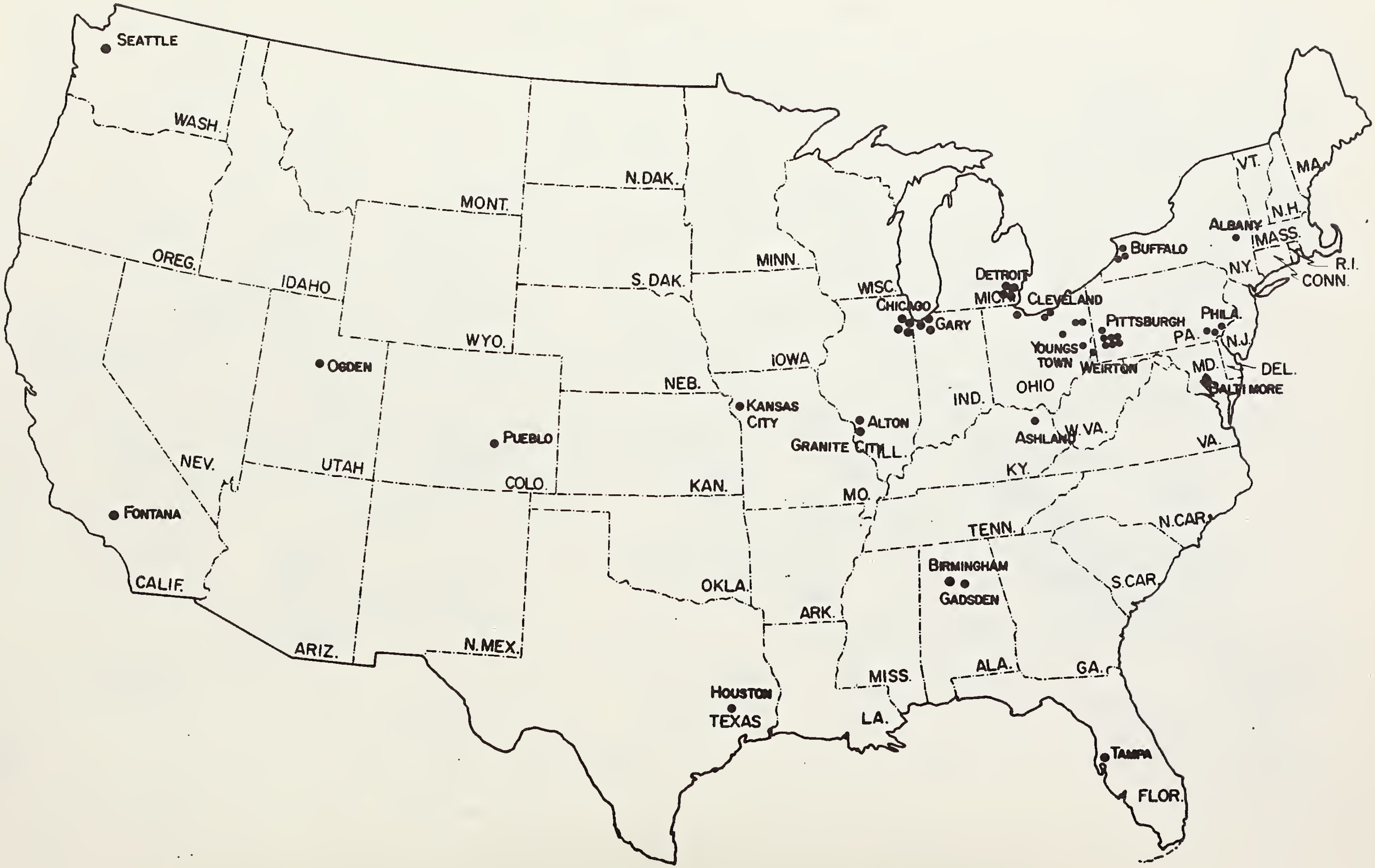

Figure 3. Location of Blast Furnace and Steel Making Slags

Figure 4. Existing Domestic Smelter Locations

Table 1. Material handled annually and marketable product for basic mineral industries.

Mining Industry	Total Material Handled (thousand tons)	Total Ore Treated (thousand tons)	Total Marketable Product (thousand tons)	Percent Of Ore Marketed
METALS				
Bauxite	11,800	2,560	2,027	79
Copper	955,000	267,000	1,640	0.2
Gold	21,500	5,090	38[1]	0.0007
Iron	377,000	210,000	87,136	41
Lead	10,100	9,560	563	6
Silver	849	648	467[1]	0.07
Uranium	178,000	6,390	13	0.2
Zinc	9,150	8,220	348	4
NON-METALS				
Asbestos	3,060	2,300	132	6
Barite	6,390	4,270	906	21
Feldspar	1,770	1,560	646	41
Fluorspar	655	654	250	38
Gypsum	28,200	12,500	12,300	98
Phosphate	382,000	125,000	40,600	32

[1]Amount in tons.

SOURCE: U.S. Bureau of Mines, Minerals Yearbook, Volume I, 1972 (117).

NOTE: 1 short ton =0.9072 metric tons.

Table 2. Mining and metallurgical wastes produced annually, in thousand tons.

Mining Industry	Waste Rock[1]	Mill Tailing	Smelter Slag	Washery Reject	Estimated Total Waste Accumulation
METALS					
Alumina	9,200	100	--	6,000	50,000
Copper	688,000	260,000	4,000	--	8,500,000
Gold	16,000	6,000	--	--	500,000
Iron Ore	30,000	30,000	--	--	800,000
Lead	600	9,000	500	--	200,000
Nickel	--	--	750	--	15,000
Silver	200	650	--	--	Uncertain
Taconite	110,000	120,000	--	--	4,000,000
Uranium	172,000	6,400	--	--	125,000
Zinc	1,000	7,900	350	--	200,000
IRON AND STEEL SLAG					
Blast Furnace	--	--	30,000	--	Uncertain
Steel Furnace	--	--	12,000	--	Uncertain

See footnotes at end of table, page 20.

Table 2. Mining and metallurgical wastes produced annually, in thousand tons (continued).

Mining Industry	Waste Rock[1]	Mill Tailing	Smelter Slag	Washery Reject	Estimated Total Waste Accumulation
NON-METALS					
Asbestos	700	2,000	--	--	15,000
Barite	2,100	3,400	--	--	25,000
Feldspar	200	900	--	--	Uncertain
Fluorspar	100	400	--	--	Uncertain
Gypsum	15,700	250	--	--	Uncertain
Phosphate	254,000	--	4,000	60,000[2]	1,000,000[3]
Slate	100	80			Uncertain
Coal		Coarse Refuse		Slurry	
Anthracite	--	500		200	1,000,000
Bituminous	--	75,000		25,000	2,500,000

[1]Includes waste rock and over burden in some operations.
[2]Includes estimated 20 million tons per year of phosphogypsum.
[3]Includes estimated 150 million tons of phosphogypsum.

SOURCE: U.S. Bureau of Mines, Minerals Yearbook, Volume I, 1972 (117).
NOTE: 1 short ton =0.9072 metric tons.

Table 3. Present generation rates for mining and metallurgical wastes.

Mining Industry	Mill Tailing[1]	Smelter Slag[2]	Washery Reject	Production of Finished Product[2] (Thousand tons)
METALS				
Alumina		----	1.0	4,903
Copper	160	2.5	----	1,594
Iron Ore	1.4	----	----	26,000[3]
Gold	170,000	----	----	1,500 troy oz.
Lead	15	0.4	----	679
Nickel	----	60	----	17
Silver	1,600	----	----	33,800 troy oz.
Taconite	2.0	----	----	57,400[3]
Uranium	500	----	----	12
Zinc	20	0.8	----	478
IRON AND STEEL SLAG				
Iron Blast Furnace	----	0.4	----	29,880
Steel Furnace	----	0.2	----	11,000
NON-METALS				
Asbestos	16	----	----	112
Barite	4.0	----	----	1,106
Feldspar	1.5	----	----	580
Fluorspar	1.6	----	----	201
Gypsum	.02	----	----	11,880
Phosphate	0.5	0.75	3.5[4]	43,374
Slate	2.0	----	----	
Coal	Coal Slurry		Slurry	
Anthracite	0.20	----	.05	
Bituminous	0.20	----	.05	601,000

[1]Refers to tons of waste per ton of finished product
[2]Latest figures from Engineering and Mining Journal
[3]Total of 83.4 million tons of iron ore produced in 1974
[4]Includes phosphate slimes and phosphogypsum

NOTE: 1 short ton =0.9072 metric tons.
1 troy ounce = 31.103 grams

A recent report published by the United States Bureau of Mines (91) identified the amount of land utilized and reclaimed by different segments of the mining industry in each state over a forty-two year period from 1930 to 1971. The findings of this investigation are summarized in Table 4, with the exception of land utilized for production of sand and gravel, crushed stone, and clay. Although no direct information on mining wastes can be determined from this table, it is useful in identifying the relative acreage in each state devoted to underground and surface mining and to waste disposal from these operations.

After reviewing these data and that from many other reports, a total of thirty-five states were selected as states having a significant amount of mining and/or metallurgical waste production and accumulation. Table 5 indicates the total estimated amount of mining and metallurgical wastes produced annually by basic mineral industries in each of these states, as derived from data presented in the 1972 Minerals Yearbook.

Volume II presents a more detailed tabulation of the description, locations, and estimated quantities of solid wastes produced at specific mining and metallurgical operations in each of these thirty-five states, together with individual maps of each state showing the type and location of the waste. This volume indicates trends in the mining industry for each state regarding opening of new facilities, anticipated closures, and planned plant expansions.

4.3 DESCRIPTION OF MINING AND METALLURGICAL WASTES

The remainder of this chapter of the report is devoted to a description of each particular classification of mining and metallurgical waste materials.

4.3.1 Waste Rock

The coarse, crushed or blocky material removed during mining and containing very little or no mineral value is termed waste rock. The amount of waste rock produced in the mining of metallic and non-metallic ores is quite variable and is dependent upon a number of factors, including the type of mine (surface or underground), shape and character of the ore body, mining methods used, and the amount of ore contained in the deposit.

Table 4. Land utilized by the mining industry in the United States from 1930 to 1971, in acres.

State	Bituminous Coal	Copper	Iron Ore	Phosphate Rock	Uranium	Other Commodities	Total
Alabama	34,900	--	7,450	--	--	280	42,720
Arizona	220	84,000	5	--	620	3,970	88,815
Arkansas	3,100	--	5	--	--	5,950	9,055
California	30	--	2,720	--	5	101,000	103,755
Colorado	8,630	30	50	--	330	17,900	26,940
Connecticut	--	--	--	--	--	150	150
Delaware	--	--	--	--	--	--	--
Florida	--	--	--	47,900	--	11,100	59,000
Georgia	40	--	370	--	--	2,640	3,050
Idaho	10	30	5	8,220	5	23,500	31,770
Illinois	234,000	--	--	--	--	900	234,900
Indiana	130,000	--	--	--	--	620	130,620
Iowa	8,600	--	--	--	--	4,110	12,710
Kansas	19,700	--	--	--	--	6,490	26,190

Table 4. Land utilized by the mining industry in the United States from 1930 to 1971, in acres (continued).

State	Bituminous Coal	Copper	Iron Ore	Phosphate Rock	Uranium	Other Commodities	Total
Kentucky	210,000	--	--	--	--	270	210,270
Louisiana	--	--	--	--	--	120	120
Maine	--	--	--	--	--	220	220
Maryland	4,610	--	--	--	--	190	4,800
Massa-chusetts	--	--	--	--	--	10	10
Michigan	560	4,800	4,700	--	--	8,980	19,110
Minne-sota	--	--	80,300	--	--	23,100	103,400
Missis-sippi	--	--	--	--	--	--	--
Montana	6,820	10,900	10	2,660	5	6,500	26,895
Nebraska	--	--	--	--	--	20	20
Nevada	--	12,800	540	--	10	20,600	33,950
New Hamp-shire	--	--	--	--	--	200	200
New Jer-sey	--	--	630	--	--	3,170	3,800
New Mexico	8,260	13,000	30	--	6,670	11,000	38,960

Table 4. Land utilized by the mining industry in the United States from 1930 to 1971, in acres (continued).

State	Bituminous Coal	Copper	Iron Ore	Phosphate Rock	Uranium	Other Commodities	Total
New York	--	--	1,830	--	--	30,900	32,730
North Carolina	--	--	5	190	--	4,670	4,865
North Dakota	27,200	--	--	--	20	10	27,230
Ohio	207,000	--	--	--	--	860	207,860
Oklahoma	13,800	340	--	--	--	2,490	16,630
Oregon	20	10	--	--	20	7,110	7,160
Pennsylvania	247,000	--	770	--	--	98,300	345,070
Rhode Island	--	--	--	--	--	370	370
South Carolina	--	--	--	--	--	1,100	1,100
Tennessee	17,900	940	20	16,220	--	2,850	37,910
Texas	770	5	1,010	--	240	8,130	10,155
Utah	3,220	38,900	3,310	1,530	20	7,340	54,320
Vermont	--	200	--	--	--	3,780	3,980

Table 4. Land utilized by the mining industry in the United States from 1930 to 1971, in acres (continued).

State	Bituminous Coal	Copper	Iron Ore	Phosphate Rock	Uranium	Other Commodities	Total
Virginia	34,800	200	--	--	--	10,500	45,325
Washington	1,370	110	5	--	350	2,330	4,165
West Virginia	196,000	--	--	--	--	70	196,070
Wisconsin	--	--	1,740	--	--	810	2,550
Wyoming	10,100	--	1,430	650	4,300	440	16,920

Total figures do not include land utilized in the production of crushed stone or sand and gravel.

SOURCE: U.S. Department of Interior, Bureau of Mines, Information Circular No. 8642. "Land Utilization and Reclamation in the Mining Industry, 1930-71" (91).

NOTE: 1 acre =0.4047 hectares.

Table 5. Estimated amounts of mining and metallurgical wastes produced annually in selected mining states, in thousand tons.

Name of State	Crude Ore Production[1]	Coal Production	Estimated Waste Production[2]
Alabama	650	19,700	5,000
Arizona	169,200	6,400	370,000
Arkansas	2,600	450	9,200
California	8,200	----	30,500
Colorado	11,000	7,000	15,000
Florida	130,200	----	206,000
Idaho	4,900	----	17,000
Illinois	700	58,100	12,500
Indiana	500	22,600	4,500
Kansas	200	680	200
Kentucky	150	136,800	25,000
Louisiana	1,000	----	500
Maryland	300	2,200	400
Michigan	32,200	----	17,200
Minnesota	138,300	----	220,000
Missouri	9,600	4,600	8,200
Montana	19,500	13,700	93,000
Nevada	21,600	----	72,500
New Jersey	4,300	----	2,200
New Mexico	44,800	9,700	113,000

See footnotes at end of table, page 28.

Table 5. Estimated amounts of mining and metallurgical wastes produced annually in selected mining states, in thousand tons (continued).

Name of State	Crude Ore Production[1]	Coal Production	Estimated Waste Production[2]
New York	2,200	----	6,000
North Carolina	1,000	----	3,400
Ohio	200	45,400	8,500
Oklahoma	1,300	2,400	6,800
Oregon	1,200	----	1,000
Pennsylvania	2,500	80,000	18,000
South Dakota	3,000	----	3,500
Tennessee	4,000	9,700	4,500
Texas	1,800	7,700	4,000
Utah	84,400	6,100	182,000
Virginia	800	34,300	7,900
Washington	500	3,900	400
West Virginia	----	101,700	20,300
Wisconsin	2,400	----	3,000
Wyoming	16,500	20,700	155,000

[1]Not including production of clay, crushed stone, and sand and gravel.
[2]Not including waste from the production of clay and crushed stone.

NOTE: 1 short ton =0.9072 metric tons.

Generally, the greatest amounts of waste rock are produced at surface mining operations, such as the open-pit copper, phosphate, uranium, and iron or taconite mines. The mining of lead, zinc, gold, gypsum, barite, feldspar, and fluorspar also results in some deposits of waste rock.

Most often, particularly in open-pit mines, the overburden material, consisting of soil and rock, is excavated and disposed in a mine waste dump along with the barren waste rock from the mine. In some operations, a large part of the material in the waste dumps is actually overburden, although it is not possible to determine the precise amounts of overburden material and waste rock from the data which is available. Therefore, the combined material found in waste dumps is often referred to simply as mine waste.

Waste rock can be quite variable in size, due to the variations in ore formations and the different mining techniques employed. Size ranges can be found from boulders on down to gravel, but only those sizes below 12 inches (305 mm) were considered as waste rock in this study. In general, it can be assumed that all sources of waste rock can be reduced to a desired gradation by normal crushing and sizing.

The value of a particular waste rock source as a useful construction material is related to the type and geological source of the parent rock formation, its hardness, and mineralogical composition, and the extent of impurities (if any) which are present. However, the manner in which ore deposits have developed in a host rock formation may alter the rock and severely affect its value as an aggregate. Table 6 outlines the basic rock types associated with predominant ore formations in the United States.

All three basic rock classifications may vary widely in their physical characteristics. In general, the igneous and metamorphic rocks are more suitable for use as aggregate, although well consolidated limestones, sandstones, and dolomites also make good aggregate. More detailed explanations of the origin and mineralogy of basic rock formations can be obtained by consulting appropriate geological references.

This section of the report describes the sources, locations, and estimated quantities of waste rock from specific mineral industries.

Table 6. Predominant ore host rocks in the United States.

Classification	Rock Type	Location	Ore
Igneous			
	Granite	Gilman, Colo.	Zinc
	Rhyolite	Pea Ridge, Mo.	Iron
	Granodiorite	Santa Rita, New Mexico	Copper
	Quartz Monzonite	Eagle Mtn., California	Iron
	Diabase	Ray, Arizona	Copper
	Quartz Monzonite	Bingham, Utah	Copper
Metamorphic			
	Taconite	Hibbing, Minn.	Iron
	Schist	Lead, South Dakota	Gold
	Hornfels	Eagle Mtn., California	Iron
Sedimentary			
	Dolomite	St. Joseph, Mo.	Lead
	Limestone	Douglas, Arizona	Copper
	Sandstone	Moab, Utah	Uranium
	Siltstone	White Pine, Mich.	Copper
	Shale	Santa Rita, New Mexico	Copper
	Oil Shale	Green River, Wyo.	Oil Shale

Copper

The amounts of waste rock and overburden generated in the mining of copper are tremendous and must be expressed in the millions of tons at each site. Kennecott Copper Corporation's Bingham Canyon mine, located at Magna, Utah, is the world's largest open-pit mine. Each year, under normal operating conditions, approximately 115 million tons (104 Mtonnes) of waste rock and overburden are added to the waste dumps.[1] Huge amounts of waste rock are also produced from open-pit mines in Arizona, the largest copper-producing state, and in New Mexico, Nevada, Montana, and Michigan.

The type of parent rock associated with copper deposits varies from one mine location to another. Many copper veins in the Southwest occur in porphyry rock formations. Copper minerals in most regions of the country are often found as copper sulfide ores in the form of chalcocite or chalcopyrite.

Copper mining is somewhat unique among metal mining operations because the recovery of additional metal values from waste materials is currently being practiced on a regular basis at most of the largest copper mines in the western United States. This practice is referred to as leaching and is well documented in the literature (99).

In order to explain this practice, it is necessary to understand the sorting process for the ore removed from the open-pit mine. Rock from "shot" holes is analyzed each day to determine the amount of copper present. If an economically recoverable amount of copper per ton of ore is present, the ore goes to the mill for pulverizing and further processing. If there is no copper present, the ore goes to the waste dump. If there is copper present in amounts less than that considered to be economically recoverable, the material goes to the leaching dump, where it is leached over long periods of time with sulfuric acid to precipitate the copper in solution.[2] At most mines, leaching dumps contain millions of tons of waste rock. Table 7 lists the copper mines where waste rock is being leached to recover copper.

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[1]Mr. D. R. Cummings, Mill Superintendent, Kennecott Copper Corporation, Utah Copper Division. Correspondence dated September 26, 1975.

[2]Mr. Noel Gillespie, Superintendent of Operations, Cities Service Company, Miami, Arizona. Personal Communication.

Table 7. Locations of copper leaching sites.

Name of Company	Name of Mine	Location	Estimated Material Being Leached
1. A.S.A.R. Co.	Silver Bell	Silver Bell, Arizona	30 million tons
2. Anaconda	Butte	Butte, Montana	33 million tons
3. Anaconda	Yerington	Weed Heights, Nevada	30 million tons
4. Cities Service	Miami	Miami, Arizona	50 million tons
5. Cyprus Johnson	Bagdad	Bagdad, Arizona	40 million tons
6. Duval	Esperanza	Sahuarita, Arizona	19 million tons
7. Duval	Mineral Park	Kingman, Arizona	5.5 million tons
8. Inspiration	Inspiration	Inspiration, Arizona	30 million tons
9. Kennecott	Bingham Canyon	Magna, Utah	4 billion tons
10. Kennecott	Chino	Santa Rita, New Mexico	425 million tons
11. Kennecott	Ray	Hayden, Arizona	185 million tons
12. Phelps Dodge	Copper Queen	Bisbee, Arizona	47 million tons
13. Phelps Dodge	Morenci	Morenci, Arizona	Not Available

SOURCE: U.S. Department of Interior, Bureau of Mines Information Circular No. 8341. "Copper Leaching Practices in the Western United States" (99).

NOTE: 1 short ton =0.9072 metric tons.

Recovery of copper from leaching dumps normally occurs over as long as a fifteen year time period. When leaching is completed, the suitability of the material for construction use would have to be determined, since the leached material would probably be acidic to some degree.

Iron Ore and Taconite

The Lake Superior mining district of Minnesota and Michigan is the primary producing area of our nation's iron ore, although there are mines with a significant amount of production in Alabama, California, Missouri, New York, Pennsylvania, Texas, Utah, and Wyoming. Natural iron oxide ores, often referred to by their characteristic colors, are identified as hematite (red), magnetite (black), and limonite (brown) iron ores. These ores contain hard, heavy minerals normally found in basic igneous or metamorphic rocks and having an iron content in the range of fifty to seventy percent.

Over the years, as some high grade iron ores became depleted, attention turned to the lower grade taconite ores principally found in the Mesabi iron range of northeast Minnesota. These ores are exceptionally hard, siliceous, banded rocks with an iron content approximately half that of the high grade iron ores. Processing technology has evolved to the point where the taconite ores now provide about seventy percent of our domestic iron ore production. (117)

At the present time, there are only five operating underground iron mines in the United States. More than ninety-five percent of all iron ore is mined from open-pit mines. These mines produce substantial amounts of overburden and waste rock. In the Minnesota taconite range, much of the waste rock is a lean, iron-bearing ore material, mostly iron oxides and iron silicates, having some future potential as a source of iron units.[3]

Some of this material is hard and blocky, while some is fine and softer. The waste rock ranges in iron analysis from fifteen to forty percent and exhibits a wide variation in

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[3]Mr. C. W. Niemi, General Superintendent, U.S. Steel Corporation, Mt. Iron, Minnesota. Correspondence dated August 11, 1975.

size range. Most of the overburden consists of glacial till mixed with unsegregated silts, clays, sands, and gravels and a few boulders. Quantities of waste rock and overburden produced at Minnesota taconite mining operations are estimated to be over 100 million tons (90 Mtonnes) annually.

The waste rock or cobber reject from high grade iron ore mining operations is usually a hard, heavy material often used in the construction of mine roads. A sample of this material is shown in Figure 5. There are several different

Figure 5. Sample of iron cobber reject (Scale in inches).

types of rock involved, ranging from diorite to rhyolite or trap rock. For example, waste rock from the Comstock mine in Utah has been reported to be mostly limestone mixed with small amounts of sandstone, conglomerate, and monzonite.[4]

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[4]Mr. James E. Hale, Resident Engineer, C. F. & I. Steel Corporation, Cedar City, Utah. Correspondence dated December 12, 1975.

In most cases, these rocks make excellent aggregate materials and have been marketed as such in many different parts of the country. An exception to this would be the waste rock or coarse reject from the processing of hematite ores in Minnesota. These materials have the undesirable characteristics of dusting, a red color, and high iron content, all of which make them a questionable source of highway material.[5]

Lead - Zinc

Since lead and zinc ores generally occur together in the same mineral formation, they will be considered together in this report. More than ninety percent of the lead-zinc ores in the United States are mined in underground mines. Therefore, the amount of waste rock produced from these mines is relatively low, compared to that produced from industries where the ore comes largely from open-pit mines.

For the most part, these ores are found in limestone and dolomitic rock formations. Some fairly large waste dumps can be found in the New Lead Belt in southeastern Missouri. There is some carbonate and chert waste rock that comprise a part of the "chat" waste piles located in the Tri-state mining district as a result of past lead-zinc mining in the Joplin, Missouri, area.

There are also some quantities of waste rock available from zinc mining in Tennessee, New York, New Jersey, Virginia, and Colorado and from lead-zinc mining in the dolomitic limestone formations of southwest Wisconsin and northwest Illinois and the carbonate rock in eastern Washington. Sometimes lead and/or zinc occur as co-products from the mining of copper, gold, or silver in such states as Idaho, Colorado, Utah, and New Mexico (117). The amount of waste rock generated at individual mines and available for possible use is probably comparably small, and would have to be more accurately determined.

Phosphate

Florida is the leading phosphorus producing state, accounting for nearly seventy-five percent of all domestic production. Phosphate deposits are also mined in North

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[5]Mr. John D. Boentje, Jr., President, Pittsburgh Pacific Company, Hibbing, Minnesota. Correspondence dated July 28, 1975.

Carolina, Tennessee, and the western states of Idaho, Montana, Utah, and Wyoming.

Nearly all of the Florida phosphate deposits are found in the land-pebble field in the central part of the state. This field is so-named because the phosphate deposits in this region occur as pebbles ranging from 1/2 inch (12.7 mm) in diameter to extremely fine-sized particles. Over 100 million tons (90 Mtonnes) of phosphate ore are mined annually in the central Florida land-pebble field.

In these deposits, the phosphate ore or matrix underlies four to sixty feet (1.2 to 18.3 metres) of overburden. In the surface mining of these deposits, the waste is composed mainly of this overburden material, which averages twenty-four feet (7.32 metres) in thickness and consists mostly of quartz sand and clay materials (115).

In other areas of the United States, phosphate rock occurs as weathered phosphatic limestones and consolidated and unconsolidated sandstones, shales, and igneous rock. These rocks contain impurities such as clay, aluminum, fluorine, and silica as quartz sand, which render them unsuitable for construction purposes.

Although huge amounts of waste are produced in the surface mining of phosphorus, these wastes are, for the most part, overburden materials with little or no associated waste rock.

Uranium

The chief sources of uranium ore in this country are found in the sedimentary rock deposits of the Colorado Plateau, an area which encompasses western Colorado, eastern Utah, northeastern Arizona, and northwestern New Mexico. These deposits are mainly sandstone and limestone rocks in which the uranium minerals occur in very small concentrations in pore fillings and along fractures.

Other uranium deposits are also being mined in Wyoming and South Dakota with some smaller deposits in California, Texas, and Nevada. In nearly all of these deposits, the uranium comprises an extremely low percentage of the deposit, on the order of 0.20 percent of uranium oxide per ton of ore.

In the mining of uranium ore, sizeable amounts of waste rock are produced, particularly in open-pit mining. Depending upon the depth of the ore zone, a tremendous amount of overburden material may also be generated during mining.

Since ore grade is such a sensitive part of uranium mining, much stockpiling and blending of material takes place prior to milling of the ore (116).

Like the copper industry, leaching techniques are also used to recover uranium from sub-grade ores and waste rock piles by means of heap leaching using acid solutions. Although leaching for uranium is not practiced to as great an extent as for copper, it does render the waste rock unavailable if it were to be considered for any further use.

Other Mineral Products

Waste rock is also produced in varying degrees from most other types of mining operations. A certain amount of waste rock is generated in the mining of asbestos, bauxite, boron, feldspar, fluorspar, gold, gypsum, and silver, but specific reports of available quantities are widely scattered and very few uses of these materials have been reported.

Principal producing areas for all of the commodities noted in this chapter can be determined by consulting the tables and state maps presented in Appendix A of this report.

4.3.2 Mill Tailings

Mill tailings are the finely graded wastes generated in the process of concentrating an ore. The basic mineral processing techniques involved in the milling or concentrating of ores are crushing and separation of the ore from the impurities. This separation is accomplished by one or more of the following methods: media separation, jigging, tabling, froth flotation, and in the case of iron and taconite ores, magnetic separation. The relative amount of ore(s) present in the gangue rock, the degree of difficulty in separating the ore from the rock, and the mineral processing techniques used in separation will determine the gradation and, to some extent, the chemical composition of the tailings.

In the final separation stages of mining and milling operations, the tailings are usually separated from the ore minerals in a wet state and are transported by pipeline in slurry form at twenty to seventy percent solids to be disposed of in tailings ponds. Dikes built for the containment of these tailings are normally constructed of waste rock and the coarse fraction of the tailings. Over a period of time, the water in the tailings ponds is recirculated or evaporated, leaving a dry or damp material.

Since tailings are essentially finely crushed rocks, their mineralogical composition generally corresponds to that of the parent rock from which the ore was derived. Tailings normally consist of various mixtures of quartz, feldspars, carbonates, oxides, ferromagnesian minerals, and minor amounts of other minerals (123).

This section on mill tailings will discuss the sources, locations, and estimated quantities of tailings from various mineral industries.

Mill Tailings - Sources, Locations, and Estimated Quantities

The largest amounts of tailings are produced as a by-product of the mining and milling of copper, iron and taconite, lead, zinc, and uranium. Other mineral processing operations that generate sizable amounts of tailings are gold, silver, molybdenum, feldspar, fluorspar, and phosphate.

The areas where the most significant production of tailings occurs are indicated in Figure 1. However, there are also many other areas throughout the country where appreciable amounts of tailings have accumulated or are being produced. These areas are shown on individual state maps presented in Volume II of this report.

The sources, locations, and quantities of mill tailings produced from several of the largest mineral extractive industries will be discussed in this chapter of the report. Subsequent chapters will focus on the current uses of these materials and an evaluation of their potential for use as a highway construction material.

Copper

Because of the extremely low percentages of copper in low grade copper-bearing ores (0.3 to 0.6 percent), nearly all of the ore processed is eventually disposed of as tailing. It is estimated that the production of copper in the United States is responsible for the generation of approximately 260 million tons (236 Mtonnes) of by-product tailings annually. This makes copper tailings the fourth most abundantly produced material in the United States, exceeded only by crushed stone, sand and gravel, and coal. The amount of copper tailings produced each year is three times greater in quantity than the annual domestic production of iron ore.

The principal copper-producing states are Arizona, where approximately fifty percent of the nation's copper is mined, Utah, Michigan, Montana, Nevada, New Mexico, and Tennessee. Over 100 million tons (91 Mtonnes) per year of copper mill tailings are produced each year in Arizona, where accumulations of this material probably exceed 4 billion tons (3.60 Gtonnes). There have been mountains of waste rock and tailings deposited from copper mining in Arizona.

To more fully comprehend the enormity of these figures, consider that the largest dam in the entire world, in terms of total volume of material, is the New Cornelia tailing dam located near Ajo, Arizona. This dam contains an estimated 275 million cubic yards (210 million cubic metres) of material, more than fifty percent greater than the second largest dam, the Tarbela Dam in Pakistan. Other tailing dams are also huge earthen structures. The Mission No. 2 tailing dam near Sahuarita, Arizona, is ranked twenty-first among all the dams in the world in terms of total volume of material.[6]

The Utah Copper Division of the Kennecott Copper Corporation reports that 37.5 million tons (34 Mtonnes) of tailing are being added yearly to their tailing ponds with estimated total accumulations of approximately 1.3 billion tons (1.18 Gtonnes). In 1972, a cyclone facility was constructed at Kennecott's concentrator plant near Salt Lake City to separate the coarser tailing particles for use as a highway embankment material.[7]

Anaconda Copper Company's Montana Mining Division estimates that approximately twenty million tons (18 Mtonnes) of tailings are produced annually at their Butte mine.[8] Quantity reports have also been received from copper producers in other states. The copper tailing produced in the vicinity of Houghton, Michigan, is often referred to as stamp sands. No estimates of quantity are available for this material.

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[6] Engineering News-Record, October 16, 1975, p. 17.

[7] Mr. D. R. Cummings, Mill Superintendent, Kennecott Copper Corporation, Salt Lake City, Utah. Correspondence dated September 26, 1975.

[8] Mr. G. M. McArthur, Director of Environmental Affairs, Anaconda Copper Company, Butte, Montana. Correspondence dated October 7, 1975.

Iron Ore and Taconite

The United States iron industry produces between 80 and 90 million tons (72 to 81 Mtonnes) of iron ore annually. Over two-thirds of our domestic iron is derived from relatively low-grade taconite ores found principally in the Mesabi range of Northeastern Minnesota. Most natural iron ore and all taconite ores are mined by open pit methods.

The processing of the taconite ores produces both a coarse and fine tailing, with the fine tailing comprising sixty to seventy percent of the total output when the two are separated. Taconite tailings are currently being produced at the rate of 120 million tons (108 Mtonnes) per year in Minnesota. Accumulations are probably on the order of two to three billion tons (1.8 to 2.7 Gtonnes) across the 100-mile length of the Mesabi range.

There is some question as to whether taconite tailings should be stockpiled for possible future extraction of iron values. Regarding the potential for future use of taconite tailings as an iron source, an official from one of the taconite mining companies has stated that "there is very little likelihood that typical taconite tailings products will ever constitute a workable source of iron units." He cites the diverse mineralogical distribution of the residual iron and the inability to reclaim it in an economical fashion.[9]

High-grade iron ores are mined in Minnesota, Michigan, California, Wisconsin, Pennsylvania, and a number of other states. Because of a higher concentration of iron in these ores, there is a smaller percentage of tailing resulting than in the processing of taconite ores. It is estimated that approximately 30 million tons (27 Mtonnes) of tailings are generated annually from the production of high-grade iron ores.

In Minnesota, the question of ownership of lean iron-bearing materials and tailings from the processing of natural iron ores is a factor to be considered in the possible availability of materials. In many cases, the mining companies lease the properties they operate and the fee owners have title to stockpiles on their land. This is particularly true in the case of the older properties in Minnesota. In cases where stockpiles of tailing material contain mineral values,

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[9]Mr. H. H. Vaughn, Chief Environmental Engineer, Eveleth Taconite Company, Eveleth, Minnesota. Correspondence dated January 20, 1976.

the complications of divided ownership, combined with possible future resource considerations, generally preclude their use as highway construction material.[10]

Lead-Zinc

Since lead and zinc usually occur as sulfide ores found in the same type of parent rock, limestone or dolomite, the tailing product is similar and will, therefore, be considered together. These ores occur in many widely scattered areas of the United States, sometimes separately as lead or zinc deposits and sometimes as combined lead-zinc ores. Ore concentrations can range from two to ten percent with average ore concentrations of about four percent. It is estimated that approximately 17 million tons (15.4 Mtonnes) of lead-zinc tailings are being produced annually. (3)

Missouri has been and still is the nation's leading lead-producing state. Production is presently centered around an area in southeast Missouri known as the New Lead Belt or Viburnum Trend, where 6 million tons (5.4 Mtonnes) of dolomitic flotation tailings are now being disposed of each year.[11] In the past, the Old Lead Belt in eastern Missouri and the Tri-State mining district (encompassing southwest Missouri, southeast Kansas, and northeast Oklahoma) were principal producing areas of lead-zinc ore. Substantial amounts of tailings from lead production in the Old Lead Belt are located mainly in St. Francois County, Missouri.

Although mining in the Tri-State district has been discontinued, there are still a considerable number of so-called "chat" piles in this area. "Chat" is the term used to denote the coarse waste product, mostly chert or flint, from the jigging and tabling processes used to concentrate these ores. This material is routinely used in highway construction, particularly in the Joplin area of Missouri, and is included in the Standard Specifications of that state.[12]

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[10]Mr. W. F. Betzler, Assistant Manager, Jones and Laughlin Steel Corporation, Virginia, Minnesota. Correspondence dated October 1, 1975.

[11]Mr. Heyward Wharton, Geologist, Missouri Department of Natural Resources. Correspondence dated November 21, 1975, Jefferson City, Missouri.

[12]Mr. William L. Trimm, Division Engineer, Materials and Research, Missouri State Highway Commission, Jefferson City, Missouri. Correspondence dated August 28, 1975.

Tennessee is the nation's leading zinc-producing state, with substantial production and marketing of the tailing from the dolomitic limestone ores at Jefferson City. There are 5 million tons (4.5 Mtonnes) per year of tailings generated in this area, with a variable ratio of coarse to fine tailings. (3)

Zinc-lead ores in southwestern Wisconsin and northwestern Illinois occur in mineralized fractures of limestone formations. Although mining activity has nearly been completed in this area, it is estimated that between five and ten million tons (4.5 to 9 Mtonnes) of dolomitic gravel and flotation sands exist. Some limited use is now being made of the coarse fraction of this material for construction purposes.[13]

Other substantial deposits of zinc or lead-zinc tailings are being produced in Colorado, New Jersey, Pennsylvania, New Mexico, and Virginia. The total tonnage of tailings produced at these locations is estimated to be in the range of three to five million tons (2.7 to 4.5 Mtonnes) per year.

Uranium

In the milling and processing of uranium ores, substantial quantities of fine tailings result. These materials, unfortunately, contain more than ninety percent of the radium originally present in the ore prior to milling. (10) Consequently, they emit radon gas at radiation levels generally considered to be a potential environmental and health hazard.

These tailings are produced in the largest quantities in states of Colorado, New Mexico, Utah, and Wyoming, with lesser amounts generated in Arizona, Nevada, South Dakota, and Texas. No precise quantity figures are available concerning the amount of waste produced at individual milling locations. However, it is estimated that over six million tons (5.4 Mtonnes) of uranium tailings are generated each year at operating uranium mills. There are also an estimated additional 125 million tons (113 Mtonnes) of stockpiled tailings which have accumulated at uranium milling locations. Because of concern for residual radiation, it is possible that in recent years a number of these stockpiles may have been stabilized by vegetation.

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[13]Mr. Ronald C. Briggs, U.S. Bureau of Mines, State Liason Officer for Minnesota and Wisconsin, Twin Cities, Minnesota. Correspondence dated July 18, 1975.

Gold

Practically all of the current domestic production of gold is by lode or vein mining, compared to the placer mining of alluvial gold-bearing deposits over a century ago. Gold is mined by open-pit and underground methods and is also recovered as a by-product of copper and silver mining.

Because gold content of most ores is about 0.3 ounces (8.5 grams) per ton of ore, nearly all of the ore treated eventually becomes tailing. Gold is recovered by flotation, gravity concentration, cyanidation, amalgamation, and smelting, or a combination of these processes. (116)

Nevada is currently the leading gold-producing state with South Dakota, Utah, Arizona, and Colorado following in that order. The largest gold mine in the United States at the present time is located in the Black Hills near Lead, South Dakota. (117) Waste rock and tailing are both generated as by-products of gold mining by the Homestake Mining Company. Approximately one million tons (0.9 Mtonnes) per year of tailings are produced at this mine, seventy-eight percent of which is disposed in slurry form, the remainder occurring as sand.[14]

The greatest amounts of solid waste from gold mining are located in the western Sierra Nevada region of northern California. These siliceous materials were initially deposited over one hundred years ago as the result of hydraulic mining operations. There are an estimated 26,000 acres (10,500 hectares) of sand and gravel deposits in Nevada and Sierra counties resulting from this activity and large amounts of these materials have been used for construction purposes over the years.

Besides the early hydraulic mining operations, gold-bearing gravel deposits in the flatter areas of Butte, Yuba, Sacramento and adjacent counties were worked by bucket-line dredges. Washing and screening operations to separate the gold minerals have left tailings deposits of clean sand and gravel strewn over 50,000 to 60,000 acres (20,000 to 24,000 hectares) in these counties. Most of these materials are of good quality, being composed of pebbles and cobbles from relatively good rock, and have been used in a number of cases as commercial sand and gravel.

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[14]Mr. Lawrence F. Jeffries, Environmental Manager, Homestake Mining Company, Lead, South Dakota. Correspondence dated October 16, 1975.

Although gold dredging was discontinued in California ten years ago, there are probably 2 billion tons (1.8 Gtonnes) of tailings which would be suitable for use as sand and gravel for the construction industry, based on reported yields of 30,000 to 50,000 tons of saleable aggregate per acre (11,000 to 18,000 tonnes per hectare) of tailings.[15]

Molybdenum

The tailings and waste rock resulting from the production of molybdenum have not been included in the tabulation of mining waste quantities presented in Tables 1 and 2 because molybdenum production was not specifically identified in the information summary presented in the 1972 Minerals Yearbook. However, significant quantities of waste, particularly tailings, do result from the processing of molybdenum ores.

The mining of molybdenum is concentrated in the Rocky Mountain area of central Colorado with additional mining in north-central New Mexico. The Climax Molybdenum Company has three mining operations in Colorado. The Climax mine has been in operation for fifty years, has accumulated over 300 million tons (270 Mtonnes) of tailing, and is producing over 40,000 tons (36,000 tonnes) per day. The Urad mine recently closed, having exhausted its ore supply. Approximately 26 million tons (23.6 Mtonnes) of tailing were deposited, but these tailing deposits are presently being stabilized.[16] A new operation, the Henderson mine, is opening during mid-1976 and is expected to produce 30,000 tons (27,000 tonnes) per day of tailing within three years, with production expected to continue for twenty years.[17]

Molycorp, Inc., operates a large molybdenum open-pit mine in New Mexico, where more than 25 million tons (22.6 Mtonnes) of waste material are produced each year.[18]

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[15]Mr. William H. Kerns, U.S. Bureau of Mines, Liaison Officer, Sacramento, California. Correspondence dated July 24, 1975.

[16]Mr. J. J. Ludwig, Manager of Mines, Climax Molybdenum Company, Western Operations, Golden, Colorado. Correspondence datedOctober 9, 1975.

[17]Mr. D. E. Julin, Chief Engineer, Climax Molybdenum Company, Henderson Mine, Empire, Colorado. Correspondence dated October 13, 1975.

[18]Mr. A. L. Greslin, Assistant to the General Manager, Molycorp, Inc., Questa, New Mexico. Correspondence dated November 7, 1975.

A sizeable portion of this waste material is probably composed of waste rock and overburden. Nevertheless, a considerable amount of tailing is also produced at this location and has occasionally been used in highway construction.

Phosphate

The beneficiation of so-called land pebble phosphate deposits by flotation produces phosphate slimes and sand tailings. Phosphate slimes will be discussed in more detail later in this chapter under the heading of "Washery Plant Rejects." Sand tailings, the coarse reject from the flotation processing of phosphate rock, are being generated at an estimated rate of ten to fifteen million tons (9 to 13.5 Mtonnes) per year and are frequently disposed of with the finer slimes or used to construct impoundment dikes. (115)

The manufacture of wet process phosphoric acid results in the generation of large quantities of impure by-product gypsum termed phosphogypsum. At the present time, more than 20 million tons (18 Mtonnes) per year of this material are being produced and disposed of in large stacks. (108)

Sand tailings and slimes are mainly found in the central Florida area, where nearly eighty percent of domestic phosphate production is centered. Smaller phosphate mining operations exist in North Carolina and Tennessee, where these wastes are produced to a lesser extent. Phosphate rock mining in the western states is hard rock mining where no sand tailings or slimes result from ore preparation. (116) The production of phosphogypsum principally occurs in central Florida, although there is also a large production of phosphogypsum in North Carolina. (108)

Alumina

A solid waste material, similar in nature to tailings, is produced as a by-product of the refining of alumina in Louisiana. This sand-like material is referred to as "pisolites" and is being generated at the rate of more than 50,000 tons (45,000 tonnes) per year by Kaiser Aluminum in Baton Rouge, Louisiana.[19] This material is not presently known to be produced at other alumina refining operations.

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[19] Mr. J. W. Melancon, Works Manager, Kaiser Aluminum and Chemical Corporation, Baton Rouge, Louisiana. Correspondence dated December 5, 1975.

Other Tailing Materials

There are also quantities of tailings generated from the production of other minerals such as asbestos, barite, silver, feldspar, fluorspar, and gypsum. In most instances, specific tonnage figures for tailing are not available from individual mining locations producing these commodities.

The production of asbestos occurs mainly in California, Vermont, and Arizona. Asbestos minerals most frequently occur in serpentine rock, from which the asbestos fibers must be separated. The tailing materials are referred to as "asbestos shorts" because of the short length of the residual asbestos fibers in the tailings. Several hundred thousand tons of this material are available at a site in California[20] and similar quantities are probably available in Vermont at the site of the Hyde Park mine and in Gila County, Arizona. There is some concern about inhalation of asbestos fibers. This aspect of asbestos tailing use will be discussed in Chapter 6 of this report.

A number of states produce barite, but the leading producing states are Nevada, Arkansas, Missouri, and Tennessee. Barite tailings in northern Nevada are predominantly chert with some low grade barite. One producer in Nevada reports that approximately 180,000 tons (162,000 tonnes) of tailings are produced annually.[21] It has been reported that an estimated 7.5 million tons (6.75 Mtonnes) of flotation mill tailings have been placed in ponds in the Magnet Cove district around Malvern, Arkansas. Coarse tailings are also found near Dierks in Howard County.[22]

The barite tailings (tiff chat) in eastern Missouri are composed mainly of chert and have often been used for construction purposes. The available quantities could not be determined.

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[20]Mr. Irving F. Moore, President, Atlas Asbestos Company, Coalinga, California. Correspondence dated November 18, 1975.

[21]Mr. Wallace Mitchell, Senior Geologist, Milchem Mineral Division, Battle Mountain, Nevada. Correspondence dated December 3, 1975.

[22]Mr. Raymond B. Stroud, U.S. Bureau of Mines Liaison Officer, Little Rock, Arkansas. Correspondence dated July 11, 1975.

As mentioned previously, silver is most often associated as a co-product with other minerals. It is often mined as an ore and it is difficult to determine the quantities of waste attributable strictly to silver mining. The largest quantities of such materials are found in Idaho, Arizona, Utah, and Colorado, with over 20 million tons (18 Mtonnes) of material reported to be in the inactive tailing ponds in the Coeur d'Alene mining district of northern Idaho.

The Spruce Pine district of western North Carolina is the principal feldspar-producing area of the United States. It has been estimated that over 250,000 tons (225,000 tonnes) of tailings, composed largely of quartz and some feldspar, are generated annually in this area. No estimates are presently available of accumulated quantities.

Fluorspar is mined primarily in southern Illinois and northern Kentucky. One producer has reported on amounts of waste rock generated and used in construction, but no information has been found on the amount of tailings, other than the annual estimates presented in the Minerals Yearbook.

Very little tailing waste is normally produced from the mining of gypsum. Most of the solid waste generated in this type of mining is overburden from open-pit operations. Tailing was reported for a gypsum mine at Shoals, Indiana, in the form of anhydrite fines. Annual quantities were reported to be quite small, on the order of 5,000 tons (4,500 tonnes) per year with 150,000 tons (135,000 tonnes) stockpiled.[23] It is felt that this operation is typical of the gypsum industry.

There are also some other solid wastes produced by mining or metallurgical processes which presently do not constitute large quantities of material, but which do pose some present or future disposal problems to their respective industries. Two such materials which deserve mention in this report are spent oil shale and steel furnace dust. Although these wastes cannot be classified as tailings in a strict sense, they are somewhat similar in physical appearance to certain other tailings and are, therefore, included under the general heading of tailings.

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[23]Mr. C. O. Campbell, Director of Mines and Properties, Gold Bond Building Products, Buffalo, New York. Correspondence dated December 8, 1975.

The development of an oil shale industry in the Green River formation of northwest Colorado, northeast Utah, and southwest Wyoming is now in the pilot plant stage. However, large scale commercial development of the tremendous reserves of oil contained in the shale deposits of this region may occur.

There are presently several experimental oil shale retorting facilities located in northwest Colorado. After the retorting or heating of the shale to extract oil, nearly all of the spent shale must be disposed of. The percentage of the spent oil shale remaining after retorting will depend on the grade of the shale and retorting process. If the oil shale industry develops on a commercial scale in the coming years, huge amounts of spent oil shale would be produced and a new solid waste problem would be created. At the moment, the future development of the oil shale industry is uncertain.

The disposal of dusts collected from steel-making furnaces ranges from being a nuisance to a costly problem for the steel industry. Depending on the type of furnace used, the generation of steel furnace dust is from 20 to 40 pounds of dust per ton (8 to 16 kg per tonne) of finished steel. From two to three million tons (1.8 to 2.7 Mtonnes) of this material are being collected annually. Integrated steel companies are able to recycle these dusts as blast furnace feed, provided concentrations of heavy metals such as lead and zinc are within acceptable levels. Non-integrated steel companies must either dispose of these materials or find commercially acceptable uses for them.

4.3.3 Mill Tailings - Physical Description and Composition

In order to properly evaluate these materials, it is essential to know something of their physical state, as well as their chemical and/or mineralogical composition. Because of the number of sources and enormous tonnages of tailings disposed of by the mining industry, it is difficult to select typical or representative samples of these materials. Whenever possible, a description of each type of tailing will be based on reported data from a number of sources, so that the reader may obtain a good idea of the overall nature of the material, as well as its range of variability. This is particularly important with respect to the gradation and chemical composition of tailings.

The grain size distribution of a tailing sample can vary considerably depending on the ore processing methods used, the percent solids of tailing slurry, the method of handling, and the type of discharge relating to the tailing pond sample location. (123) Therefore, gradation curves will indicate ranges of material sizes if sufficient information is available. Where meaningful, a comparison will be made with the ASTM gradation requirements for fine aggregates in bituminous mixtures.

Copper

A sample of copper mill tailing is shown in Figure 6. A sample of "classified" copper mill tailing, in which a centrifugal or cyclone separation was made to reclaim the coarse fraction, is shown in Figure 7.

Several gradations have been reported for copper tailings. This information is summarized in Table 8. Figure 8 shows typical ranges of gradation for various methods of copper tailings discharges, as reported by Volpe. (123)

Further insight into the variation in grain size characteristics of copper tailings can be obtained from additional reported data. Mr. R. D. Estes of Cities Service Company, Copperhill, Tennessee, reports that "mill tailings are fine grained with one hundred percent minus 140 mesh and a large fraction minus 200 mesh." Mr. J. P. McCarty of Duval Corporation, Battle Mountain, Nevada, has indicated that mill tailing from their operation is about sixty-five to seventy percent minus 100 mesh and averages from 3 to 40 percent moisture. Mr. E. R. Staley of Magma Copper Company of Magma, Arizona, has noted that mill tailing from their facility are 56.2 percent minus 200 mesh. Tailing from Phelps Dodge's Morenci mine in Arizona "are produced as water slurry, containing approximately forty-five percent solids by weight. Particle size distribution ranges from approximately fifteen percent plus 65 mesh to fifty-five percent minus 200 mesh," according to Mr. William S. Hannan, Jr., concentrator superintendent. Mr. H. L Shively of the Duval Sierrita Corporation in Sahuarita, Arizona, has reported that the particle size of the mill tailing at their plant is "nominally seventy percent minus 100 mesh and pH is approximately 9.5."

The Utah Division of Kennecott Copper Corporation has built a facility for separating their copper mill tailing into coarse and fine fractions. It has been reported by Mr. D. R. Cummings, mill superintendent, that the coarse fractions of the tailings contain a maximum of twenty percent minus 200 mesh material, compared to more than fifty percent 200 mesh material for unclassified tailing. The classified tailing, shown in Figure 7, is a fine sand.

Figure 6. Sample of copper mill tailing
(Scale in inches).

Figure 7. Sample of classified copper mill tailing
(Scale in inches).

Table 8. Particle size distribution of copper mill tailings in percent finer by weight

Screen Size (Mesh)	Phelps Dodge Ajo, Ariz.	Kennecott Magna, Utah[1]	Kennecott Magna, Utah[2]	Kennecott Magna, Utah[3]
# 10		100		
20		99		
35			90.4	99.4
40		97		
48			74.1	98.0
65	70.3		53.8	95.4
80		26		
100	59.2	19	34.5	92.4
150	49.7		22.9	90.2
200	42.0	15	13.6	87.8
270		7		

[1]Reported from particle size distribution curve of classified tailing prepared for Kennecott Copper Corporation by Caldwell, Richards, and Sorenson, Inc., Consulting Engineers, Salt Lake City, Utah.

[2]Gradation of coarse fraction of tailing sample as reported in Illinois Institute of Technology Research Institute report entitled, "Techno-Economic Analysis of Mining and Milling Wastes," p. 48.

[3]Gradation of fine fraction of tailing sample as reported in Illinois Institute of Technology Research Institute report entitled, "Techno-Economic Analysis of Mining and Milling Wastes," p. 48.

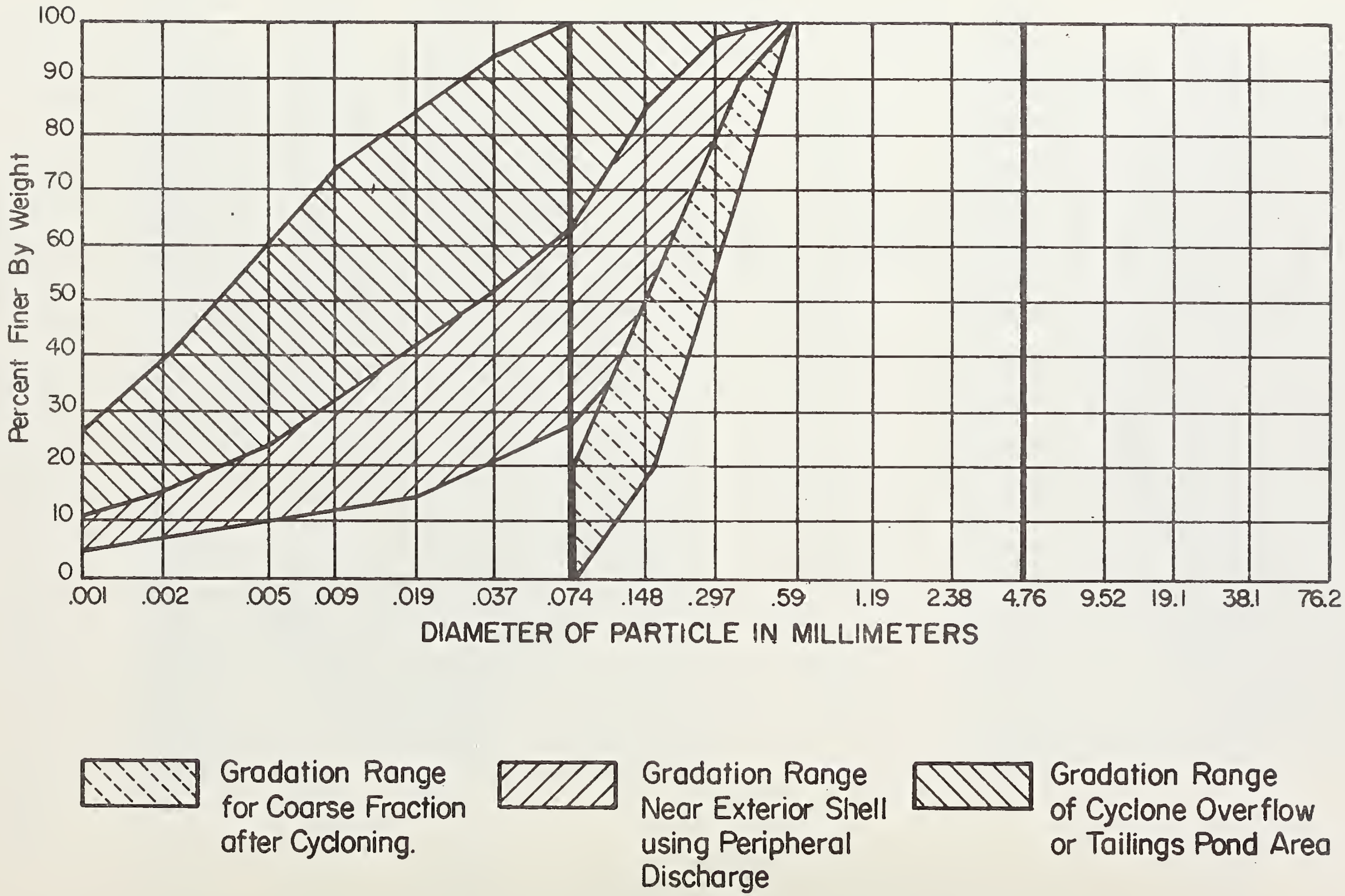

Figure 8. Gradation of copper mill tailings.

Although not a great deal of information has been provided concerning particle shape and hardness of copper tailings, the material generally is composed of hard, angular particles. Volpe reports that the majority of copper tailings are non-plastic, having specific gravity values in the range of 2.64 to 2.78, and exhibiting uniformly high shear strength (123).

Table 9 presents a summary of information provided by several copper companies relative to the chemical composition of their tailing product. Although composition varies with location due to differences in mineral deposits, copper mill tailings are basically a siliceous material with some trace amounts of copper and other heavy metals.

Iron Ore and Taconite

The tailings from taconite ores possess good physical properties. The magnetic portion of the ore is removed during processing, leaving a siliceous, non-magnetic portion composed of sharp, angular fragments. Mr. C. W. Niemi of United States Steel Corporation in Mt. Iron, Minnesota notes that "the angular structure and high internal strength of these tailings, coupled with a high degree of permeability, produces excellent embankments." Mr. H. H. Vaughn of Eveleth Taconite Company in Eveleth, Minnesota recommends that interest be confined to the coarse tailings which, he notes, have "sharp, irregular particles giving good coherence and improved surface traction."

Reported gradations for various sources of taconite tailings from the Mesabi range in northeast Minnesota are given in Table 10. The grain size distribution range of these materials is shown in Figure 9. Figure 10 shows a typical sample of coarse or classified taconite tailing. Mr. Ronald Briggs, U. S. Bureau of Mines Liaison Officer for Minnesota, has noted that "fine tailings...comprise fifty to seventy percent of the total tailings discharged from taconite processing operations."

The reported chemical composition of taconite tailings is presented in Table 11. These data confirm that taconite tailings are predominantly siliceous in nature. A recent controversy has arisen in Minnesota over the presence of asbestiform fibrous particles in the tailing discharge from some taconite ore-processing locations. These asbestiform fibers are reported to be present only in taconite ores from the eastern portion of the Mesabi range.[24]

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[24] St. Paul Dispatch, November 27, 1975, p. 44.

Table 9. Chemical composition of copper mill tailings[1].

	Phelps Dodge Ajo, Ariz.	Phelps Dodge Morenci, Ariz.	Cyprus Bagdad Bagdad, Ariz.	Cities Service Copperhill, Tenn.
SiO_2	67.3	68.2	70.0	50.0
Al_2O_3	16.3	16.0	15.0	----
CaO	2.8	1.4	2.5	----
Fe	2.1	3.4	1.3	9.0
Cu	0.1	0.2	0.13	0.05
S	0.5	1.7	0.4	3.0
Residual	10.9	9.1	10.67	----

NOTE: Residual material consists largely of sodium, potassium, and magnesium oxides with very low percentages (less than 0.1%) of heavy metals, such as lead, zinc, cadmium, chromium, nickel, cobalt, titanium, and arsenic.

[1]Chemical composition expressed in percent by weight.

Table 10. Grain size distribution of taconite tailings[1].

Sieve Size	Hanna Hibbing, Minn.[2]	Butler Nashwauk, Minn.	Eveleth Eveleth, Minn.[3]	Eveleth Eveleth, Minn.[4]	U.S. Steel Mt. Iron, Minn.[5]
3/8"					99.3
#4	100			99.1	
#6				96.7	94.3
10	97	96.3		77.0	63.7
20	92.5	89.2		50.3	34.0
35	86.5	69.9	99.4	28.4	
48	83		98.9	19.0	
65	79	58.9	96.9	11.6	4.5
100	74		94.9	6.9	
150	68	48.1	91.5	4.3	
200	62.5		86.3	2.9	
270	53	35.5	80.3		0.9
325	46	33.4	76.3	2.3	
400			71.3		
500			64.6		

[1] Grain size distribution expressed as percent finer by weight.

[2] Reported from grain size distribution curve submitted on December 16, 1975, by Mr. C. J. Meli, Supervisor of Engineering, Hanna Mining Company.

[3] Reported as fine fraction from spiral classifier by Mr. H. H. Vaughn, Chief Environmental Engineer, Eveleth Taconite Company.

[4] Reported as coarse fraction from spiral classifier in Illinois Institute of Technology Research Institute report entitled, "Techno-Economic Analysis of Mining and Milling Waste," p. 34.

[5] Reported as typical coarse taconite tailing by Mr. C. W. Niemi, General Superintendent, U.S. Steel Corporation in letter dated August 11, 1975.

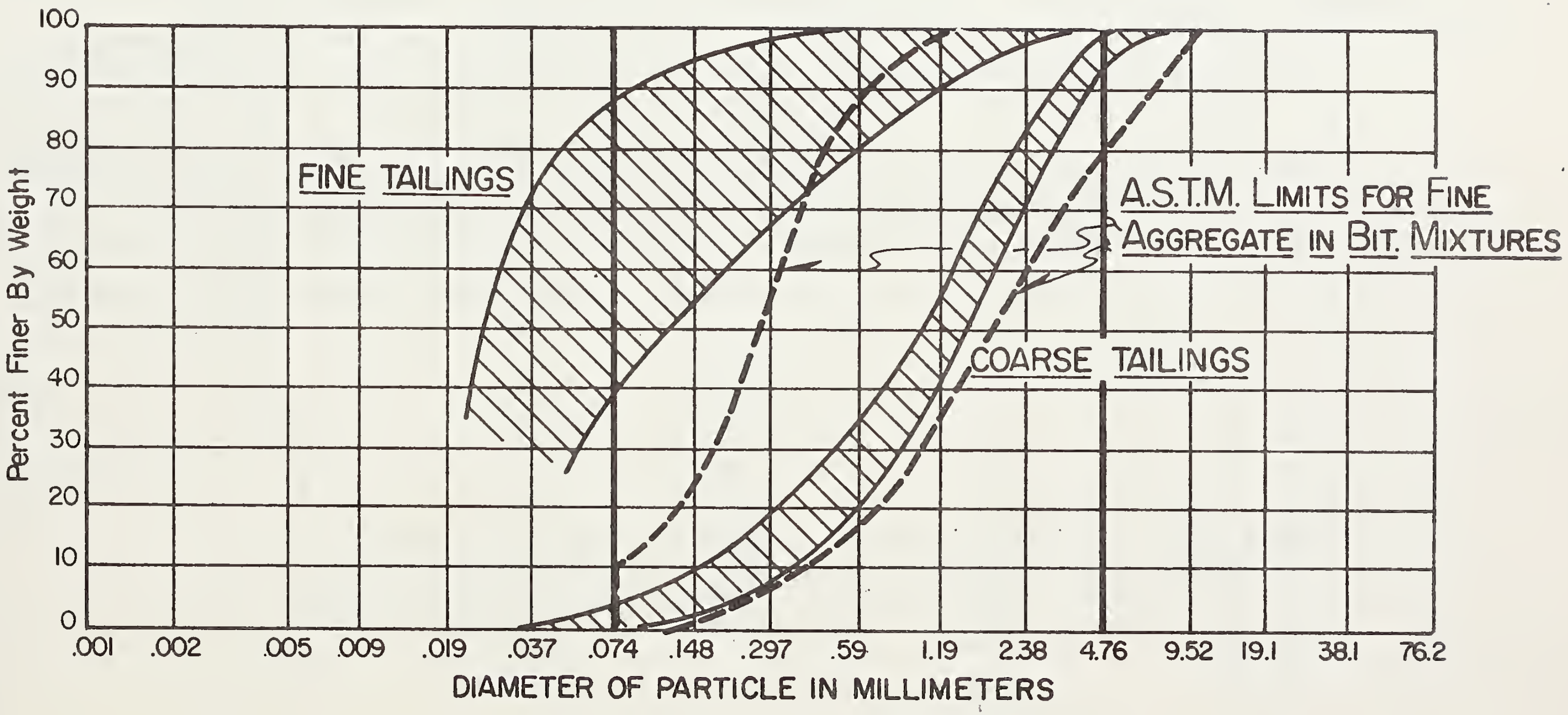

Figure 9. Gradation of taconite tailings.

Figure 10. Sample of coarse taconite tailing
(Scale in inches).

Table 11. Chemical composition of taconite tailings, in percent by weight.

	U.S. Steel Mt. Iron, Minn.	Eveleth Eveleth, Minn.[1]	Eveleth Eveleth, Minn.[2]	Reserve Silver Bay, Minn.
SiO_2	70.19	67.56	64.34	33.03[3]
Fe (Total)	13.33	13.74	11.57	14.93
CO_2	4.17	5.85	7.57	0.11[4]
MgO	2.38	2.78	4.15	2.55[5]
Al_2O_3	0.17	0.23	0.25	0.35
CaO	0.59	1.69	3.57	1.67[6]
O_2	-	-	-	46.40

[1] Reported as coarse tailing product.

[2] Reported fine tailing product.

[3] Reported as Silicon.

[4] Reported as Carbon.

[5] Reported as Magnesium.

[6] Reported as Calcium.

As with taconite ore processing, the beneficiation of high-grade iron ores sometimes results in coarse and fine tailing products. In Minnesota, beneficiation of high-grade iron ores produces coarse and fine tailings, generally separated at the 1/4 inch (6.35 mm) screen. For the most part, only the coarse fraction, if it has been separated, has proven to be useful.

Figure 11 depicts a coarse tailing product from the beneficiation of high-grade iron ore. Available grain size distribution information for high-grade iron ore tailings is presented in Table 12 and plotted in Figure 12. A variety of gradations are evident from this data, especially from the Lone Star plant. These gradations are indicative of the variation in extent of processing required to liberate the iron ore from the host rock.

The tailings themselves vary in mineral character and usually contain enough residual iron to impart a black color. Tailings from the beneficiation of high-grade iron ores in Minnesota have iron contents as high as twenty-five to thirty-five percent and are considered by the owners of the properties to be potentially recoverable iron sources.

The tailing particles from U.S. Steel's Atlantic City mine in Wyoming have been reported to be "extremely sharp, tough, and abrasive."[25] Nevertheless, most iron producers consider the fine fraction of tailings from high-grade iron ore beneficiation to be unsuitable for highway construction use.

Some information on the chemical composition of high-grade iron ore tailings is presented in Table 13. Although some of the data is incomplete, it can be determined that the tailings from the processing of natural iron ores are considerably less siliceous than the taconite tailings and possess much higher percentages of iron.

Lead-Zinc

Lead and zinc are primarily associated with sulfide-bearing ore minerals. Normally, these minerals are found as co-products in dolomitic or limestone parent rocks. Chat tailings from the Tri-State district were produced from past

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[25]Mr. John D. Quinn, Chief Engineer, United States Steel Corporation, Lander, Wyoming. Correspondence dated December 19, 1975.

Figure 11. Sample of coarse iron ore tailing (Scale in inches).

Table 12. Grain size distribution of iron ore tailings, in percent finer by weight.

Sieve Size[1]	Kaiser Eagle Mtn. Calif.[2]	Lone Star Lone Star, Texas[3]	Lone Star Lone Star, Texas[3]	Lone Star Lone Star, Texas[3]	Lone Star Lone Star, Texas[3]
3/4"	99.7				
1/2"	83.4				
3/8"	65.1				
1/4"	46.8				
#4	36.7				
6		99.6	91.0	96.6	99.0
8	20.5	89.5	75.0	89.8	97.5
10	17.6	74.6	50.5	80.3	95.1
20	7.9	63.1	38.5	76.2	93.3
28	5.7	53.1	30.4	71.2	90.9
35	4.1	38.6	23.1	64.2	85.7
48	2.8	28.2	15.1	45.9	75.0
65	1.9	16.9	10.5	28.5	58.8
100	1.4				
150	0.9				
200	0.7				

[1]Sieves are given in mesh numbers except for 3/4", 1/2", 3/8", and 1/4" sizes.

[2]Reported as coarse fraction of tailing product by D. E. Wick of Kaiser Steel Corporation.

[3]Four separate samples of drained tailing as reported by V. F. Malone of Lone Star Steel Company.

Note: 1 inch = 25.4 mm.

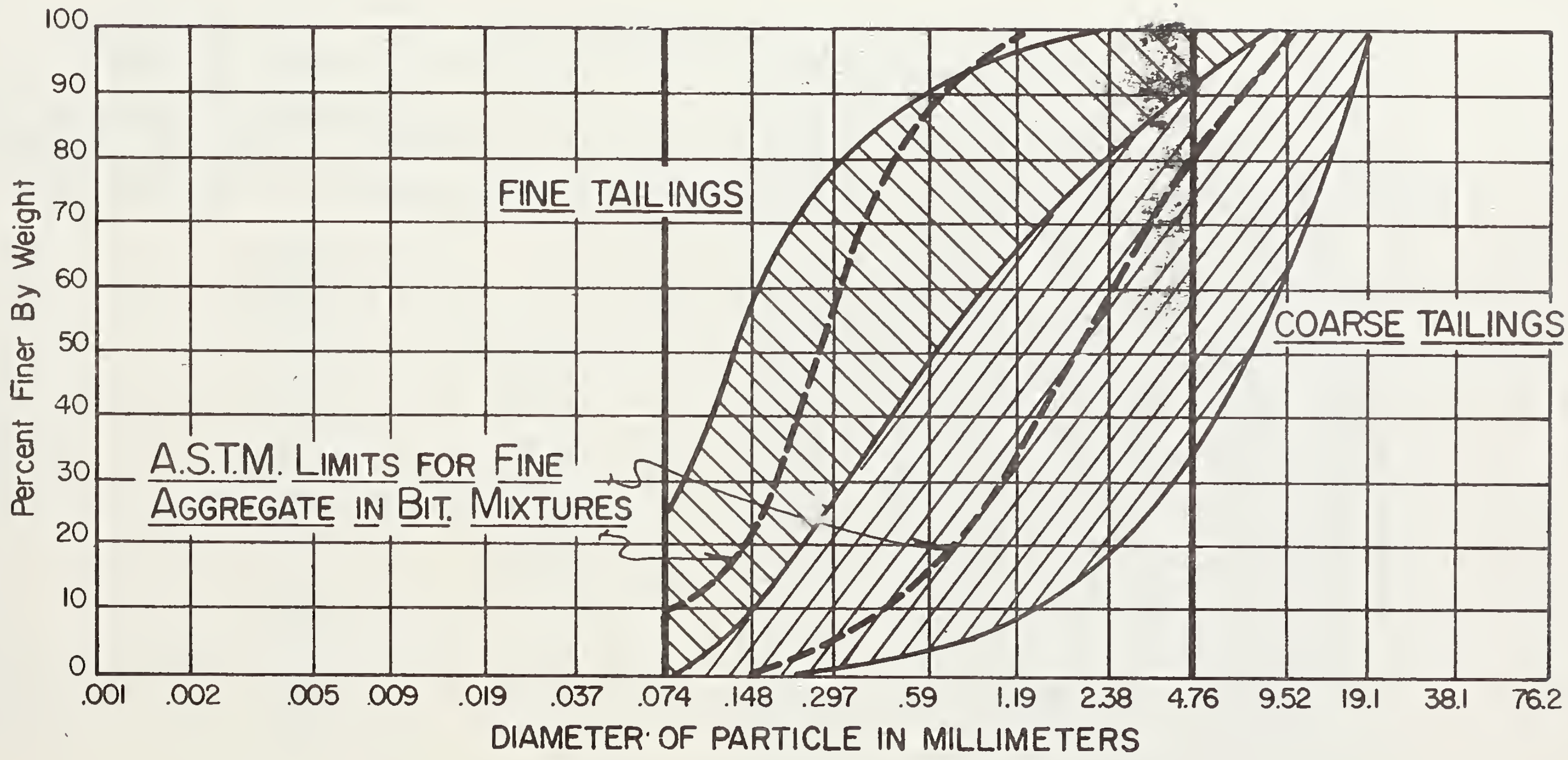

Figure 12. Gradation of iron ore tailings.

Table 13. Chemical composition of iron ore tailings[1].

	Kaiser Eagle Mtn., Calif.	Lone Star Lone Star, Texas	Lone Star Lone Star, Texas	Lone Star Lone Star, Texas	Lone Star Lone Star, Texas
SiO_2	48.57	33.86	27.12	48.14	52.14
Fe	18.8	30.6	36.0	23.0	20.0
Al_2O_3	----	15.04	13.02	14.12	14.20
CaO	5.74	----	----	----	----
MgO	4.64	----	----	----	----
S	0.67	----	----	----	----
P	0.05	----	----	----	----
Mn	0.066	----	----	----	----
Cu	0.026	----	----	----	----

NOTE: Chemical compositions are reported for the same samples listed in Table 12.

[1] Chemical compositions reported in percent by weight.

jigging and tabling processes and are of a coarser nature than the flotation tailings now being produced from the beneficiation of lead-zinc ores, which require a finer grinding for separation.[26]

The tailings from lead-zinc operations can generally be categorized as calcerous dolomitic sand and gravel or silt materials, depending on whether the coarse and fine fractions are separated. Lead-zinc tailing from northwest Illinois consists of minus 9/16 inch (14.2 mm) washed dolomite gravel and minus 48 mesh flotation sand.[27] The processing of zinc ore in Tennessee also results in a coarse (1-3/4" or 45.4 mm to 1/4" or 6.35 mm) and fine (minus 20 mesh) tailing.[28] However, operations located in Missouri, Pennsylvania, Colorado, Idaho, and Washington do not separate tailings into coarse and fine fractions. A typical zinc tailing is shown in Figure 13.

Available particle size information is presented in Table 14 and plotted on a gradation curve in Figure 14.

Where separation of the tailings is not employed, the resultant material is usually quite finely divided. St. Joe Minerals reports that tailing from their mill in eastern Missouri has a screen analysis of fifty percent minus 200 mesh.[29] Lead-zinc tailings from Washington are 200 mesh minus with rounded particles.[30]

Although lead and zinc usually occur together, there can be a wide variation in the respective amounts of lead and zinc in different host rock sources. In some cases, lead and

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[26]Mr. Walter J. Dean, Chief Engineer, Amax Lead Company, Boss Missouri. Correspondence dated October 7, 1975.

[27] Mr. Harold H. Haman, Manager, Eagle-Picher Industries, Inc., Galena, Illinois. Correspondence dated August 13, 1975.

[28]Mr. J. H. Polhemus, Superintendent of Surface Operations, American Smelting and Refining Company, Mascot, Tennessee. Correspondence dated January 25, 1973.

[29]Mr. L. W. Casteel, Division Manager, St. Joe Minerals Corporation, Bonne Terre, Missouri. Correspondence dated December 3, 1975.

[30]Mr. L. M. Kinney, Mine Manager, Bunker Hill Company, Metaline Falls, Washington. Correspondence dated December 12, 1975.

Figure 13. Sample of zinc mill tailing
(Scale in inches).

Table 14. Grain size distribution of lead-zinc tailings, in percent finer by weight.

Sieve Size	A.S.A.R. Co. Mascot, Tenn.[1]	U.S.S.R.M. Co. Midvale, Utah[2]	Amax Boss, Mo.[3]
10			
20	99.6	99.9	
35	91.6	96.6	
48		90.5	96.6
65	69.2	79.5	88.2
100	58.2	64.2	77.8
150	47.4	49.7	62.9
200	41.4	33.6	48.0

[1]Reported in Illinois Institute of Technology Research Institute report entitled, "Techno-Economic Analysis of Mining and Milling Wastes," p. 60.

[2]Reported in Illinois Institute of Technology Research Institute report entitled, "Techno-Economic Analysis of Mining and Milling Wastes," p. 57.

[3]Reported by Mr. Walter J. Dean, Chief Engineer, Amax Lead Company, Boss, Missouri. Correspondence dated October 7, 1975.

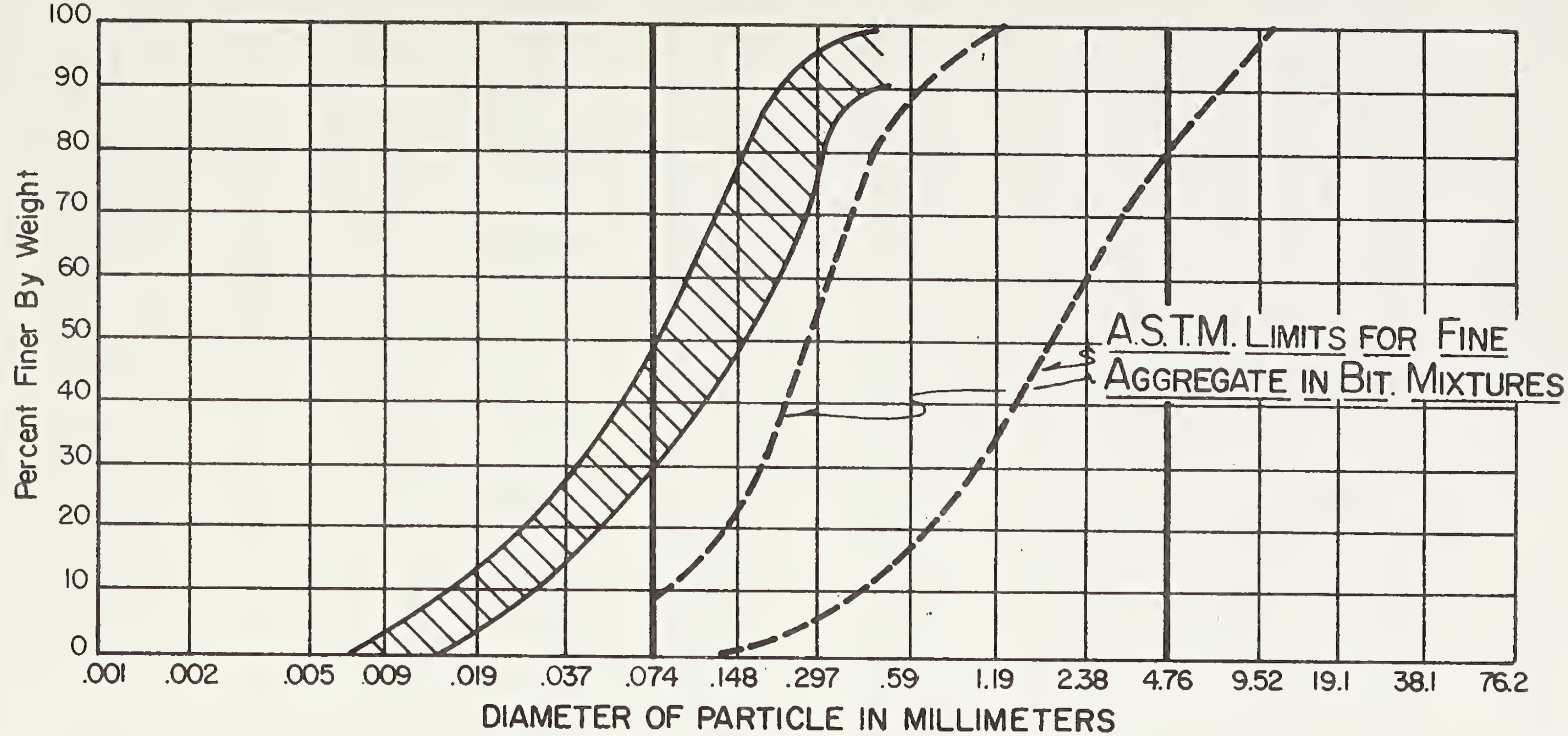

Figure 14. Gradation of lead-zinc tailings.

zinc are mined separately. Variations in host rock sources often result in a wide variation in tailings from different locations.

The composition of lead-zinc tailings is an essential element to be considered prior to a decision to use such materials. The tailing produced at Gilman, Colorado, is composed of from sixty-five to seventy-five percent pyrite[31], which would render it undesirable for any sort of highway use. On the other hand, the tailing material reported by Amax in Boss, Missouri, is composed essentially of calcium and magnesium oxides. Reported chemical analyses for different sources of lead and zinc mill tailings are presented in Table 15. These values illustrate the variations in composition that can occur between tailing sources. It is difficult to generalize concerning the chemical composition of tailings from the mining of ores that are predominantly lead or zinc.

It would appear that only the coarse fraction of lead-zinc tailings is usable for construction purposes, provided no objectionable elements are contained in the tailings.

Uranium

Although no reported information is available on the physical nature and properties of uranium mill tailings, these materials normally occur as clean fine to medium sands, once they have dried following disposal. Figure 15 shows a typical sample of this material.

The main objection to the use of uranium mill tailings in construction applications is the presence of by-product radium-226 in the tailings in amounts which, although comparatively low, are nearly equal to the concentrations originally found in the ore prior to milling. Eventually, the radium decays into radon, producing gaseous radioactive particulates which escape into the surrounding air and become respirable. The levels of radioactivity associated

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[31]Mr. H. C. Osborne, Manager, New Jersey Zinc Company, Gilman, Colorado. Correspondence dated October 1, 1975.

Table 15. Chemical composition of lead and zinc tailings, in percent by weight.

Lead Tailing[1]		Lead Tailing[2]		Lead Tailing[3]	
SiO_2	53.91	CaO	33.7	SiO_2	9.80
Al_2O_3	2.27	MgO	18.4	$CaCO_3$	52.30
Fe	11.4	Fe	2.59	$MgCO_3$	36.35
S	12.0	Pb	0.50	R_2O_3	1.45
MgO	2.16	Zn	0.11	ZnS	0.18
CaO	7.14	Cu	0.06		
Zn	1.01	Ni	0.015		
Pb	0.58	CO	0.009		
MnO	0.35	Sb	0.006		
Ag	0.2	Cd	0.006		
Cu	0.08				
Au	0.01				

[1]Tailing produced at U.S.S.R.M. Co., Midvale, Utah, as reported in Illinois Institute of Technology Research Institute report entitled, "Techno-Economic Analysis of Mining and Milling Wastes," p. 57.

[2]Tailing produced at Amax Lead Company, Boss, Missouri, as reported by Mr. Walter Dean, Chief Engineer, in correspondence dated October 7, 1975.

[3]Tailing produced at A.S.A.R. Co., Mascot, Tennessee, as reported in Illinois Institute of Technology Research Institute report entitled, "Techno-Economic Analysis of Mining and Milling Wastes," p. 60.

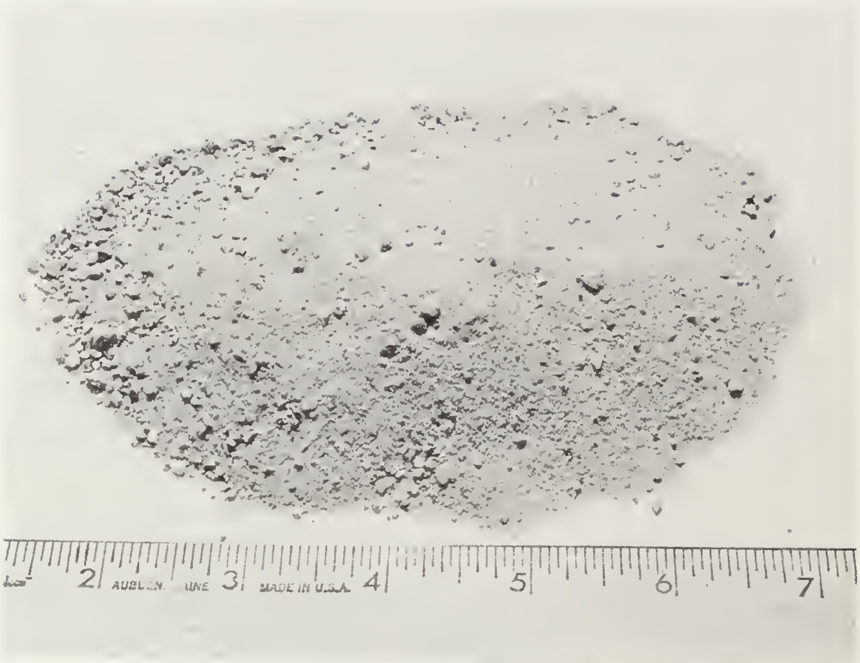

Figure 15. Sample of uranium mill tailing, (Scale in inches).

with the radon gas have often been found to be in excess of levels generally considered tolerable by the office of the United States Surgeon General.[32]

An unfortunate example of the inadvisability of using uranium mill tailings on an indiscriminant basis occured in Grand Junction, Colorado, where radioactive tailing material from a nearby uranium mill was used as fill beneath and around the homes in a housing development. After some time, the presence of radon gas within the living space of these dwellings caused radiation levels to exceed normally safe limits. Several millions of dollars in state and federal monies are currently being spent in the removal and replacement of the uranium tailings in order to remedy this situation.[33]

Gold

The only report received concerning the nature of gold mine tailings was from the Homestake Mining Company in Lead, South Dakota. The tailing discharge at this location is a slurry consisting of fine, sharp-edged, jagged particles that are very abrasive. The size distribution of this tailing is reported as follows:

Sieve Size (Mesh)	Passing
80	99.0%
100	97.6
150	94.6
200	90.3
270	82.4
325	72.1

The following chemical composition was reported and approximates the composition of the tailing:

SiO_2	52.8%
Al_2O_3	1.6
FeO	34.0
MgO	8.2
MnO	0.5
CaO	1.0
Na_2O	0.5

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[32] Dr. Hilding G. Olsen, Associate Professor Of Mechanical Engineering, Colorado State University, Fort Collins, Colorado. Correspondence dated December 2, 1975.

[33] Mr. Paul B Smith, Regional Representative, Radiation Program, U.S. Environmental Protection Agency, Denver, Colorado. Correspondence dated October 15, 1975.

In order to reclaim the tailing from the impounding area, dewatering of the material would be necessary. The Company is anticipating a substantial capital expenditure during the next three years to stabilize the impounding area and implement a water recycling program for the mine and mill.[34]

Molybdenum

Reports on the gradation and chemical analysis of molybdenum tailings in Colorado have been provided by the Climax Molybdenum Company for their Urad, Climax, and Henderson mines. Table 16 summarizes the gradation of these three tailing sources. The gradation range is shown in the particle size distribution curve of Figure 16.

Reported chemical and mineralogical compositions for these tailings are shown in Table 17. The use of the tailing from Climax is not recommended due to the presence of iron pyrite and its remote location.[35]

Coarse tailing produced by Moly Corporation at Questa, New Mexico, has the following average gradation:

100%	passing	3/4"	(19.1 mm)
65%	passing	1/2"	(12.7 mm)
28%	passing	3/8"	(9.52 mm)
2%	passing	4 mesh	
1%	passing	10 mesh	

No information is available on the chemical composition of this material, although it has been used for highway construction in New Mexico.[36]

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[34]Mr. Lawrence F. Jeffries, Environmental Manager, Homestake Mining Company, Lead, South Dakota. Correspondence dated October 16, 1975.

[35]Mr. James A. Brown, Environmental Control Engineer, Climax Molybdenum Company, Climax, Colorado. Correspondence dated October 28, 1975.

[36]Mr. Robert D. Williams, Materials and Testing Engineer, New Mexico State Highway Department, Santa Fe, New Mexico. Correspondence dated May 10, 1973.

Table 16. Grain size distribution of molybdenum tailings, in percent finer by weight.

Sieve Size (Mesh)	Empire Colorado[1]	Climax Colorado[2]	Empire Colorado[3]
14		99.8	
20		99.5	
28		98.5	
35	97	95.8	
48	90	89.5	88
65	76	81.1	78
100	65	70.7	66
150	54	60.3	55
200	35	50.0	48
270[4]		44.2	42
325[4]		41.5	38
400[4]		35.5	35

[1]Tailing for newly developed Henderson mines as reported by Mr. J. J. Ludwig, Manager of Mines, Climax Molybdenum Company, Golden, Colorado. Correspondence dated October 9, 1975.

[2]Tailing for Climax mines as reported by Mr. C. A. Corn, Climax Molybdenum Company, Climax, Colorado. Correspondence dated October 30, 1975.

[3]Tailing for recently closed Urad mine as reported by Mr. William R. Hinken, Mill Superintendent, Climax Molybdenum Company, Empire, Colorado. Correspondence dated October 9, 1975.

[4]U. S. Sieve series number.

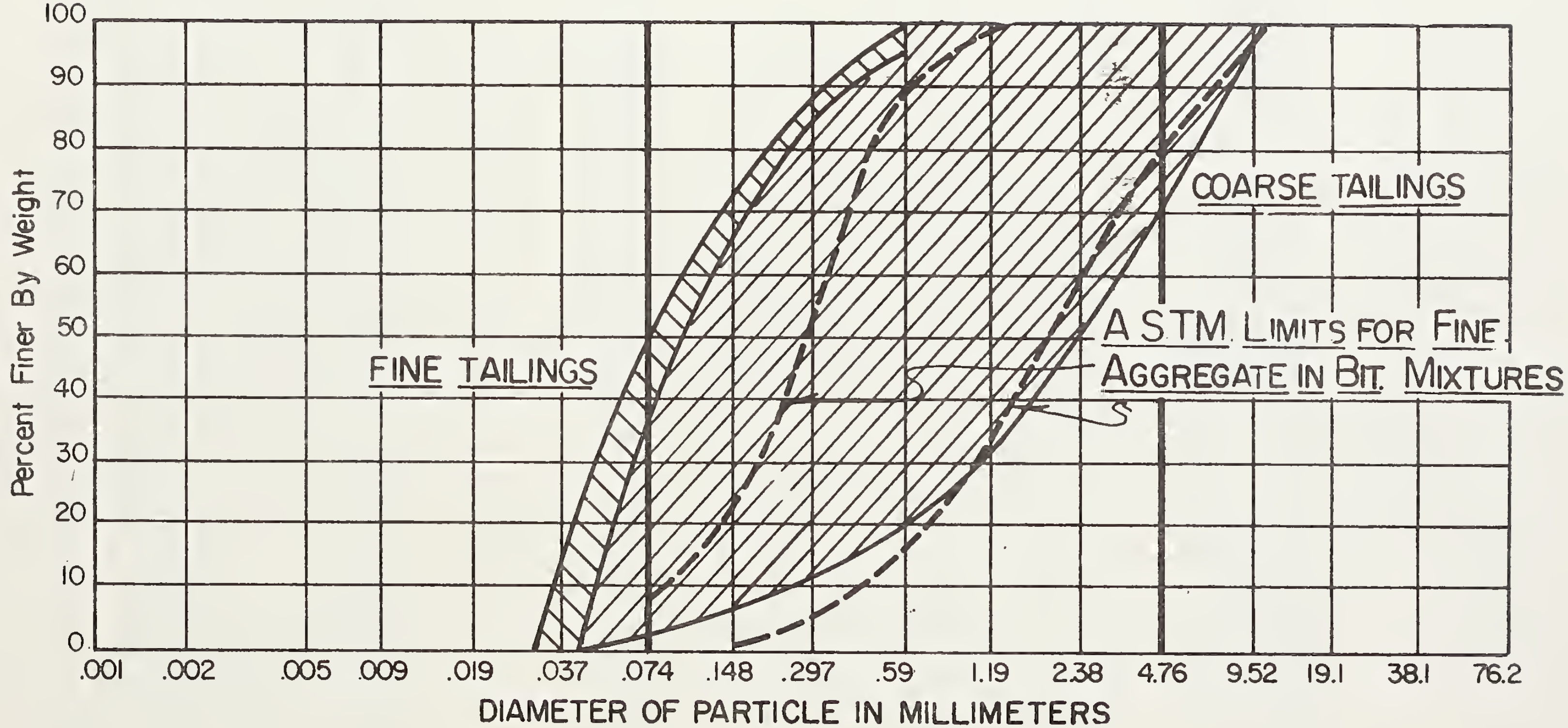

Figure 16. Gradation of molybdenum tailings.

Table 17. Chemical and mineralogical composition of molybdenum tailings, in percent by weight

Henderson Mine[1]		Climax Mine[2]	
SiO_2	75 - 80	Quartz	35 - 45
Al_2O_3	7 - 12	Alkali Feldspar	18 - 23
Fe_2O_3	0.2 - 3	Plagioclase	13 - 17
FeO	~1	Mica	4 - 6
MgO	~0.1	Pyrite	4 - 6
CaO	0.12 - 1	Clay Minerals	4 - 6
Na_2O	0.5 - 4	Fluorite	2 - 4
K_2O	4 - 8	Limonite	1 - 3
		Calcite	1 - 3
		Magnetite	0.5 - 1.5
		Topaz	0.5 - 1.5
		Rutile	0.5 - 1.5

[1]Reported by Mr. J. J. Ludwig, Manager of Mines, Climax Molybdenum Company, Golden, Colorado. Correspondence dated October 9, 1975.

[2]Reported by Mr. C. A. Born, Climax Molybdenum Company, Climax, Colorado. Correspondence dated October 30, 1975.

Phosphate

Very little data has been received concerning the nature and properties of phosphatic sand tailings, aside from the fact that the size of the particles ranges 16 to 150 mesh (1.0 to 0.1 mm), which is in the size range of a fine to medium sand. These sand tailings are composed of ninety percent quartz sand, eight percent carbonate fluorapatite, with the remaining two percent being feldspar and heavy minerals. Since most of the sand tailings in the industry are used for land reclamation or to help dewater slimes, little, if any, of this material would be available for highway construction.

Phosphogypsum occurs as plates or aggregates, roughly 100 microns in size and contains eighty-eight percent gypsum, eight percent quartz sand, two percent carbonate fluroapatite, and two percent Na_2SiF_6, along with some interstitial weak phosphoric acid.[37] Figure 17 shows a typical sample of phosphogypsum produced in the central Florida phosphate region.

Alumina

Information on a sand-type by-product from aluminum refining known as "pisolites" was provided by one producing plant. The grain size distribution of the material from this plant is as follows:

100 percent passing	1/2" (12.7 mm)
35 percent passing	40 mesh
12 percent passing	60 mesh
2 percent passing	200 mesh

This gradation indicates that the material is predominantly a coarse to medium sand with some fine gravel particles. It is composed of fifty percent Fe_2O_3, ten percent Al_2O_3, with the remainder being silica and other oxides.[38] Figure 18 shows a sample of this material recently received from the plant.

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[37]Mr. William C. Warneke, Geologist, Smith-Douglas Division, Borden Chemical, Inc., Plant City, Florida. Correspondence dated December 16, 1975.

[38]Mr. J. W. Melancon, Works Manager, Kaiser Aluminum and Chemical Corporation, Baton Rouge, Louisiana. Correspondence dated December 5, 1975.

Figure 17. Sample of phosphogypsum, (Scale in inches).

Figure 18. Sample of alumina refining waste (pisolites) (Scale in inches).

Other Tailing Materials

The only information concerning silver tailings was from a company in Colorado, noting that tailing from their plant is minus 60 mesh with the greater portion being minus 100 mesh.[39] No chemical analysis was provided.

Spent oil shale is a black residue which remains after oil shale is retorted to vaporize an organic oil-bearing substance called kerogen. Spent oil shale can range in size from a very fine ash (minus 200 mesh) to relatively large chunks, up to nine inches (228 mm) or more in diameter. Figures 19 and 20 show samples of a coarse and fine spent oil shale sample received from two experimental retorting sites in Colorado. Because of its large particle size, the coarse spent shale more closely resembles waste rock. The nature of the spent shale will depend to a great extent on the type of retorting process used.

A study was made of the feasibility of spent oil shale as a highway construction material. The spent shale was from a process that produced large chunks of material graded from nine inches (228 mm) to less than 200 mesh. The material was crushed to a maximum size of 3/4 inch (19.1 mm) and was described as a relatively dense, well-graded aggregate. No further gradation information is available for either spent shale. (44)

The preceding has been a description of all information received on mill tailings. Subsequent portions of this chapter will describe other classifications of mining and metallurgical wastes.

4.3.3 Coal Refuse

At the present time, there are approximately 4800 active coal mines located in twenty-four coal-producing states. (117) More than 600 million tons (540 Mtonnes) of coal are being mined each year in the United States. Although this total is somewhat less than the peak coal production of over 800 million tons (720 Mtonnes) in 1947, coal production has been increasing in recent years. In this age of energy shortages, the prospects are for even more dramatic increases in coal production in the foreseeable future.

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[39] Mr. Alfred G. Hoyl, Coronado Silver Corporation, Rollinsville Colorado. Correspondence dated December 2, 1975.

Figure 19. Sample of coarse spent oil shale (Scale in inches).

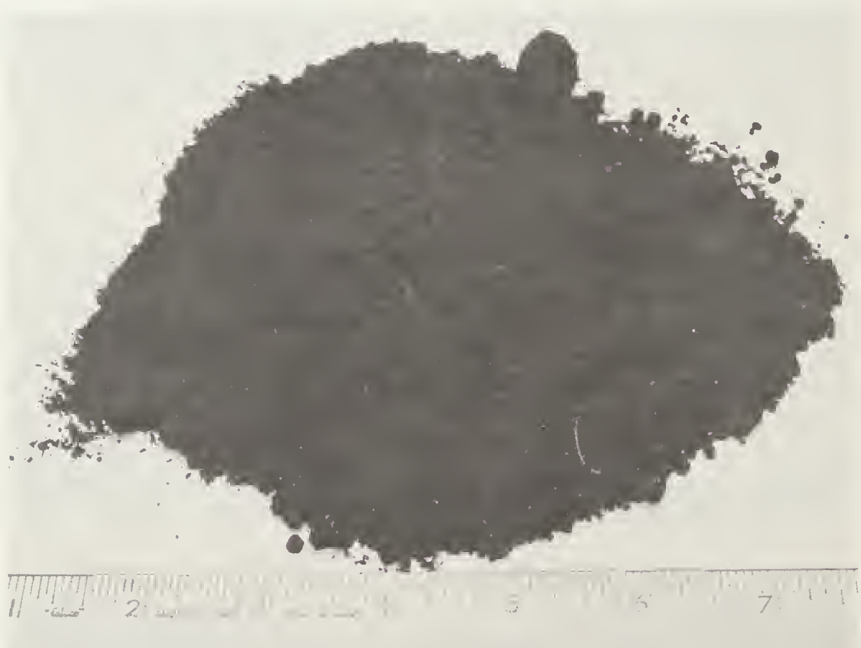

Figure 20. Sample of fine spent oil shale (Scale in inches).

4.3.4 Coal Refuse - Sources, Locations and Estimated Quantities

More than ninety-five percent of the coal mined each year in the United States is bituminous coal, with the remainder being anthracite and lignite coal. The leading coal producing states in 1974 were Kentucky, West Virginia, Pennsylvania, Illinois, Ohio, Virginia, Indiana, Wyoming, Alabama, and Montana, in that order. Table 18 presents a breakdown of the amount of coal mined in each coal producing state during 1974 and the mining method used. (127)

The primary markets for coal are metallurgical coking plants and steam production at power generating stations The quality and gradation of the coal required for a particular market determines the need for preparation of the coal prior to shipment. Generally, most of the steam coals are not cleaned and prepared, while many of the metallurgical coals are cleaned and prepared. A higher percentage of deep-mined coals are prepared than strip-mined coals.[40]

Although coal mining has been a substantial asset to our nation's economy, it has left the unfortunate legacy of its productivity in the form of unsightly refuse banks, commonly termed "gob piles" or "culm banks." These banks, while being aesthetically unattractive, present the added disadvantages of contributing to air and water pollution through spontaneous combustion, airborne particulates, and acid mine drainage, while usurping otherwise valuable land. Unfortunately, many of these offensive heaps of material are situated relatively close to, and sometimes actually in, populated areas, particularly in the Appalachian region.

Coal refuse is produced at the preparation plant as the discard from the coal preparation and cleaning process. In the preparation of coal, various mineral processing techniques are used to separate the coal from unwanted foreign matter. The equipment most frequently used in these plants operates on the principle of the differences in specific gravity between the coal and host rock.

Coal refuse is a variable material. The amount of refuse produced at a specific location depends on the quality or yield of the coal seam. The higher the yield, the less the

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[40]Mr. Donald W. Cooper, Assistant Director for Coal Preparation, United States Steel Corporation, Pittsburgh, Pa. Personal communication.

Table 18. Coal production by state.

State	Total Coal Produced (thousand tons)	Percent Underground	Percent Surface & Auger	Rank
Alabama	19,725	38.6	61.4	9
Arizona	6,432	----	100	16
Arkansas	445	0.7	99.3	24
Colorado	6,960	47.1	52.9	15
Illinois	58,073	53.6	46.4	4
Indiana	22,601	0.6	99.4	7
Iowa	680	59.2	40.8	22
Kansas	679	----	100	23
Kentucky	136,769	46.8	53.2	1
Maryland	2,170	4.2	95.8	21
Missouri	4,625	----	100	18
Montana	13,677	0.1	99.9	10
New Mexico	9,669	8.1	91.9	11
North Dakota	7,400	----	100	14
Ohio	45,352	31.8	68.2	5
Oklahoma	2,375	----	100	20
Pennsylvania	80,042	52.9	47.1	3
Tennessee	7,681	44.2	55.8	13
Texas	7,684	----	100	12
Utah	6,047	100	----	17
Virginia	34,284	66.1	33.9	6
Washington	3,915	0.4	99.6	19
West Virginia	101,714	80.8	19.2	2
Wyoming	20,650	0.2	99.8	8
TOTAL	601,000	45.6	54.4	

NOTE: Alaska production included in total figure, but not shown in state production figure.

NOTE: 1 short ton =0.9072 metric tons.

amount of refuse produced. At the present time, more than half of all coal is prepared and cleaned. It has been estimated that approximately 100 million tons (90 Mtonnes) of coal refuse are being generated annually. Therefore, the average amount of refuse produced is approximately twenty-five to thirty percent of the total amount of coal which is prepared and cleaned. Table 19 summarizes the number of cleaning plants and estimated coal refuse production by state.

The location, magnitude, and physical condition of the hundreds of refuse banks that dot the landscape of our nation's coal-producing areas have been fairly well documented. Figure 2 shows the locations of coal refuse as determined from a review of the literature.

During the late 1960's, the U.S. Bureau of Mines surveyed and identified a total of 863 refuse banks containing an estimated 910 million cubic yards (695 million cubic meters) of material in the Pennsylvania anthracite region (70). Locations of burning or burned-out coal refuse banks throughout the United States have been reported by McNay (75). Many of these banks are still burning to some extent, despite efforts to extinguish the fires.

As a result of the Buffalo Creek disaster in West Virginia, the locations of bituminous coal waste banks and impoundments were determined and their stability characteristics analyzed. Reports of studies performed by the U.S. Army Corps of Engineers (111) and the U.S. Department of the Interior (118) were used to locate coal refuse banks in the bituminous coal regions throughout the United States. Since quantity estimates were not always available from the reports, it is virtually impossible to precisely determine the total amount of material contained in these banks. However, Vogely (122) reported in 1965 that over 1.5 billion tons (1.35 Gtonnes) of bituminous coal waste had accumulated at that time and there has probably been nearly one billion tons (900 Mtonnes) of additional coal refuse since then.

Aside from coal refuse from preparation plants, there is little else in the way of solid waste generated by the coal mining industry. Because of recently enacted mining legislation in most mining states, mine waste and overburden from the coal strip mines are being stockpiled for ultimate disposal back into the excavations and reclamation of the mined area for future land development. There is little, if any, mine waste generated in the mining of coal from underground mines, once the tunnels have been extended to the coal seam.

Table 19. Estimated production of coal refuse by state, in thousand tons.

State	Total Coal Produced	Number of Cleaning Plants[1]	Percent Cleaned Coal	Estimated Refuse Production
Alabama	19,725	21	60	4,000
Arizona	6,432	----	----	----
Arkansas	445	----	----	----
Colorado	6,960	3	25	400
Illinois	58,073	33	80	13,500
Indiana	22,601	9	90	5,500
Iowa	680	----	----	----
Kansas	679	2	100	200
Kentucky	136,769	69	40	18,000
Maryland	2,170	1	N.A.	N.A.
Missouri	4,625	2	20	300
Montana	13,677	----	----	----
New Mexico	9,669	1	10	300
North Dakota	7,400	----	----	----
Ohio	45,352	20	40	6,000
Oklahoma	2,375	----	----	----
Pennsylvania	80,042	89	60	15,000
Tennessee	7,681	5	20	400
Texas	7,684	----	----	----
Utah	6,047	5	60	1,000
Virginia	34,284	43	60	7,000
Washington	3,915	1	100	1,400
West Virginia	101,714	142	85	26,000
Wyoming	20,650	1	5	300
TOTAL	601,000	447	50	99,300

[1]SOURCE: 1975 Keystone Coal Industry Manual, McGraw-Hill Mining Information Services, New York.

NOTE: 1 short ton =0.9072 metric tons.
N.A. denotes not available.

In addition to the reports noted above, there have been other efforts made in some areas to identify and quantify the locations and amounts of coal refuse, especially in the states of Illinois and Indiana. The results of these efforts have been helpful in further identifying the locations of coal refuse piles in those states and deserve further mention.

The Cooperative Wildlife Research Laboratory of Southern Illinois University has published a report entitled, "Problem Sites - Surface Mined Lands in Illinois", which identifies 290 refuse banks throughout the state which were formed from the preparation of surface-mined coal. This report also presents source and quantity data for these refuse bank locations. A similar study is presently being conducted for the state of Illinois, Institute for Environmental Quality, also by Southern Illinois University, to survey the environmental effects of coal refuse from the preparation of underground-mined coal.[41]

During 1971 and 1972, the Earth Satellite Corporation conducted an aerial survey of the coal refuse piles in the state of Indiana under the auspices of a grant from the National Aeronautics and Space Administration. This remote sensing inventory revealed that there were 149 coal refuse piles two acres or larger in size located in fifteen counties in southwest Indiana. This study is believed to be the only one of its type made to date.

Because of the hundreds of coal refuse piles which are presently in existence, it was decided to indicate their location on individual state maps in terms of the areas where such piles are located, instead of the locations of specific banks. These maps are shown in Volume II of this report. Precise locations of refuse banks can be readily determined by referring to one of the reports noted in the list of references at the end of this report. (70, 74, 118)

4.3.5 Coal Refuse - Physical Characteristics

Coal refuse can be classified as coarse and fine; with the dividing size usually being the No. 4 sieve. The amount of coarse refuse produced is about seventy to eighty percent by weight of the total refuse. The remaining

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[41] Mr. Thomas O. Glover, U.S. Bureau of Mines Liason Officer for Illinois, Springfield, Illinois. Correspondence dated July 11, 1975.

twenty to thirty percent is a silt or slurry material.

The coarse refuse from the preparation of anthracite and bituminous coals is similar in physical appearance, being a dark grey material composed largely of slate or shale particles with some coal, sandstone, and clay intermixed. Some bituminous coal seams contain greyish rock which, when disposed in a refuse bank, will weather easily and decompose into silt or clay-size particles over a comparatively short period of time (several days to a week). Most older refuse banks contain a fairly high percentage of carbonaceous material, which because of poor refuse disposal practices in the past, often became burning banks. Hence, a number of these banks can be expected to contain some incinerated coal refuse, termed "red dog," because of its reddish color.

Samples of anthracite and bituminous coal refuse exhibit a marked similarity in their physical appearance. Figure 21 shows a typical sample of coarse anthracite coal refuse, obtained from the Eastern Middle Field in northeastern Pennsylvania. Figure 22 shows a typical sample of coarse bituminous coal refuse, obtained from western Pennsylvania. Another bituminous coal refuse sample, obtained from northern West Virginia, is shown in Figure 23. These figures all depict material with a widely ranging gradation consisting of a mixture of rock, flat shale or slate particles, some coal, and varying amounts of pyrite.

A dried coal waste slurry from the Eastern Middle Field in northeastern Pennsylvania is shown in Figure 24. This material can be considered as representative of fine coal refuse throughout the country. Most of these deposits are somewhat similar, at least in size and appearance, to the fine mill tailings described earlier in this report.

Several studies have been conducted to determine the physical properties of coarse and fine coal refuse in this country. The most recently completed studies were reported by the U.S. Bureau of Mines Spokane Mining Research Center (13, 14) and Michael Baker, Jr., Inc. (4) In these studies, samples of coarse and fine coal refuse were obtained in the field and laboratory investigations were performed to determine the engineering properties of these materials.

A summary of the composite findings of grain size analyses for coarse coal refuse from these studies is presented in Figure 25. The material is well graded with nearly all particles less than 4 inches (101.6 mm). The difference in the range of particle sizes can be attributed to a varia-

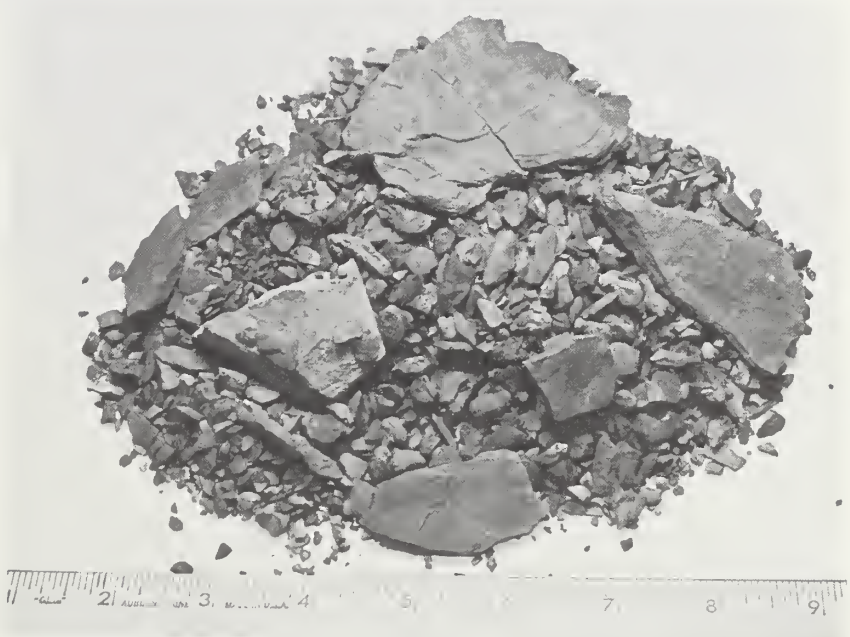

Figure 21. Sample of anthracite coal refuse (Scale in inches).

Figure 22. Sample of bituminous coal refuse from Pennsylvania (Scale in inches).

Figure 23. Sample of bituminous coal refuse from West Virginia (Scale in inches).

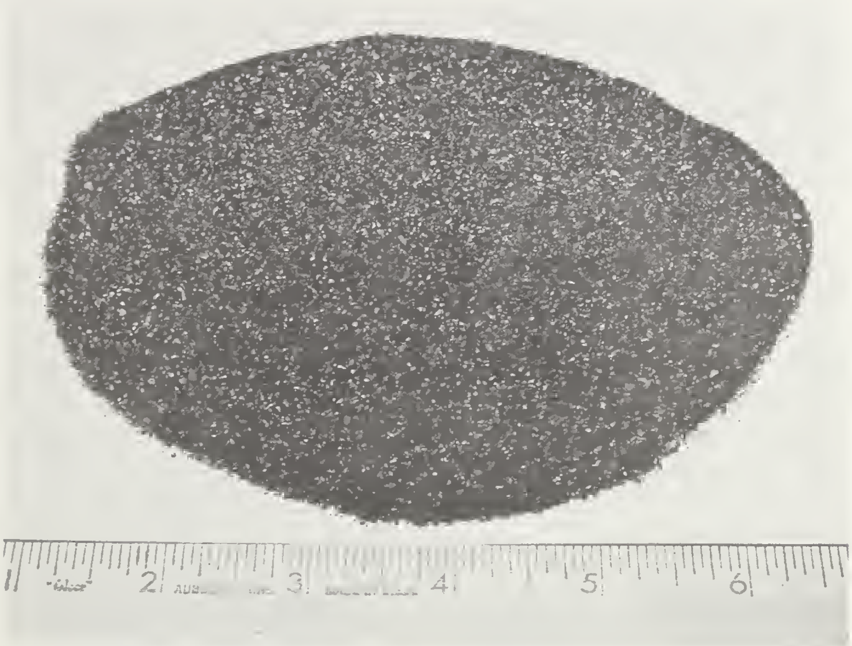

Figure 24. Sample of anthracite coal slurry (Scale in inches).

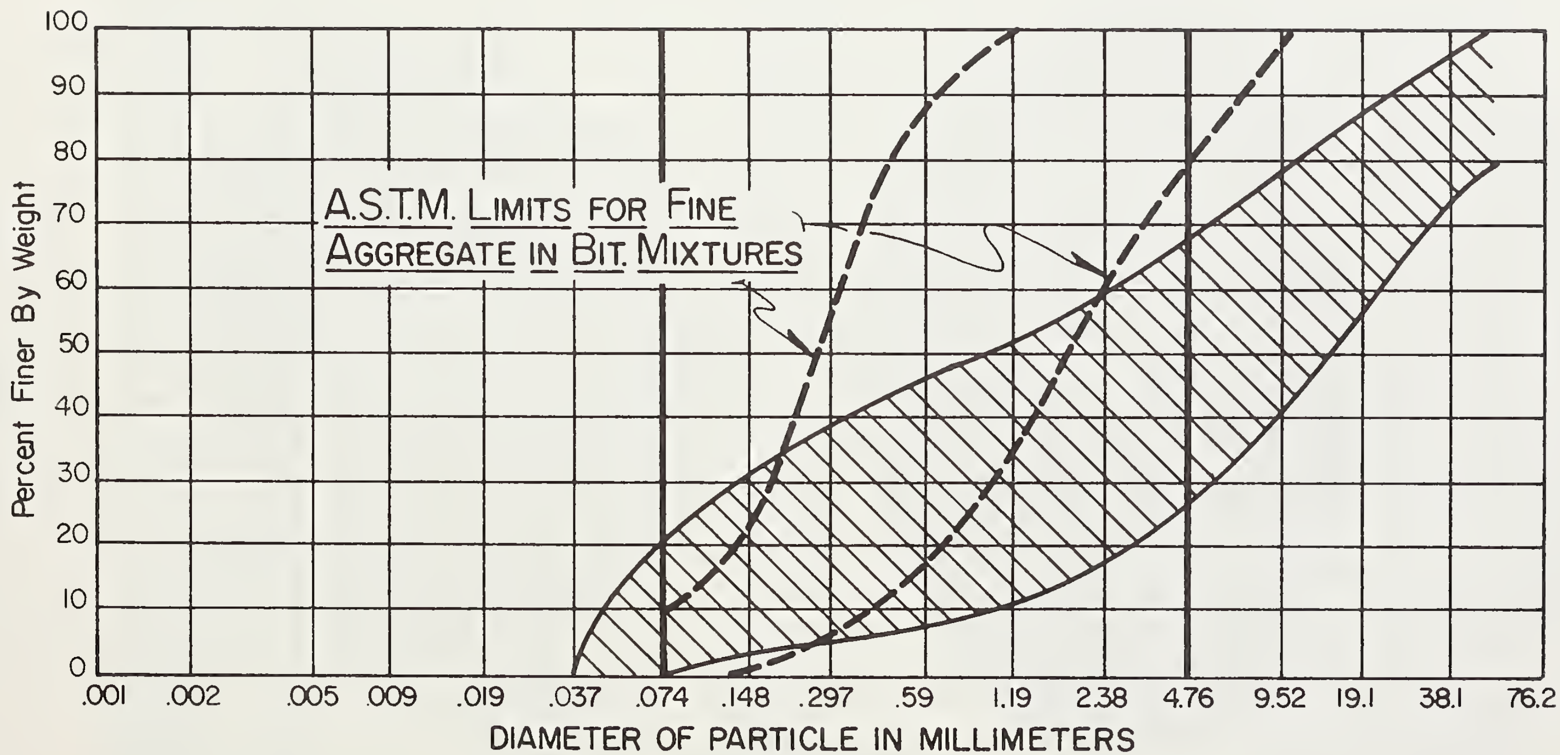

Figure 25. Gradation of coarse coal refuse.

tion in the processing methods employed at different coal preparation plants. A similar summary for fine coal refuse is presented in Figure 26. For the most part, fine refuse is more uniform in gradation than coarse refuse. Baker studied the effects of weathering and compaction on the particle size distribution of coarse coal refuse and concluded that both factors contribute equally to the degradation of coal refuse and subsequent increase in its fine content (4).

Laboratory tests were also conducted to determine specific gravity, Atterburg limits, permeability, compaction characteristics, unconfined compression and shear strengths. A substantial number of these tests were performed by Baker and the U.S. Bureau of Mines, results of which are presented in detailed fashion in their respective reports.

The results of these tests indicate that physical properties of coarse coal refuse (notable density, permeability, and shear strength) are fairly uniform once the refuse is compacted to its maximum dry density and that coarse coal refuse, if properly compacted in the field, can be a useful engineering material (4). However, these same physical properties and field moisture conditions of coal slurry combine to make deposits of this material unstable with very little strength carrying capability (14). Baker has recommended that coal slurry be utilized as a fuel rather than as a construction material (4).

4.3.6 Coal Refuse - Chemical and Mineralogical Properties

In the research for this project, there was little discovered in the way of chemical analyses of coal refuse. Instead, most of the data available is in the form of proximate or ultimate coal analyses.

It is well known that coal refuse does contain a certain amount of sulfur-bearing minerals, such as pyrite and marcasite, and that the leachate from these minerals is acidic in nature. In a study of anthracite refuse, Pennsylvania State University determined that it contained from 3.0 to 4.4 percent pyrite (69). There is also a variable percentage of coal contained in refuse, the amount of which depends upon the efficiency of the coal preparation plant.

The U.S. Bureau of Mines reports the findings of an atomic absorption analysis on its coarse coal refuse specimens that identifies iron, magnesium, potassium, and sodium as the most predominant chemical components, particularly iron (13). In the companion study, coal slurry was

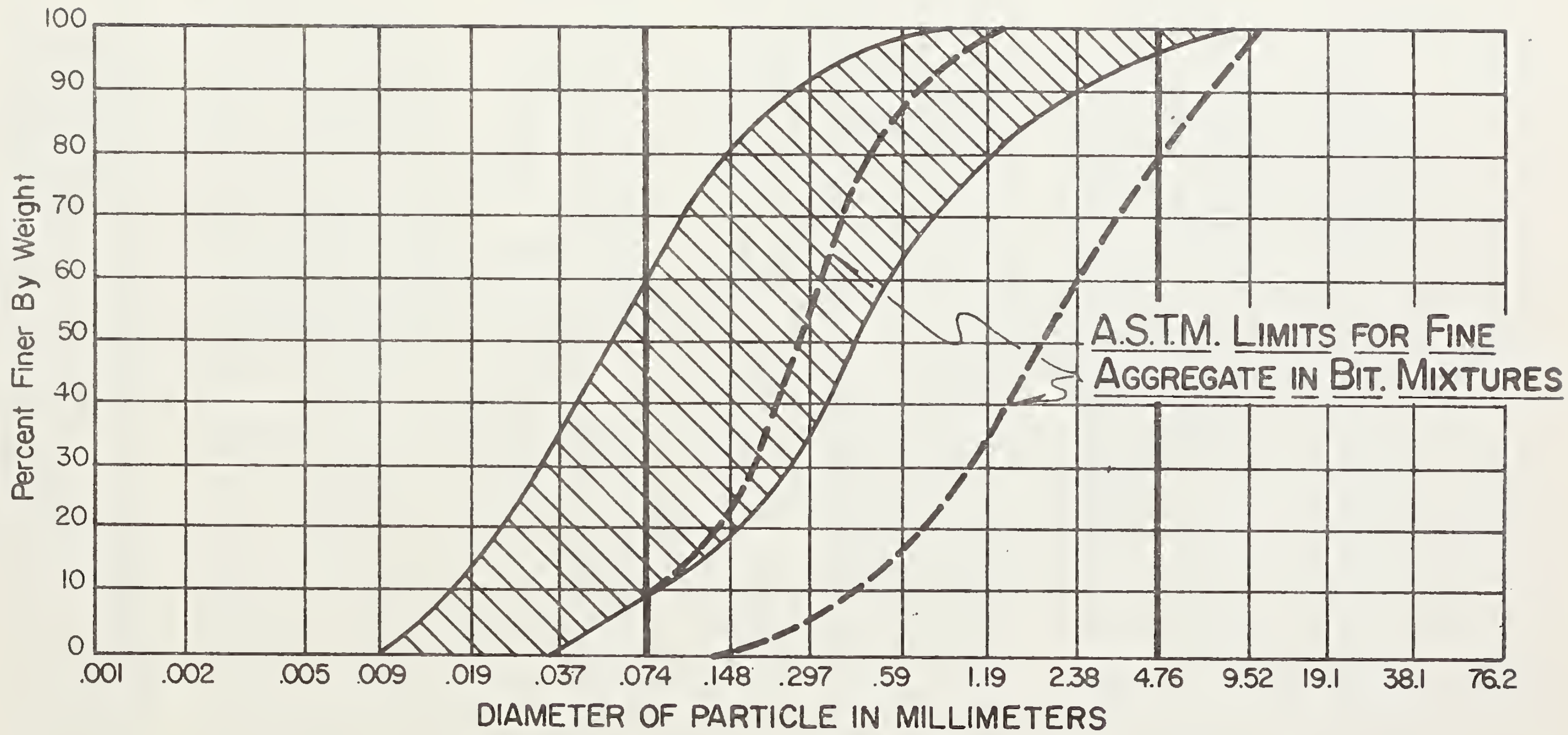

Figure 26. Gradation of coal slurry.

analyzed chemically and found to contain sixty percent silica (SiO_2), twenty-five percent alumina (Al_2O_3), and seven percent iron oxide (Fe_2O_3). (14)

The North American Coal Company's Ohio Division at Powhatan Point, Ohio, reports that a chemical analysis of their refuse indicated the following composition:[42]

Silica (SiO_2)	60.16%
Alumina (Al_2O_3)	25.81%
Iron Oxide (Fe_2O_3)	3.27%
Titania (TiO_2)	1.16%
Lime (CaO)	0.12%
Magnesia (MgO)	0.84%
Alkali Oxides (Na_2O, K_2O)	0.59%

Other chemical analyses performed by Baker (4) and Butler (15) mainly involved a determination of percent of soluble sulfate (SO_3) and pH levels of the refuse in accordance with the standard methods of test developed by the British National Coal Board Standard 1377:1967 for Testing of Colliery Spoil. Anthracite refuse samples had a mean of .03 percent for sulfate and 5.2 for pH. Bituminous refuse samples had a mean of .02 percent for sulfate and 4.5 for pH. (15)

4.3.7 Coal Refuse - Availability

Although coal refuse is being generated at the rate of 100 million tons (90 Mtonnes) per year and there are an estimated 2.5 billion tons (2.25 Gtonnes) of this material currently in place, it should not be assumed that all of this material is available for possible use. There are several factors involved which serve to restrict the amount of this material available for use.

In the first place, establishing the ownership of some of these refuse piles can sometimes be a difficult, costly, and time-consuming process, particularly if the bank is an

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[42]Mr. Michael J. Gregory, Preparation Manager, North American Coal Company, Powhatan Point, Ohio. Correspondence dated December 17, 1975.

abandoned or so-called "orphan" spoil bank. Records are usually kept of the ownership of coal refuse banks by tax assessment or deed recording offices at the county level. However, for older, inactive banks, records may be inaccurate or, worse yet, unavailable. It is also possible that one person or company may own title to the land, while another person or company may hold mineral rights to a refuse bank and to the underlying material (4).

Some refuse banks in the anthracite and bituminous coal regions are being reworked to reclaim coal values from them. As the price of coal increases, such practices may become more economically attractive. It has also been reported that the Allegheny Electric Power Company has used coal slurry as fuel for their power generating boilers.[43] There are also other instances in which coal refuse and/or slurry has been used directly as a fuel or blended with higher grade coals for this purpose.

Concern over the haphazard disposal practices of coal mining in the past have prompted most states to enact much stricter legislation controlling the present disposal and ultimate land reclamation activities at mining sites. Although the wording and requirements may be somewhat different, the net effect of these laws is to require that the land devoted to active disposal sites and mined areas be utilized in accordance with previously approved plans and ultimately be restored to its natural conditions.

As a result of these improved practices, most coal refuse disposal areas are now being operated as controlled fill sites, with proper grading and the employment of layering and compaction techniques. Some abandoned refuse banks are also being reclaimed with the long-range objective of restoring the land for some useful purpose. Since these activities preclude to a certain extent the availability of coal refuse for other uses, it is important to be aware of reclamation efforts when considering the possible use of a specific material source.

There is also a certain amount of coal refuse used by the coal companies themselves to construct or maintain mine haul roads or roads to disposal areas. This is a common practice among the coal companies and the refuse material

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[43] Raymond Henderson, Vice President, Consolidation Coal Company, Christopher Division, Osage, West Virginia. Personal communication.

has usually performed well in such applications. The construction use of coal refuse and other mining and metallurgical wastes will be more fully discussed in a later chapter of this report.

Despite the above factors, it is still recognized that many millions of tons of coal refuse are readily available. However, the availability of each particular source of refuse must be carefully investigated and will probably be decided on a case-by-case basis.

4.3.8 Metallurgical Slags

In order to convert certain concentrated metallic ores into useful metals, metallurgical heat treatment or smelting processes are employed. The concentrated ores constitute the feed to the blast or reverberatory furnace. Coke is normally used as the fuel and, depending on the character of the ore, a fluxing material, such as limestone, is added to permit melting and allow the molten metal to settle to the bottom of the furnace as a matte, where it can be tapped off.

Although smelting practices vary with different metals, all processes are similar insofar as the heavier matte is collected at the bottom of the furnace, while the lighter residual materials are skimmed off the top surface in the form of a molten slag.

Despite the fact that metallurgical slags have different origins, they are all somewhat loosely related because they are derived from similar elevated heat treatment methods and employ similar cooling and processing techniques. This section of the report will discuss the sources, locations, available quantities, and characteristics of these slag by-products. Their use as materials for highway construction will be discussed in Chapter 5 of this report.

Iron Blast Furnace Slag

Blast furnace slag has been defined as "the non-metallic by-product, consisting essentially of silicates and aluminosilicates of lime and other bases, which is developed simultaneously with iron in the blast furnace" (57). Because of its wide acceptance as an all purpose construction material, blast furnace slag can rightfully be considered more of an aggregate source than a waste product.

The most recently available figures indicate that thirty million tons (27 Mtonnes) of blast furnace slag were produced during 1974.[44] Table 20 lists the principal areas producing blast furnace slag.[45] These locations are shown in Figure 3. Most slag-producing areas have associated slag dumps. Leading slag-producing states are Pennsylvania, Ohio, Illinois, Indiana, and Maryland.

There are three basic types of blast furnace slag: air-cooled, granulated, and expanded. These slags are characterized by the methods used to cool the molten slag.

Air-cooled slag is dumped into open pits where it gradually loses its heat and is then broken up and removed by heavy equipment. Granulated slag is cooled by sudden quenching in water, causing it to crystallize into sand-size particles. Expanded slag is a foamed lightweight product which is formed by the application of water sprays on the molten slag for short periods of time in limited quantities (less than that required for granulation). Air-cooled slag presently comprises approximately ninety percent of all blast furnace slag being produced (57).

Figure 27 shows a typical sample of air-cooled blast furnace slag, while Figure 28 shows a typical sample of granulated blast furnace slag. Air-cooled slag is removed from the cooling pits periodically by slag processors and crushed into specified size ranges by conventional crushing and sizing equipment.

There are a few blast furnace locations in the United States which produce iron from a ferro-manganese ore and in the process generate a ferro-manganese slag. This slag, shown in Figure 29 is a very non-uniform product and is not recommended for any use other than as fill material.

Blast furnace slag contains oxides of silica, alumina, lime, and magnesia, along with other minor elements. Since the raw materials charged into the blast furnaces are carefully selected and blended for quality and uniformity, the

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[44] U.S. Department of Interior, Bureau of Mines, Mineral Industry Surveys. "Slag-Iron and Steel in 1974."

[45] Mr. Donald W. Lewis, Chief Engineer, National Slag Association, Alexandria, Virginia. Correspondence dated April 21, 1976.

Table 20. Principal producing areas for blast furnace slag.

State	Location	Estimated Production[1]
Alabama	Birmingham	N.A.
	Gadsden	350
California	Fontana	850
Colorado	Pueblo	700
Illinois	Chicago	N.A.
	Granite City	N.A.
Indiana	Burns Harbor	1,100
	Gary	N.A.
Kentucky	Ashland	N.A.
Maryland	Baltimore	1,600
Michigan	Detroit	550
New York	Albany	1,500
	Buffalo	N.A.
Ohio	Cleveland	N.A.
	Lorain	90
	Middletown	N.A.
	Mingo Junction	N.A.
	Toledo	N.A.
	Warren	300
	Youngstown	N.A.
Pennsylvania	Bethlehem	750
	Conshohocken	160
	Johnstown	500

N.A. denotes information not available.

Footnotes placed at end of table, p. 98.

Table 20. Principal producing areas for blast furnace slag (continued).

State	Location	Estimated Production[1]
Pennsylvania	Midland	165
	Morrisville	N.A.
	Pittsburgh	N.A.
	Sharon	330
	Vanderbilt[2]	----
	West Aliquippa	N.A.
Texas	Houston	N.A.
Utah	Geneva	N.A.
West Virginia	Weirton	N.A.

[1]Expressed in thousands of tons per year.

[2]This location is a currently operating slag dump. It has been estimated that 4 million tons of granulated slag have accumulated in this dump. Information supplied by Robert C. Zellers, Executive Secretary of the Pennsylvania Slag Association in correspondence dated October 30, 1975.

NOTE: 1 short ton =0.9072 metric tons.

SOURCES: National Slag Association.

"Directory of Iron and Steel works of the United States and Canada." American Iron and Steel Institute, Washington, D.C., 1974.

Figure 27. Sample of air-cooled blast furnace slag (Scale in inches).

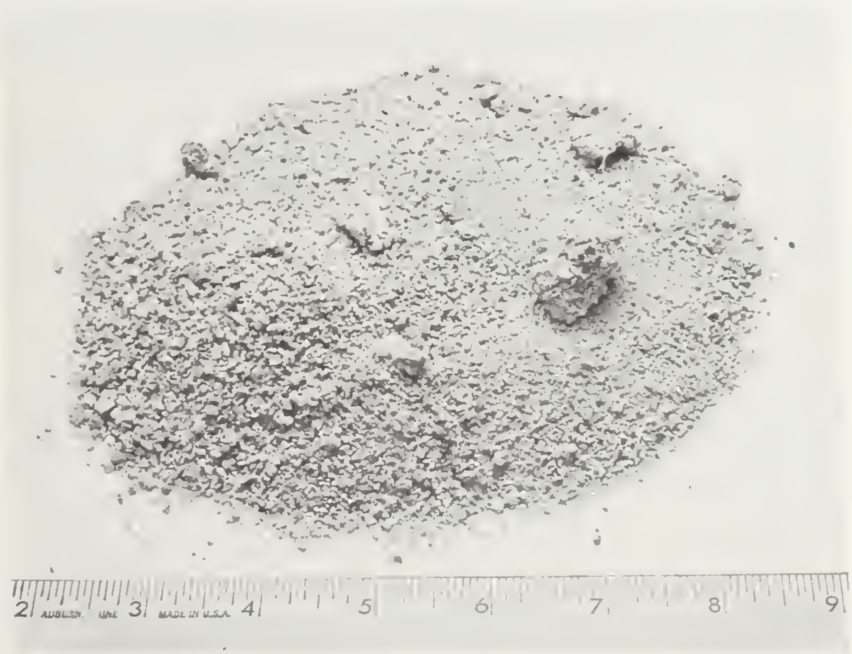

Figure 28. Sample of granulated blast furnace slag (Scale in inches).

Figure 29. Sample of ferro-manganese slag (Scale in inches).

composition of the slag from one blast furnace to another will vary within rather well-defined limits. Table 21 presents the reported chemical analyses of blast furnace slags produced by several of the largest steel companies in the United States. Examination of the figures in this table reveals the uniform composition of blast furnace slag.

There are many physical properties of air-cooled blast furnace slag which recommend its use as a construction material. It has high hardness, a vesicular (non-interconnected) pore structure, angular and interlocking particle shape, high durability and wear resistance, and is lighter (70 to 100 pounds per cubic foot or 1.1 to 1.6 grams per cubic centimeter) than conventional aggregates (57).

Blast furnace slag has become such a universally acceptable material for so many uses that practically all of the slag produced annually is being marketed. Many of the slag stockpiles which had accumulated in some areas over a thirty to forty year period have been diminished somewhat in recent years.

In certain cases, slag dumps are being graded and will eventually become part of land reclamation and future development, thereby making these materials unavailable. Another factor which may limit the highway use of blast furnace slag, specifically its use in Portland cement concrete, is the blending of blast furnace and steel slag. When the two slags are disposed together, the blast furnace slag is said to be "contaminated." Blended slag is used in some areas of the country for applications other than Portland cement concrete.[46]

The marketing of blast furnace slag is a function of the slag processors who contract with the steel companies for the complete handling of the slag from cooling to the crushing and selling of the graded product. Therefore, blast furnace slag is available only through purchase from a commercial slag producer.

<u>Steel Slag</u>

Slag is also produced in the making of steel, although the steel-making process differs somewhat from that of the blast furnace. In the blast furnace, the reduction of iron

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[46]Mr. William Kish, Heckett Slag Products, Butler, Pennsylvania. Personal communication.

Table 21. Chemical analysis of blast furnace slags[1].

Steel Company	Plant Location	SiO_2	Al_2O_3	CaO	MgO	S
Alan Wood Steel Co.	Conshohocken, Pa.	35.3	13.0	34.3	13.5	1.59
Bethlehem Steel Co.	Baltimore, Md.	36.5	12.3	35.0	12.7	1.60
	Bethlehem, Pa.	35.4	14.3	36.0	12.0	1.24
	Buffalo, N.Y.	34.7	12.2	39.2	12.2	1.70
	Johnstown, Pa.	35.7	10.6	38.0	13.7	1.60
Crucible Steel Co.	Midland, Pa.	34.0	10.0	38.3	15.6	----
Ford Motor Company	Dearborn, Michigan	35.9	10.5	36.0	13.0	1.13
Interlake, Inc.	Chicago, Illinois	36.0	10.0	23.0	14.0	1.50
Kaiser Steel Corp.	Fontana, California	36.0	9.6	32.4	18.3	1.19
Republic Steel Corp.	Chicago, Illinois	38.0	9.5	38.5	11.5	1.40
	Cleveland, Ohio	36.0	10.5	39.8	10.5	1.60
	Gadsden, Alabama	37.0	14.5	34.5	11.5	1.75
	Youngstown, Ohio	36.5	10.0	40.5	10.5	1.80
Sharon Steel Corp.	Sharon, Pa.	34.0	13.0	38.0	13.0	1.70
Youngstown Steel Co.	East Chicago, Indiana	36.0	11.0	39.0	12.0	2.21
	Youngstown, Ohio	35.5	9.4	39.0	14.3	1.20

[1]Chemical analysis expressed in percent by weight.

ore to pig iron is a continuous operation; the slag resulting from this process is a reasonably uniform by-product. On the other hand, the steel-making process is a batch process, which results in a non-uniform slag by-product.

During this steel-making process, part of the molten metal charge in the furnace becomes entrapped within the slag itself. There is, therefore, a certain amount of ferrous metal value contained in the slag.

After the slag has been tapped from the steel furnace, it is transported to pits where it is dumped and allowed to air cool prior to processing. Part of the processing operation involves the magnetic removal of the ferrous metal contained in the slag and its recycling back into the steel furnace. It has been estimated that ferrous metal may comprise twenty to twenty-five percent by weight of the steel slag.

Recent figures indicate that total steel slag production is from 10 to 12 million tons (9 to 10.8 Mtonnes) per year.[47] The principal producing areas of steel slag are listed in Table 22 and shown in Figure 3. The leading steel slag-producing states are essentially the same states that lead in blast furnace slag production.

The basic types of steel slag presently being produced are determined by the type of furnace operation employed in the steel-making process. The three types of furnaces used in making steel are the basic oxygen, electric arc, and open hearth. These processes differ in the composition of the charge, method of heating, and length of time required to produce the steel.

More than sixty percent of all current steel production originates from the basic oxygen furnace, which is to a large extent supplanting the open hearth furnace due to increased productivity. The electric arc furnace, using a charge that is almost totally scrap, comprises ten to fifteen percent of all current steel production. The remaining production is accomplished by means of the open hearth furnace.[48]

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[47]U.S. Department of Interior, Bureau of Mines, Mineral Industry Surveys. "Slag-Iron and Steel in 1974."

[48]Mr. Robert Pote, Jones and Laughlin Steel Company, Aliquippa, Pennsylvania. Personal communication.

Table 22. Principal producing areas for steel slag.

State	Location	Type(s)	Production[1]
Alabama	Birmingham	Open Hearth Basic Oxygen	N.A.[2]
	Gadsden	Basic Oxygen Electric Arc	N.A.
California	Fontana	Open Hearth	500
Colorado	Pueblo	Basic Oxygen Electric Arc	400
Delaware	Claymont	Electric Arc	55
Florida	Tampa	Electric Arc	N.A.
Illinois	Alton	Electric Arc	N.A.
	Chicago	Basic Oxygen Electric Arc Open Hearth	N.A.
	Granite City	Basic Oxygen	N.A.
	Peoria	Electric Arc	110
Indiana	Burns Harbor	Basic Oxygen	N.A.
	Gary	Basic Oxygen Electric Arc Open Hearth	N.A.
	Kokomo	Electric Arc	50
Kentucky	Ashland	Basic Oxygen	N.A.
Maryland	Baltimore	Basic Oxygen Open Hearth	N.A.
Michigan	Detroit	Basic Oxygen Electric Arc	N.A.
Missouri	Kansas City	Electric Arc	N.A.

Footnotes placed at end of table, p. 106.

Table 22. Principal producing areas for steel slag (continued).

State	Location	Furnace Type(s)	Estimated Production[1]
New York	Buffalo	Open Hearth Basic Oxygen	N.A. N.A.
Ohio	Canton	Electric Arc	184
	Cleveland	Open Hearth Basic Oxygen	765 (Combined)
	Lorain	Open Hearth	N.A.
	Mansfield	Electric Arc	N.A.
	Mingo Junction	Basic Oxygen	N.A.
	Warren	Basic Oxygen Electric Arc	360 (Combined)
	Youngstown	Open Hearth	450
Pennsylvania	Bethlehem	Basic Oxygen Electric Arc	N.A. N.A.
	Coatesville	Open Hearth Electric Arc	200
	Conshohocken	Basic Oxygen	205
	Johnstown	Open Hearth	300
	Middletown	Electric Arc	N.A.
	Midland	Basic Oxygen Electric Arc	150 50
	Morrisville	Open Hearth Electric Arc	N.A.
	Pittsburgh	Open Hearth Basic Oxygen Electric Arc	N.A.
	Phoenixville	Open Hearth	N.A.

Footnotes placed at end of table, p. 106.

Table 22. Principal producing areas for steel slag (continued).

State	Location	Furnace Type(s)	Estimated Production[1]
Pennsylvania (continued)	Sharon	Basic Oxygen	200
	West Aliquippa	Basic Oxygen	N.A.
Texas	Houston	Electric Arc	N.A.
Utah	Geneva	Open Hearth	N.A.
Washington	Seattle	Electric Arc	N.A.
West Virginia	Weirton	Basic Oxygen	800

NOTE: 1 short ton =0.9072 metric tons.

SOURCES: National Slag Association.

"Directory of Iron and Steel Works of the United States and Canada." American Iron and Steel Institute, Washington, I.C. , 1974.

[1]Expressed in thousands of tons per year.

[2]N.A. denotes information not available.

Figure 30 shows a sample of slag from a basic oxygen furnace. Figure 31 is a slag sample from an electric arc furnace. Figure 32 is a slag produced from an open hearth furnace. Because most of the past steel production used open hearth furnaces, the great majority of slag in existing dumps is probably open hearth slag.

As noted previously, there is considerable variability in the composition of steel slag. There are differences in the chemistry of steel slags produced in different types of furnaces and even in furnaces within the same company. Table 23 presents the findings of chemical analysis of various steel slags as reported by steel producers. This table illustrates the fact that the chemical composition of different steel slags is quite variable and unpredictable.

The National Slag Association has noted that "the quality and composition of steel-making slags as related to furnace type is a question that has been discussed on several occasions at meetings of our Association's Technical Committee. We finally concluded that the type of steel being produced and the philosophy of the furnace superintendent with respect to operating procedures probably were such major variables that no meaningful distinction by furnace type was possible. We tend, therefore, to lump them all together."[49]

Steel slag possesses a number of physical properties which must be recognized before considering its use in highway construction. It is a hard, dense, material, with a unit weight which normally ranges from 115 to 125 pounds per cubic foot (1.84 to 2.0 grams per cubic centimeter). The unit weight of steel slag is considerably higher than that of blast furnace slag and is also heavier than most conventional aggregates. Steel slag is very resistant to abrasion and wear, has an angular particle shape, and a vesicular pore structure. It is denser and harder than blast furnace slag, probably because of higher iron content.

One of the objectionable properties of all steel slags is their expansive tendency. This is caused by large amounts of free or unslaked lime (CaO) and magnesium oxide (MgO) which are contained in the slag. The unslaked lime will hydrate fairly rapidly (within a period of weeks) and its hydration will result in significant volume expansion.

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[49] Mr. Donald W. Lewis, Chief Engineer, National Slag Association, Alexandria, Virginia. Correspondence dated August 28, 1975.

Figure 30. Sample of basic oxygen furnace slag (Scale in inches).

Figure 31. Sample of electric arc furnace slag (Scale in inches).

Figure 32. Sample of open hearth furnace slag (Scale in inches).

Table 23. Chemical analysis of steel furnace slags, percent by weight.

Steel Company	Plant Location	Furnace Type	SiO_2	Al_2O_3	CaO	MgO	FeO[1]	MnO
Kaiser Steel Corp.	Fontana, Cal.	Basic Oxygen	23.0	0.7	40.6	6.7	27.2[1]	---
Keystone Steel & Wire	Peoria, Ill.	Electric Arc	14.3	4.2	49.9	4.8	20.7	5.1
Continental Steel Corp.	Kokomo, Ind.	Electric Arc	14.0	3.0	35.0	7.5	22.0	6.0
Ford Motor Company	Detroit, Mich.	Basic Oxygen	19.0	1.5	44.0	6.5	15.0	5.0
Youngstown Steel Co.	Youngstown, Oh.	Open Hearth	2.12	2.7	20.1	9.9	35.6[2]	8.3
	E. Chicago, In.	Basic Oxygen	11.0	1.0	43.0	9.4	18.1	10.3
Republic Steel Corp.	Buffalo, N.Y.	Basic Oxygen	19.5	1.2	58.6	2.9	6.4	3.1
	Chicago, Ill.	Electric Arc	8.9	7.2	42.1	7.6	25.5	6.7
	Chicago, Ill.	Open Hearth	9.8	2.8	47.3	6.6	27.3	5.1
	Cleveland, Oh.	Basic Oxygen	12.9	0.6	42.6	6.1	23.7	2.6
	Cleveland, Oh.	Open Hearth	16.4	0.9	29.6	5.4	28.6	6.1
	Gadsden, Ala.	Basic Oxygen	12.6	1.3	47.5	3.1	21.5	2.7
Crucible Steel Co.	Midland, Pa.	Basis Oxygen	23.2	---	43.6	---	5.1	3.4
		Electric Arc	22.4	3.2	32.5	3.1	2.7	3.2
Alan Wood Steel Co.	Conshohocken, Pa.	Basic Oxygen	18.0	2.0	45.4	6.7	19.0	---
Bethlehem Steel Co.	Johnstown, Pa.	Open Hearth	18.0	4.0	30.0	5.0	27.5[3]	5.0

[1]Expressed as Fe_2O_3

[2]Includes 8.8% as Fe_2O_3

[3]Average of values from 20 to 35 percent

However, the free oxides of magnesium hydrate much more slowly, causing volume changes that may continue for many years. (58)

The problem of the expansion of steel slag has been counteracted in a number of areas by subjecting the steel slag to a controlled aging process over a time period of six to twelve months. During this aging process, care is taken to make sure that the steel slag maintains a minimal moisture content in order to continue and accelerate the hydration reactions which result in volume expansion. Once the slag has been properly cured for a sufficient period of time, it should be acceptable for construction use in most cases.

There are two factors which tend to limit the availability of steel-making slags for further use. One is the fact that in many integrated steel plants, steel slag is used as feed material into the blast furnace in place of limestone because of its high free lime content. Therefore, at some plants where blast furnaces and the steel furnaces are located within the same operation, a relatively low percentage of steel slag may actually be available. The other factor is that some slag dumps are used as controlled fill areas. These areas are frequently planned as sites for future plant expansion. In this type of disposal, any future use of steel slag in constructing would be impossible.

Despite these factors, the great majority of the steel slag produced each year is being processed and marketed by slag producers. The following chapter will discuss experiences in utilizing steel slag for highway construction.

Copper Smelter Slag

The primary extraction processes used in the smelting of metallic concentrates to produce relatively pure metal products are similar in some respects to the reactions occurring in the blast furnace and the steel furnace. Copper concentrate is smelted in a furnace to obtain a copper-bearing matte and a by-product slag is formed. This slag is a hard, dense, dark grey, metallic material which is either air-cooled or granulated. Figure 33 shows a typical sample of an air-cooled copper smelter slag. Air cooled slags can range in size from 4 mesh and larger with chunks measuring up to several inches.[50] Figure 34 shows a typical sample of a

[50]Mr. Lee C. Travis, General Manager, American Smelting and Refining Company, Lake City, Utah. Correspondence dated November 14, 1975.

Figure 33. Sample of air-cooled copper smelter slag (Scale in inches).

Figure 34. Sample of granulated copper smelter slag (Scale in inches).

granulated copper smelter slag. Granulated slags have a nominal size of minus 8 mesh plus 100 mesh[51] diameter and the specific gravities for both of these materials are normally between 3.0 and 3.5.[52]

Copper smelter slags are principally produced in Arizona, although there are a number of smelters located in other states. At the present time, there are fifteen copper smelters in operation in the United States, seven of which are in Arizona (97). The locations of these smelters are shown in Figure 4. Table 24 lists the locations and estimated quantities of slag produced annually at these smelters.

These slags are basically iron silicates containing lime and alumina with small amounts of copper, lead, zinc, and other metals. The chemical composition of the furnace slags produced from a number of these smelters is given in Table 25. From examining these data, it appears that these slags are fairly uniform in their chemical composition, despite their various locations.

In several instances, the slag production from these plants is processed and marketed by a slag processor. This is the case in Ajo, El Paso, and Tacoma and may also be true at a number of other locations.

Cities Service Company presently consumes the bulk of the slag produced at its Copperhill, Tennessee, smelter for internal purposes. However, all companies that reported do have slag dumps with quantities ranging from a few hundred thousand to several million tons of slag available. Anaconda Company has reported that forty million tons (36 Mtonnes) of copper slag are readily available at their plant with highway and rail service to this site.[53]

The reverberatory furnace has been used extensively for many years in the smelting of copper, but federal and state air pollution regulations have brought about the introduction

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[51]Mr. R. D. Estes, Supervisor of Environmental Control, Cities Service Company, Copperhill, Tennessee. Correspondence dated November 17, 1975.

[52]Mr. C. H. Randt, Assistant Manager, American Smelting and Refining Company, Tacoma, Washington. Correspondence dated November 17, 1975.

[53]Mr. Jack B. McCoy, Metallurgist, Anaconda Company, Anaconda, Montana. Correspondence dated December 3, 1975.

Table 24. Location of domestic copper smelting facilities.

State	Location	Company	Annual Slag Production[1]
Arizona	Ajo	Phelps Dodge Corp.	170
	Douglas	Phelps Dodge Corp.	N.A.
	Hayden	A.S.A.R. Co.	350
	Hayden	Kennecott Copper Corp.	N.A.
	Miami	Inspiration Copper Co.	N.A.
	Morenci	Phelps Dodge Corp.	N.A.
	San Manuel	Magma Copper Co.	N.A.
Michigan	White Pine	White Pine Copper Co.	220
Montana	Anaconda	Anaconda Co.	350
Nevada	McGill	Kennecott Copper Corp.	N.A.
New Mexico	Hurley	Kennecott Copper Corp.	N.A.
Tennessee	Copperhill	Cities Service Co.	N.A.
Texas	El Paso	A.S.A.R. Co.	N.A.
Utah	Garfield	Kennecott Copper Corp.	600
Washington	Tacoma	A.S.A.R. Co.	200

[1]Expressed in thousand tons.

NOTE: 1 short ton =0.9072 metric tons.

N.A. denotes information not available

Table 25. Chemical analysis of copper smelter slags[1].

Copper Company	Location	Slag Type	SiO_2	FeO	CaO	Al_2O_3	Cu	S
Anaconda Company	Anaconda, Mont.	Granulated	36.0	33.5	4.5	4.5	0.6	1.3
A.S.A.R. Co.	Hayden, Ariz.	Air Cooled	38.0	42.0	6.0	6.0	0.5	1.0
A.S.A.R. Co.	Tacoma, Wash.	Air Cooled	38.0	33.0	6.0	4.0	0.4	---
Cities Service Co.	Copperhill, Tenn.	Granulated	30.0	43.0	1.2	2.2	---	2.2
Phelps Dodge Corp.	Ajo, Arizona	Granulated	35.8	35.4	5.0	7.2	0.5	1.0
White Pine Copper Co.	White Pine, Mich.	Air Cooled	42.0	17.0	20.0	12.0	1.3	---
Kennecott Copper Corp.	Garfield, Utah	Air Cooled & Granulated	37.0	37.0	4.0	5.0	---	1.0

NOTE: Small percentages of arsenic, lead, zinc, and magnesium have also been identified as constituents of copper smelter slag.

[1]Chemical analysis expressed in percent by weight.

of electric furnaces and flash smelting in order to comply with these regulations (97). Despite substantial expenditures by the industry to meet these air pollution regulations, several copper smelters in Arizona may be forced to close or severely cut back production because of the stricter air quality standards recently imposed by the Environmental Protection Agency, particularly the facilities at Miami, Hayden and Douglas.[54]

Lead Smelter Slag

Lead sulfide ores, concentrated at the mill to approximately sixty percent lead, are sintered in a blast furnace along with limestone, silica, and scrap iron to produce an impure lead bullion and a by-product slag. The slag is removed from the blast furnace and conveyed to a fuming furnace for the recovery of lead and zinc (114).

The resultant slag is most often produced as a black, glassy, granulated material, although some air-cooled slag is also produced. Figure 35 shows an air-cooled lead smelter slag which is quite porous and graded from the #4 mesh diameter up to 2 inch (50.8 mm) size.[55] Figure 36 shows a typical granulated lead smelter slag, which is normally graded in the coarse sand range from the 8 mesh diameter through the 60 mesh diameter particle size.[56] Lead smelter slag does not absorb moisture, retains its black color indefinitely, and has a hardness rating of six on the Mohs scale.[57]

There are six lead smelting facilities currently in operation in the United States, three of which are in Missouri. The locations of these smelters are shown in Figure 4. Table 26 lists the locations and estimated quantities of slag produced annually at these smelters.

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[54]Engineering and Mining Journal, February, 1976, p. 32.

[55]Mr. Lee C. Travis, General Manager, American Smelting and Refining Company, Salt Lake City, Utah. Correspondence dated November 14, 1975.

[56]Mr. Harvey L. Rowland, Chief Engineer, Amax Lead Company, Boss, Missouri. Correspondence dated November 12, 1975.

[57]Mr. J. E. McKay, Vice President of Technical Services, Bunker Hill Company, Kellogg, Idaho. Correspondence dated November 6, 1975.

Figure 35. Sample of air-cooled lead smelter slag (Scale in inches).

Figure 36. Sample of granulated lead smelter slag (Scale in inches).

Table 26. Location of domestic lead smelting facilities.

State	Location	Company	Annual Slag Production[1]
Idaho	Kellogg	Bunker Hill Co.	140
Missouri	Boss	Amax Lead Co.	40
	Glover	A.S.A.R. Co.	N.A.
	Herculaneum	St. Joe Minerals Corp.	
Montana	East Helena	A.S.A.R. Co.	160
Texas	El Paso	A.S.A.R. Co.	N.A.

[1]Expressed in thousand tons.

NOTE: 1 short ton =0.9072 metric tons.

N.A. denotes information not available

Lead smelter slags are somewhat similar in chemical composition to copper smelter slags, except that larger percentages of lead and zinc are contained in these materials. The chemical composition of lead smelter slags from three different locations is reported in Table 27. These analyses indicate some variation in composition between

Table 27. Chemical analysis of lead smelter slags, percent by weight.

	Bunker Hill Co. Kellogg, Idaho[1]	A.S.A.R. Co. East Helena, Mont.[2]	Amax Lead Co. Boss, Missouri[1]	St. Joe Minerals Herculaneum, Missouri[1]
SiO_2	29.0	26.0	22.0	22.8
FeO	32.0	36.0	20.0	35.9
CaO	20.0	21.0	14.0 avg.	9.8
Al_2O_3	7.0	----	----	----
MgO	----	2.0	4.5	4.4
MnO	2.0	----	----	----
Pb	----	0.1	3.1	2.7
Zn	----	2.0	12.5 avg.	10.2
S	----	----	1.5	2.0

[1]Produced as a granulated slag.
[2]Produced as an air-cooled slag.

different furnaces with an unusually high zinc content reported from the smelter in Kellogg, Idaho. It is possible that this slag sample from a lead-zinc ore was not de-zinced in a fuming furnace prior to disposal.

Although some use is being made of some of the annual slag production at certain smelters, there are large stockpiles of slag reported at each of these smelter locations, ranging from over one million tons (0.9 Mtonnes) at Boss, Missouri[58] to six million tons (5.4 Mtonnes) at East Helena, Montana.[59]

Despite the availability of the material, there is concern on the part of state environmental authorities, especially in Missouri, about the amounts of lead and zinc contained in the slag and the possibility that these components will become soluble through leaching action.[60] More specific information is needed on the possible leaching effects of these slags before recommending further use.

Zinc Smelter Residues

Zinc ores, like lead ores, are most often found in nature as sulfides, together with impurities of other metals. Concentrated zinc ores, containing approximately sixty percent zinc, are roasted and sintered to burn off excess sulfur and the resultant zinc oxide is metallurgically reduced by electrolytic or retort furnaces to produce metallic zinc, resulting in a slag residue (114).

These residues are produced as porous, reddish, brown or black, cohesionless, granular materials having hard, sharp, angular particles. Specific gravity values range from 2.18 to 3.14. Figure 37 shows a typical zinc retort residue. Particle sizes are generally well graded from 1/2 inch (12.7 mm) on down to 200 mesh. Some slag residues with larger particles from one to several inches in size are also produced at some smelters, as indicated in Figure 38.

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[58]Mr. Harvey Rowland, Chief Engineer, Amax Lead Company, Boss, Missouri. Correspondence dated November 12, 1975.

[59]Mr. Lee C. Travis, General Manager, A.S.A.R. Company, Salt Lake City, Utah. Correspondence dated November 14, 1975.

[60]Mr. Robert M. Robinson, P.E., Director of Solid Waste Management, Missouri Department of Natural Resources, Jefferson City, Missouri. Correspondence dated October 28, 1975.

Figure 37. Sample of zinc retort residue (Scale in inches).

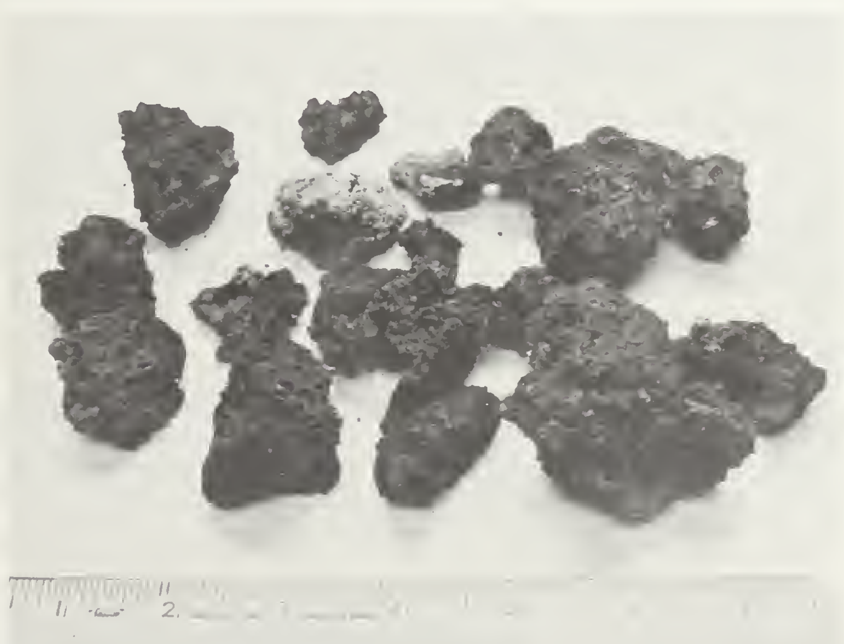

Figure 38. Sample of coarse zinc smelter residue (Scale in inches).

There are seven zinc smelting facilities currently in operation in the United States, as listed in Table 28. Slag-like smelter residues are produced at five of these plants. The facilities at Kellogg, Idaho, and Corpus Christi, Texas, use electrolytic processes that produce more of a sludge-like residue.

Three different types of residues are produced at New Jersey Zinc Company's Palmerton, Pennsylvania, smelting facilities. These include oxide furnace and vertical furnace residues and a rotary kiln residue from the vaporizing of a high grade zinc ore.[61]

A horizontal retort smelter at Henryetta, Oklahoma, was closed several years ago, as was a vertical retort smelter at Depue, Illinois. However, stockpiles of residue still exist at these locations. The smelter facility at Amarillo, Texas was closed in May, 1975. No slag residue is available at that location because it was sold to local contractors for construction use.[62]

Table 29 presents the findings of chemical analyses of several of these residues. It can be seen from this table that each of these residues is quite different, probably due to the fact that different types of furnaces were employed in their production. Analysis of these materials indicated that zinc smelter residues are variable in their composition and physical appearance.

There are stockpiles of zinc smelter residue at each smelter location. Some stockpiles have been partially depleted because an effort has been made to find markets for the material. The largest accumulation of these residues is at Palmerton, Pennsylvania, where approximately five million tons (4.5 Mtonnes) of residues exist.

<u>Phosphate Slag</u>

Phosphate rock, sometimes processed into nodules, is heated in an electric furnace together with coke and silica to produce elemental phosphorous from which a number of chemical products, most notably fertilizers, are derived.

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[61]Mr. James Ord, Engineering Department, New Jersey Zinc Company, Palmerton, Pennsylvania. Personal communication.

[62]Mr. S. Y. Stennis, A.S.A.R. Company, Amarillo, Texas. Correspondence dated November 10, 1975.

Table 28. Location of domestic zinc smelting facilities.

State	Location	Company	Annual Residue Production[1]
Idaho	Kellogg	Bunker Hill Co.	----
Ohio	Columbus	A.S.A.R. Co.	N.A.
Oklahoma	Bartlesville	National Zinc Co.	N.A.
	Blackwell	Amax Zinc Co.	N.A.
Pennsylvania	Monaca	St. Joe Minerals Co.	50
	Palmerton	New Jersey Zinc Co.	195[2]
Texas	Corpus Christi	A.S.A.R. Co.	----

[1]Expressed in thousand tons.

[2]Composed of residue from three different locations.

NOTE: 1 short ton =0.9072 metric tons.

N.A. denotes information not available

Table 29. Chemical analysis of zinc smelter residues, in percent by weight.

	St. Joe Minerals Co. Slag Residue Monaca, Pa.	New Jersey Zinc Co. Vertical Retort Residue Palmerton, Pa.	New Jersey Zinc Co. Oxide Furnace Residue Palmerton, Pa.
C	----	23	26
SiO_2	28-32	28	26.3
FeO	18-22	10	6.6
Al_2O_3	----	14	11.6
CaO	6-7	5	9
MgO	----	2	1.9
Zn	5-8.4	2-5	5-12
Pb	.07-.17	0.3	----
Cu	.64-.92	0.25	----
S	----	4	2.2

A slag forms during this thermal process, consisting of the non-phosphatic components of the phosphate rock and the silica. This slag is tapped as a molten liquid, cooled and broken by water, and used as a construction material. (68)

Phosphate slags are characteristically light grey, heavy, extremely hard, somewhat porous materials, whose size after cooling can range from solid pieces larger than one foot down to dust size particles. Figure 39 shows a typical phosphate slag, which is normally crushed and sized to meet specified gradation requirements by slag processing contractors.

Elemental phosphorous furnaces are located in five states, with the largest quantities of slag being produced in Idaho and Tennessee (68). The locations of elemental phosphorous furnaces are shown in Figure 4. Table 30 lists the locations of these furnace facilities. Estimates of annually produced quantities of phosphate slag at each location are not presently available, but it is known that approximately eighty-five percent of each ton of ore becomes slag.[63] Stockpiles of phosphate slag are available at most furnace locations through slag processors.

The average chemical composition of phosphate slag from sources in Idaho is given in Table 31. Although only two sources of phosphate slag are noted, this is believed to be representative of typical phosphate slag production. From this table, phosphate slag can be described chemically as a lime-silicate material.[64]

Phosphate slag, because of its hardness and uniform, inert composition, is an excellent aggregate material which has been utilized for construction purposes in several states in which it is produced. In areas where it is fully accepted and recognized for its structural value, the stockpiled quantities are fairly small. Further information on the utilization of this material is given in the following chapter of this report.

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[63] Mr. Gordon A. Aland, Mining Superintendent, Monsanto Industrial Chemicals Company, Soda Springs, Idaho. Correspondence dated November 24, 1975.

[64] Mr. C. D. Holmes, Water Quality Supervisor, FMC Corporation, Pocatello, Idaho. Correspondence dated October 15, 1975.

Figure 39. Sample of phosphate slag (Scale in inches).

Table 30. Location of domestic phosphate furnace facilities.

State	Location	Company
Alabama	Muscle Shoals	Stauffer Chemical
Florida	Pierce	Holmes Company
	Tarpon Springs	Stauffer Chemical
Idaho	Pocatello	FMC Corporation
	Soda Springs	Monsanto Company
Montana	Silver Bow	Stauffer Chemical
Tennessee	Columbia	Monsanto Company
	Mt. Pleasant	Stauffer Chemical

Table 31. Chemical analysis of phosphate slag, in percent by weight.

	FMC Corporation Pocatello, Idaho	Monsanto Company Soda Springs, Idaho
SiO_2	43.1	45
CaO	45.0	45
Al_2O_3	5.0	
F	3.0	
P_2O_5	1.9	
K_2O	1.0	10
MgO	0.7	
Na_2O	0.5	
Fe_2O_3	0.2	

Nickel Slag

The only nickel smelting facility in the United States is operated by the Hanna Nickel Smelting Company in Riddle, Oregon. Approximately 800,000 tons (720,000 tonnes) of granulated nickel slag are produced annually at this location. A sample of this material is shown in Figure 40. It is a dark grey, porous, fairly lightweight slag with some greenish coloration.

A chemical analysis of this slag is presented in Table 32. This analysis indicates that the slag is a ferrosilicate material with a substantial amount of magnesium and numerous trace elements.

At the present time, there are approximately fourteen million tons (12.6 tonnes) of this material stockpiled with very little in the way of reported utilization.[65] Figure 4 indicates location of this material.

Aluminum Smelter Slag

Primary aluminum smelters do not generate large quantities of waste and what little waste that is generated by these facilities is in the form of potliner sludge and carbonaceous anode remnants which are not suitable for highway construction.[66]

One exception to this is a primary aluminum smelting facility in West Virginia, which produces a slag by-product termed "gravel dross." This material is basically an aluminum oxide with a lesser percentage of magnesium oxide and trace amounts of nitrides, carbides, and chlorides. Physically, the material is a loose, mixed gravel with fifty percent passing a two-inch (50.8 mm) screen.

The anticipated production of the "gravel dross" is 12,000 tons (10,800 tonnes) per year. Since the smelter is a comparatively new facility, there is not as yet any large accumulation of this material.[67]

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[65] Mr. E. J. Maney, General Manager, Hanna Nickel Smelting Company, Riddle, Oregon. Correspondence dated August 1, 1975.

[66] Mr. A. A. Rambikur, Environmental Control Supervisor, Aluminum Company of America, Point Comfort, Texas. Correspondence dated March 2, 1976.

[67] Mr. H. R. Kirby, Casting Superintendent, Kaiser Aluminum Corporation, Ravenswood, West Virginia. Correspondence dated November 11, 1975.

Figure 40. Sample of granulated nickel slag
(Scale in inches).

Table 32. Chemical analysis of granulated nickel slag, in percent by weight.

SiO_2	53.3
MgO	30.1
Fe	9.7
Al_2O_3	1.52
CaO	0.59
Ni	0.15
Cr_2O_3	0.80
MnO	0.22
Na_2O	2.04
K_2O	0.03
CO	0.006
Cu	0.004

Note: Slag produced at the Hanna Nickel Smelting Company, Riddle, Oregon.

This section of the report has described the most significant types of metallurgical slags currently being produced. Although there are some smelting operations conducted for other metals, these are very small in scope and do not involve large enough tonnages to consider as a possible resource for highway construction.

4.3.9 Washery Rejects

This category of mineral wastes deals essentially with the by-products of two industries: the phosphate industry and the aluminum industry. The predominant wastes generated by each of these industries are classified as washery rejects because these wastes are disposed of in a slurry form and tend to remain in this form indefinitely. This is in contrast to tailings and fine coal refuse, which are initially disposed of as slurries, but ultimately dry out and become solid or semi-solid materials.

Phosphate

The Florida phosphate industry supplies about seventy-five percent of our domestic phosphate production. Smaller amounts of phosphate are produced from deposits located in Tennessee, North Carolina, Idaho, and Montana. Large amounts of land pebble phosphate rock ores are located in Florida and in the southeastern United States. The ore matrix is processed by flotation to remove the phosphate rock from the remaining material. This matrix is composed of approximately equal portions of phosphate rock, sand, and clay.

The beneficiation of land-pebble phosphatic deposits by washing and flotation results in the generation of two by-products: sand tailings, which have been described previously (on page 45), and phosphate slimes. The slimes are generated in approximately a 1:1 correspondence by weight with the amount of phosphate rock produced.[68]

Phosphate slimes are essentially colloidal materials which vary somewhat in grain size distribution from one plant to another due to slight differences in the nature of the matrix being mined and variations in beneficiation methods. A typical phosphate slime is minus .1 millimeter in particle diameter with over seventy percent of the

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[68] Environmental Science and Technology, April, 1974. pp. 312-313.

particles being less than one micron in diameter.[69] The slimes are usually deposited at from two to six percent solids. Due to their colloidal particle size, settlement rates are extremely slow. Even after years of settlement, solids contents do not often exceed twenty percent (115).

Huge volumes of these slimes are generated as a by-product of phosphate production in central Florida. Lesser quantities of phosphate slimes are also produced in Tennessee and North Carolina. It is estimated that a total of approximately 40 million tons (36 Mtonnes) of these colloidal clay-bearing slimes must be disposed of each year by the phosphate industry. These wastes have accumulated over the years in large storage ponds. It is almost impossible to precisely estimate the amount of slimes impounded at the present time, but there are probably more than a billion tons of solids in these holding ponds. Vasan has estimated that from 1.5 to 2 billion tons (1,350 to 1,800 Mtonnes) of slimes are currently being stored in impoundments in the Florida phosphate-producing area (121).

Disposal of these materials has caused several environmental problems. Large areas are required for their impoundment. Estimates are that as much as 4,000 acres (1,600 hectares) of new ponds are being added each year in Florida (115). A great deal of water is impounded with the slimes and, due to the slow settling rate of the slimes, this water is entrapped and becomes unavailable for other uses for many years. Approximately seven tons (6.3 tonnes) of make-up water are required for every ton of phosphate rock that is produced (121).

Table 33 shows the reported range in the chemical composition of Florida phosphate slimes, together with a chemical analysis from a producer in central Florida. Mineralogically, these slimes have been analyzed and found to be composed mainly of carbonate fluorapatite, montmorillonite, and quartz with lesser amounts of kaolinite, attapulgite, and feldspar (115) The analyses confirm that these slimes are essentially clay-like and contain a substantial amount of phosphate mineral value.

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[69]Mr. William C. Warneke, Geologist, Smith-Douglass Division of Borden Chemical, Inc., Plant City, Florida. Correspondence dated December 16, 1975.

Table 33. Chemical analysis of Florida phosphate slimes, in percent by weight.

	Range[1]	Typical[1]	Reported[2]
P_2O_5	9 - 17	9.1	10
SiO_2	31 - 46	45.7	45
Fe_2O_3	3 - 7	4.0	5
Al_2O_3	6 - 18	8.5	10
CaO	14 - 23	13.9	15
MgO	1 - 2	1.1	5 (Other)
CO_2	Trace- 1	0.8	
F	Trace- 1	0.9	
Loss on Ignition at 1000°C	9 - 16	10.6	10

[1]Presented in U.S. Bureau of Mines Information Circular Number 8668, p. 11.

[2]Reported by Smith-Douglass Division of Borden Chemical, Inc., Plant City, Florida.

In order to consider utilizing these materials, it is necessary to recover the slimes from the holding ponds and to reduce the moisture content to a more manageable range. After thickening, the slimes could probably be retrieved by pumping. The problem of dewatering is the biggest deterrent to possible utilization of these slimes. Conventional settling practices have proven to be ineffective. Although various other techniques for dewatering, such as centrifuging and freezing, have been investigated, to date there has been no technically and economically feasible method for reducing the moisture content of these slimes to workable levels (115).

The following chapter will discuss some possible uses for phosphate slimes and additional research that is now being conducted to determine more effective ways to dewater these materials.

Aluminum

The extraction of alumina from bauxite ores produces clay-like solid waste by-products which are disposed of in slurry form at about a twenty percent solids content. These materials are termed alumina muds because they are initially deposited at a consistency that resembles mud. After years of settling, these muds approach a solids content of fifty percent. The types of muds disposed of in the extraction of alumina depend on the source and nature of the bauxite ore and the type of processing techniques employed.

Aluminum companies in the United States process bauxite ores from three sources. Ninety percent of the bauxite ores processed each year are Jamaican or Surinam bauxites. The remaining ten percent are domestic bauxite ores mined in Arkansas.

There are two basic types of extraction processes currently used by the aluminum industry: the Bayer proocess and the combination process. The Bayer process is used to refine Jamaican or Surinam bauxite ores and produces alumina and a red mud. The combination process consists of the Bayer process, followed by sintering and leaching of the red mud from high silica domestic bauxite ore to obtain higher recovery of silica and alumina. The combination process produces alumina and a brown mud waste (95).

Approximately six million tons (5.4 Mtonnes) of red and brown muds are generated annually by the aluminum industry, with about five million tons (4.5 Mtonnes) consisting of red muds. These muds are produced at alumina refining plants located along the lower Mississippi River, the Gulf Coast, and in central Arkansas (54). Table 34 lists the locations of domestic alumina refining plants and notes the estimated quantities of muds produced at each location where information has been reported.

Although alumina muds do settle over time to approximately fifty percent solids content, the high annual rainfall in these regions of the country retards this settlement. Therefore, a number of the aluminum companies provide for decanting surface water and have facilities, such as sand filters and drains so that these muds will eventually dry.[70] Figure 41 shows a sample of dried alumina red mud. The material is reddish in color, somewhat porous and lightweight, with moderately hard particles having a dust coated surface.

The particle size distribution of alumina muds is in the clay range. Nearly all particles are finer than 200 mesh (95). The Illinois Institute of Technology Research Institute (54) determined the particle distribution of a typical Jamaican red mud sample to be as follows:

Sieve Size (mesh)	Percent Passing
20	97.8
30	95.9
40	94.5
50	93.1
70	91.6
100	90.8
140	90.1
200	89.6
325	89.0

The mineral compositions of the red and brown muds are essentially claylike and have been described as complex compounds of soda, silica, alumina, and water. The actual minerals depend on the composition of the ore and conditions in the Bayer digesters (95). There is also some variation in the chemical composition of alumina muds from different locations. Table 35 lists the reported chemical analyses of three sources of alumina red mud. The analyses show that these materials have a high iron content and a relatively high alumina content. The pH of alumina muds is high, ranging from 10.5 to 12, or even higher (93).

Possible uses and research activities concerning alumina muds will be discussed in the following chapter of the report.

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[70] Mr. A. A. Rambikur, Environmental Control Supervisor, Aluminum Company of America, Point Comfort, Texas. Personal communication.

Table 34. Locations of domestic alumina refining plants.

State	Location	Company	Amount of Mud Produced[1]
Alabama	Mobile	Alcoa	N.A.
Arkansas	Bauxite	Alcoa	N.A.
	Hurricane Creek	Reynolds	N.A.
Louisiana	Baton Rouge	Kaiser	N.A.
	Burnside	Ormet	400
	Gramercy	Kaiser	600
Texas	Point Comfort	Alcoa	800
	Sherwin	Reynolds	1200

[1]Expressed as thousands of tons per year.

NOTE: 1 short ton = .9078 metric tons.

N.A. denotes information not available

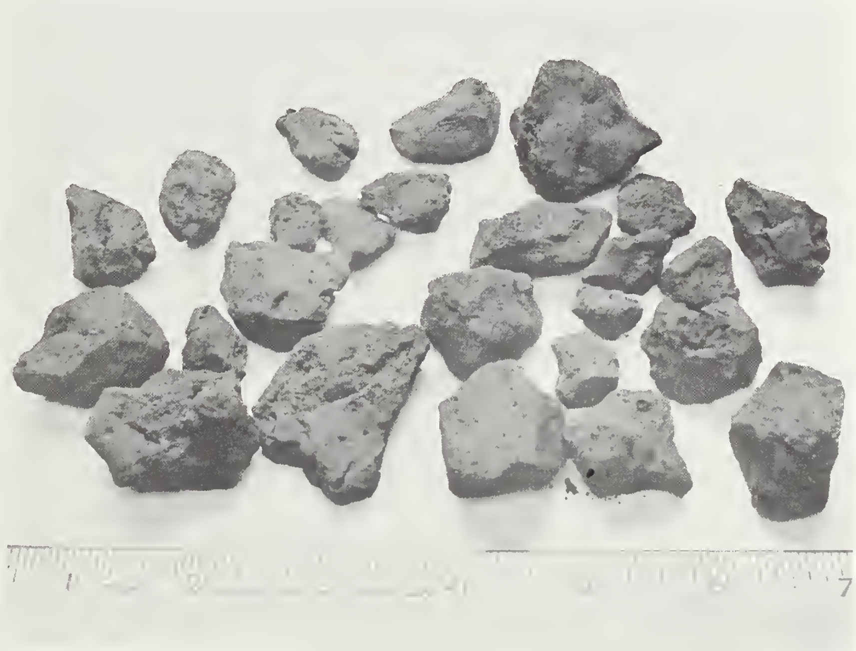

Figure 41. Sample of dried alumina red mud
(Scale in inches).

Table 35. Chemical analysis of alumina red muds, in percent by weight.

	Kaiser Gramercy, La.[1]	Reynolds Sherwin, Texas[2]	Alcoa Point Comfort, Texas[3]
FeO_3	49.1	47.95	35.0
Al_2O_3	14.8	11.75	20.0
TiO_2	7.75	6.16	7.0
CaO	7.90	7.68	8.0
Na_2O	2.52	3.85	7.0
SiO_2	1.45	4.95	10.0
MnO_2	1.50	2.66	
P_2O_5	0.50	3.77	
Other	1.50	12.58	
Loss on Ignition at 1100°C	10.0		10.0

[1]Reported by Mr. T. C. Buchanan, Works Manager. Correspondence dated February 20, 1976.

[2]Reported by Norton Thompkins, Plant Purchasing Agent. Correspondence dated November 25, 1975.

[3]Reported by A. A. Rambikur, Environmental Control Supervisor. Correspondence dated March 22, 1976.

5. UTILIZATION OF MINING AND METALLURGICAL WASTES

Prior to evaluating the suitability of mining and metallurgical wastes for possible utilization in highway construction, the use of these materials was studied in terms of the following:

1. Current and past applications in highway construction.

2. Other known or potential uses of specific waste materials.

3. Related research directed toward developing additional uses.

Although a number of mining and metallurgical waste applications are reported in the literature, the majority of the information presented in this chapter of the report was derived from contacts with knowledgeable personnel in the mining industry and in state highway and transportation departments throughout the country.

5.1 HIGHWAY CONSTRUCTION USE

Over the years the construction of highway facilities has consumed an increasingly large amount of raw materials. Inevitably, some highway construction projects were situated some distance from established material supply sources, but in proximity to mining and metallurgical waste supplies.

The mining industry has traditionally used its own waste materials for internal construction purposes. A great deal of information has been received from mining officials substantiating the fact that it has been standard practice in the industry to use mining and metallurgical wastes to build roads, fills, and impoundments on mining property. Ultimately, attempts were made in some areas to incorporate certain of these materials into the construction of public highway facilities. While many of these attempts have not been previously documented, information has been received concerning a large number of such uses.

This portion of the report will discuss many of the known uses of mining and metallurgical wastes in highway construction, most of which have proved to be successful. These uses will be discussed in terms of the major categories of mining and metallurgical wastes described in the preceding chapter of this report.

5.1.1 Waste Rock

Because waste rock from mining operations is often derived from the same type of rock formations as those developed by the crushed stone industry, it is logical to consider the use of some of these materials as construction aggregate. A number of applications of waste rock from different sources have been found in the literature or reported by reliable sources from the highway or mining industry.

In Arizona, waste rock from a mine dump at the Mission mine south of Tucson was used some years ago as a source of aggregate. The rock ranged from cobble to boulder size and was crushed and used in highway construction. An environmental improvement project allowed the waste rock to be covered with mill tailings and the slopes seeded, making the source unavailable for further use.[71]

One of the original attempts to use mining waste in road construction occurred during the 1930's in the State of Colorado and involved the use of crushed waste rock and tailing from gold mining operations. These materials were used to build the so-called "Million Dollar Highway" from Durango to Silverton.[72] This road is known as U.S. Route 550 or Colorado Route 789. Some 26,000 tons (23,600 tonnes) of rhyolite waste rock from the silver-lead-zinc mining area near Creede, Colorado, was used for county road construction,[73] according to mining personnel in the area.

Waste rock and heavy-media tailings from the mining of fluorspar in Illinois are contracted to a firm which sells this material as road construction aggregate. These materials are sized from 1-1/4 inches (31.8 mm) to 10 mesh in diameter and approximately 100,000 tons (90,000 tonnes)

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[71]Mr. Grant J. Allen, Engineer of Materials, Arizona Department of Transportation, Phoenix, Arizona. Correspondence dated August 18, 1975.

[72]Mr. Anthony B. Rubner, Assistant Staff Materials Engineer, Colorado State Department of Highways, Denver, Colorado. Correspondence dated September 5, 1975.

[73]Mr. James E. Gilfillan, District Geologist, Minerals Engineering Company, Denver, Colorado. Correspondence dated November 28, 1975.

per year are used[74] as aggregate in the southeastern part of the state in the gradations and quality classes they satisfy.[75]

For many years, Louisiana had used a very low grade iron ore as a flexible base course layer for secondary roads. Due to depletion of available sources, its use was discontinued over five years ago. There are large reserves of this material in northwest Louisiana, but it is not considered economical to develop these resources at the present time.[76]

Waste rock from copper mining operations in Ontonogan County, Michigan, were used in the construction of embankments and sub-base for U.S. Route 45 near Military Hills during 1963.[77]

A considerable amount of material has been used from the "poor rock" piles located in the copper mining district of Houghton and Keweenaw Counties in the Upper Peninsula of Michigan. This rock, so-called because it has little or no copper content, is composed of trap, amygdaloid, and conglomerate, varying in size from boulders of about one foot (304.8 mm) in diameter to chunks 4 inches (101.6 mm) in diameter or smaller.[78] The Keweenaw County Road Commission has used these materials throughout the county in various stages of construction and found them to be extremely adequate for base and sub-base materials, depending upon the particle size.[79]

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[74]Mr. C. B. Rash, Superintendent of Milling, Ozark-Mahoning Company, Rosiclare, Illinois. Correspondence dated December 4, 1975.

[75]Mr. Miles E. Byers, Engineer of Materials and Physical Research, Illinois Department of Transportation, Springfield, Illinois. Correspondence dated August 19, 1975.

[76]Mr. E. J. Breckwoldt, Materials and Research Engineer, Louisiana Department of Highways, Baton Rouge, Louisiana. Correspondence dated November 3, 1975.

[77]Mr. K. A. Allemeier, Engineer of Testing and Research, Department of State Highways and Transportation, Lansing, Michigan. Correspondence dated September 23, 1975.

[78]Mr. T. W. Knight, Property Manager, Universal Oil Products Company, Calumet, Michigan. Correspondence dated August 11, 1975.

[79]Mr. James M. Heikkila, County Engineer, Keweenaw County Road Commission, Mohawk, Michigan. Correspondence dated December 9, 1975.

The waste rock from iron mining operations in the western portion of the Upper Peninsula have also been used in highway construction. During 1962 and 1963 several hundred thousand tons of this material were used for swamp backfill, embankment, and sub-base in the construction of U.S. Route 2 from Ironwood to Bessemer in Gogebic County.[80]

In Missouri, coarse waste rock from the now closed Iron Mountain underground iron mine was sold to an aggregate producer, who crushes and sells approximately 125,000 tons (113,400 tonnes) per year of this material for use as skid-resistant aggregate for bituminous paving in Missouri and Illinois. The waste rock is trap rock, crushed to meet standard specification size requirements for aggregate. Trap rock sand is also produced from this rock for use in concrete mixtures.[81]

Waste rock from abandoned lead mining operations in St. Francois County have been used for many years as aggregate for bituminous paving. This material is also sold to the City of St. Louis for use in the street paving work.[82]

Both the waste rock and tailing from a molybdenum mining operation in northern New Mexico have been used as bituminous paving aggregate. The waste rock is andesite and aplite, varying in size up to 3 feet (.915 meter) in diameter and crushed to meet gradation requirements for coarse aggregate.[83]

The New York State Department of Transportation reports that waste rock from the mining of iron ore and titanium have been used since 1930 for bituminous and Portland cement concrete pavements.[84] These materials occur largely in Essex and St. Lawrence Counties and have been used in areas that are located close to the mining operations.[85]

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[80]Mr. K. A. Allemeier, Engineer of Testing and Research, Department of State Highways and Transportation, Lansing, Michigan. Correspondence dated September 23, 1975.

[81]Mr. E. Paul Black, Black Trap Rock Materials, Iron Mountain, Missouri. Correspondence dated March 30, 1976.

[82]Mr. C. W. Easteel, Division Manager, St. Joe Minerals Corporation, Bonne Terre, Missouri. Correspondence dated December 3, 1975.

[83]Mr. A. L. Greslin, Assistant to General Manager, Molycorp, Inc., Questa, New Mexico. Correspondence dated November 7, 1975.

[84]Mr. Harry H. McLean, Director of Engineering Materials, New York State Department of Transportation, Albany, New York. Correspondence dated September 9, 1975.

[85]Mr. L. F. Heising, U.S. Bureau of Mines Liaison Officer for New York, Albany, New York. Correspondence dated July 14, 1975.

Waste rock from iron mining has been used in a number of highway construction projects in Pennsylvania. Waste rock from Bethlehem Steel Company's Cornwall iron ore mine in Lebanon County was processed and used as commercial aggregate for the construction of the Pennsylvania Turnpike eastward from Carlisle to King of Prussia during 1950. The material used was a limestone intermixed with some magnetite (66). The mine has been closed since 1972, but some waste rock is still available.

Waste rock from Bethlehem Steel Company's Grace iron ore mine in Berks County is presently being processed by a commercial aggregate producer as a highly skid-resistant aggregate. This aggregate was used in the bituminous resurfacing of the Pennsylvania Turnpike from Morgantown to Valley Forge two years ago.[86]

For many years the South Dakota Highway Department, the Lawrence County Highway Department, and the City of Lead have all made use of the waste rock produced at the Homestake Mining Company from the mining of gold ore. This material has been used mainly as a backfill, embankment or fill material, and sub-base, although waste rock has also been crushed and used in a paver laid seal coat resurfacing project near Lead.[87]

Crushed slate waste rock from two slate producers located in Buckingham County, Virginia is being used as a stone base course aggregate by the Commonwealth of Virginia. An average of approximately 85,000 tons (76,500 tonnes) of this material are used each year, mainly in Buckingham and Cumberland Counties. Satisfactory aggregate has been produced by carefully controlling the amount of flat, elongated particles through the use of more exacting crushing methods.[88]

The Bunker Hill Company in Metaline Falls, Washington produces a waste rock from its lead-zinc mine which has been used by city, county, and state agencies for base and sub-base construction, bituminous resurfacing, and seal coat work. The waste rock itself is a carbonate rock, which is primarily 4 inches (101.6 mm) or less in size. A parking

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[86] Mr. Fred Eben, Chief Mining Engineer, Bethlehem Steel Company, Grace Mine, Morgantown, Pennsylvania. Personal communication.

[87] Mr. Robert J. Sliper, Chief Construction Engineer, Homestake Mining Company, Lead, South Dakota. Correspondence dated November 16, 1975.

[88] Mr. L. W. Butler, Resident Engineer, Virginia Department of Highways and Transportation, Dillwyn, Virginia. Correspondence dated December 11, 1975.

lot at Gardner Cave State Park used both coarse and fine materials in the bituminous mixtures. Private interests have also purchased the material for the resurfacing of driveways.[89]

Material from the mine dump at the Sunrise Mine in Wyoming was used in the construction of a subgrade for Wyoming State Highway 270 during the late 1950's. The material consisted primarily of a dolomite with some quartzite and siliceous limestone.[90]

5.1.2 Mill Tailings

Although mill tailings are finely divided by-products form the concentration of mineral ores, the gradation of the tailings from different operations can vary substantially, as seen in the previous chapter. Some processes do not involve fine grinding, while in other operations a separation is made of the coarse and fine fractions of the tailing by-product.

The known uses of mill tailings in highway construction are described in this section of the report. It should be noted that in some instances reference will be made to crushing of the tailing materials prior to use. Some information sources choose to include the finer sizes of waste rock in the general category of tailings.

The Alabama Highway Department is investigating the possible use of iron ore tailings as an aggregate, but the presence of large amounts of shale almost preclude the use of this material for embankments.[91] No previous use of these tailings in highway construction has been documented.

There have been numerous instances in which the sand and gravel tailings from past gold mining operations in California have been successfully used in highway and other construction projects. Large amounts of this material are being processed

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[89]Mr. L. M. Kinney, Mine Manager, Bunker Hill Company, Metaline Falls, Washington. Correspondence dated December 12, 1975.

[90]Mr. R. W. MacCannon, Superintendent, C. F. & I. Steel Corporation, Guernsey, Wyoming. Correspondence dated December 30, 1975.

[91]Mr. W. F. McCullough, Assistant Materials and Tests Engineer, Alabama Highway Department, Montgomery, Alabama. Correspondence dated September 2, 1975.

as commercial aggregate by two producers in a ten-square mile (25.8 square kilometer) area east of Marysville and north of Sacramento[92] and in the Rancho Cordora-Folsom area east of Sacramento.

Among the specific highway projects in which gold mine tailings have been used for construction in California are U.S. Route 40 freeway in Placer County, U.S. Route 50 freeway near Placerville in El Dorado County, a portion of Interstate Route 80 in the vicinity of Gold Run and Dutch Flat in Placer County, and the relocation of the Feather River Highway in Butte County. It has also been reported that gold tailings were used in the construction of the Oroville Dam, an earth-filled dam a mile (1.6 kilometers) wide and 770 feet (235 meters) high, located in Butte County.[93]

Mr. Blackburn of the California Department of Transportation notes that some of the raw materials for base courses, Portland cement concrete, and asphaltic concrete mixtures used in the construction of freeways in the metropolitan Sacramento area have come from the tailings of past gold mining operations. He also states that the California Department of Transportation is concerned primarily with specifications for the material for highway construction and not with the source of the material per se.

Coarse tailing from iron ore mining at Eagle Mountain in Riverside County were used as aggregate for the bituminous paving mix placed on a new County road in the vicinity of Eagle Mountain during 1974. These tailing have also been used as aggragate for concrete structures built during the construction of Interstate Route 10 and as concrete aggregate for industrial construction projects.[94]

The finer size tailing product from the processing of asbestos has been utilized in asphalt wearing surface mixtures in California and Nevada. This material, called asbestos shorts because of the shortness of the residual fibers remaining after processing, must be separated from

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[92]Mr. L. V. Blackburn, District Materials Engineer, California Department of Transportation, Marysville, California. Correspondence dated December 4, 1975.

[93]Mr. William S. Kerns, U.S. Bureau of Mines Liason Officer, Sacramento, California. Correspondence dated July 24, 1976.

[94]Mr. D. E. Wick, Superintendent for Engineering Services, Kaiser Steel Corporation, Eagle Mountain, California. Correspondence dated January 23, 1976.

the serpentine host rock prior to use. It has been reported that by-product asbestos shorts were used in the asphalt mix placed on Interstate Route 15 near Las Vegas, Nevada and are also frequently used in the resurfacing of playgrounds and parking lots.[95]

A previous report received from the California Department of Transportation noted that waste products from boron mining have been used in highway construction in specific instances, although no details are readily available concerning specific applications.[96]

In addition to the gold waste rock and tailings used in the construction of the "Million Dollar Highway" in Colorado, gold dredge tailings are also being crushed and used for highway construction around Breckenridge and Fairplay in Clear Creek County.[97]

Phosphogypsum has been used as sub-base material for in-plant roads in the central Florida phosphate-producing area for years with excellent results.[98] This material has also been used in Florida for the construction of a sub-base for one mile (1.6 kilometer) of a company-owned blacktop road and, more recently, as a limestone substitute for the sub-base of a ten-mile (16 kilometer) section of blacktop.[99] In North Carolina, about 100,000 tons (90,000 tonnes) of phosphogypsum were used locally as base material for a road crossing a swampy area.[100]

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[95]Mr. Irving F. Moore, President, Wheeler Properties, Inc., Reno, Nevada. Correspondence dated January 12, 1976.

[96]Mr. George B. Sherman, Supervising Materials and Research Engineer, California Department of Transportation, Sacramento, California. Correspondence dated June 1, 1973.

[97]Mr. Anthony Rubner, Assistant Staff Materials Engineer, Colorado State Department of Highways, Denver, Colorado. Correspondence dated September 5, 1975.

[98]Mr. William C. Warneke, Geologist, Borden Chemical, Inc., Plant City, Florida. Correspondence dated December 16, 1975.

[99]Mr. Charles C. Cook, Senior Process Engineer, Brewster Phosphates, Bradley, Florida. Correspondence dated November 17, 1975.

[100]Mr. Ralph S. Chamness, Chief Geologist, Texasgulf, Inc., Aurora, North Carolina. Correspondence dated November 24, 1975.

In 1963, over one million cubic yards (760,000 cubic meters) of tailing from silver-lead-zinc mining in the Coeur d'Alene mining district of northern Idaho were used to construct embankments for a four-mile (6.4 kilometer) section of Interstate Route 90 near Kellogg, Idaho. The material presented no unusual problems in handling and compacted well on the job (93).

Gold dredge tailings from Custer County were used as road base fill for a forest service road up the Yankee Fork of the Salmon River.[101] The Idaho Transportation Department states that gravel tailings from many rivers in Idaho have been used in construction with coordination through proper state or federal governmental bodies.[102]

Over 100,000 tons (90,000 tonnes) of coarse tailings from lead-zinc mining operations have been used as aggregate in hot-mix applications on state highways in northwest Illinois and southwest Wisconsin. Their use has been mainly in the shoulders and surface courses of local roads.[103]

Chat, the coarse tailing product from the beneficiation of lead-zinc ores in the Tri-State mining district, has been used as an aggregate material in various phases of highway construction for years in Kansas, Missouri, and Oklahoma. This material has been used in portland cement concrete, but its major application is in bituminous base courses and wearing surfaces.[104]

A considerable amount of chat is still available in the Tri-State areas. However, an asphalt material supplier in Kansas has indicated that the highest quality chat material has already been used and that some of the remaining flint chat has a shiny surface, indicative of asphalt stripping problems and the dislodging of aggregate particles from the paving surface.[105]

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[101] Mr. Richard N. Appling, Jr., Chief, U.S. Bureau of Mines, Western Field Operation Center, Spokane, Washington. Correspondence dated July 18, 1975.

[102] Mr. Claude B. Humphrey, Materials Supervisor, Idaho Transportation Department, Boise, Idaho. Correspondence dated August 27, 1975.

[103] Mr. Harold H. Haman, Manager of Illinois - Wisconsin Operations, Eagle-Picher Industries, Inc., Galena, Illinois. Correspondence dated August 13, 1975.

[104] Mr. William L. Trimm, Division Engineer for Materials and Research, Missouri State Highway Commission, Jefferson City, Missouri. Correspondence dated August 28, 1975.

[105] Mr. Merle Shilling, President, Shilling and Aubel Asphalt, Inc., Manhattan, Kansas. Personal communication.

This opinion is reinforced by Mr. Trimm of the Missouri State Highway Commission, who indicates that, although a lot of chat has been used in the past, the Highway Commission is now more selective in the use of the remaining material in the waste piles because the slick surface of these particles has been somewhat of a problem. The eastern chat from the Old Lead Belt near Bonne Terre has proven to be a better material than the western chat from the Tri-State District. This eastern chat has been used in asphaltic concrete, aggregate in bituminous bases, and maintenance work.[106]

Coarse taconite tailings have been used in Minnesota as embankment fill, base and sub-base material, and in bituminous mixtures. The Department of Highways has allowed the use of these tailings as an alternate to sand and gravel at the contractor's option. The main difficulty in using taconite tailings as a base or sub-base material is the lack of cohesiveness of the material. The solution has been to keep the tailings in a moist condition and to stabilize the top three inches (76.2 mm) of the material with an asphalt emulsion.[107]

The primary use of taconite tailings is for thin surface overlays of one inch (25.4 mm) or less in thickness. The servicability of these taconite overlays has been exceptional. It has been found that the use of coarse taconite tailings definitely improves the skid resistance of pavements in which it is used. In the future, taconite tailings may be specified as the sole material used for surface overlays because of their skid resistance qualities.

During 1975, approximately 60,000 tons (54,000 tonnes) of taconite tailings were utilized in various state highway and bridge deck resurfacing projects throughout Minnesota, including several in the Minneapolis and Duluth metropolitan areas. An additional 23,000 tons (20,700 tonnes) were used in 1975 on Interstate Routes 35-E and 35-W in the Minneapolis - St. Paul area.[108]

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[106]Mr. William L. Trimm, Division Engineer for Materials and Research, Missouri State Highway Commission, Jefferson City, Missouri. Personal communication.

[107]Mr. R. M. Canner, Research Planning Engineer, Minnesota Department of Highways, St. Paul, Minnesota. Correspondence dated May 23, 1973.

[108]Mr. B. F. Himmelman, Materials Engineer, Minnesota Department of Highways, St. Paul, Minnesota. Correspondence dated August 22, 1975.

Because of the presence of asbestiform fibers in some sources of taconite tailings, there has been some recent concern expressed due to the use of taconite tailings in highway construction. This aspect of taconite tailings use will be discussed in greater detail in the following chapter as part of the environmental evaluation.

In Missouri, the tailings from barite mining operations have been used as aggregate in highway construction. These materials, locally referred to as "tiff chat," are available in the east central portion of the state and have been used in bituminous wearing surfaces. Their use is permitted in the Missouri Standard Specifications.[109]

Barite tailings have also been used as highway construction material in Nevada. The tailing material, composed mainly of chert with a particle size less than 3/4-inch (19.1 mm) diameter, was used by the Nevada Department of Highways to resurface a section of Interstate Route 80 near Battle Mountain in Lander County.[110]

Iron ore tailing from the Mt. Hope area in Morris County, New Jersey, have been used in the past as a dense aggregate in concrete and asphalt paving mixtures. The tailing material used was a granitic gneiss. No information is available on the performance of pavements containing this tailing material. The mine which provided the material is not in operation at the present time.[111]

In New Mexico, earlier reference was made to the use of waste rock and tailing from Molycorp as aggregate in bituminous mixtures. The most recent known use of these materials was in 1970 and reports indicate that the pavement in which these materials were used has been performing satisfactorily.[112] Reference was also made to the use of mine tailings from the Socorro-Silver City areas for road building, but no further information is known concerning such uses.

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[109]Mr. William L. Trimm, Division Engineer for Materials and Research, Missouri State Highway Commission, Jefferson City, Missouri. Correspondence dated August 28, 1975.

[110]Mr. Wallace Mitchell, Senior Geologist, Milchem Mineral Division, Battle Mountain, Nevada. Correspondence dated December 3, 1975.

[111]Mr. R. M. Hagerman, Halecrest Company, Edison, New Jersey. Correspondence dated November 26, 1975.

[112]Mr. Robert D. Williams, Materials and Testing Engineer, New Mexico State Highway Department, Sante Fe, New Mexico. Correspondence dated May 10, 1073.

Tailings from feldspar production in the Spruce Pine district of western North Carolina have been used quite successfully as fill material, due to the good compaction properties exhibited by these tailings. From reports of this use, it is unclear whether or not the material has been used as fill in highway construction. The application referred to is probably for use as fill material on mining property.[113]

Zinc chat tailings from Mascot, Tennessee have been used as aggregate in portland cement concrete highway structures for more than fifty years. Bridges in which these materials were used in the concrete have provided excellent performance (1).

One of the most notable applications of tailings for highway construction is in Utah where, in 1972, the Kennecott Copper Corporation constructed a separation facility to produce a tailing product suitable for use as an embankment material in highway construction. Fifty percent of the tailing from one of Kennecott's concentrator plants is diverted through this facility, which classifies and deposits up to 20,000 tons (18,000 tonnes) per day of the coarser tailing particles with a maximum of twenty percent minus 200 mesh.[114]

Since 1972, more than 5.5 million tons (4.95 Mtonnes) of this classified tailing have been used to construct highway embankments in Utah with very satisfactory results. The most outstanding single example of the use of classified tailing was the construction of six miles (9.6 kilometers) of embankment for Interstate Route 215 west of Salt Lake City, using a total of 3.3 million tons (2.97 Mtonnes) of the tailing.[115]

The Utah Department of Highways has been very pleased with the compaction characteristics of classified copper tailing and are considering making the material an alternate for fill on primary and secondary state roads. The only problem experienced to date in its use as an embankment material has been a tendency to erode easily. In order to combat this problem, the finished embankment must be covered with topsoil to provide the necessary erosion control.

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[113]Mr. Ben Robinson, Manager, The Feldspar Corporation, Spruce Pine, North Carolina. Correspondence dated November 18, 1975.

[114]Mr. D. R. Cummings, Mill Superintendent, Kennecott Copper Corporation, Magna, Utah. Correspondence dated September 26, 1975.

[115]"Smelter Waste Builds Highway Embankments." Roads and Streets, July, 1975, pp. 50-51.

Classified copper mill tailing has also been used as a mineral filler in bituminous mixtures in Utah. However, its use for this purpose has not been quite as successful as for embankment construction. The problem is that the use of classified tailing as a mineral filler seems to cause aging and hardening of the asphalt, more so than for other mineral fillers that have been used. To date, there has not been any good explanation for this phenomenon, but chemists for the Utah Department of Highways are presently attempting to determine the cause of this problem.[116]

Coarse iron ore mine tailings from Jackson County, Wisconsin were crushed and shipped to an asphalt producer for use as aggregate in a bituminous paving mixture on U.S. Route 141 in the metropolitan Milwaukee area.[117] Reference has already been made to the highway use of waste rock and tailings from lead-zinc mining in southwest Wisconsin and northwest Illinois.

The coarse fraction of iron ore tailings from United States Steel Company's Atlantic City mine in Fremont County, Wyoming have been separated and used by the Wyoming Highway Department for sanding icy roads and also as a patching material for nearby state highway maintenance efforts. This material has also been used on mine haul roads.[118]

5.1.3 Coal Refuse

Although several billion tons of coal refuse have been generated over the years as an unwanted by-product of coal mining and preparation in the United States, there has been little effort made thus far in this country toward attempting to use any of this vast material resource. The western Europeans, and in particular the British, have recognized the value of utilizing coal refuse, or colliery spoil as it is termed in Britain, as a construction material and have researched and developed its use for this purpose to the extent that colliery spoil is now an acceptable alternate material source for the construction of embankments and sub-bases in Great Britain.

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[116]Mr. Wallace Stephenson, Engineer of Materials and Tests, Utah Department of Highways, Salt Lake City, Utah. Personal communication.

[117]Mr. Ralph L. Musin, Field Materials Control Engineer, Wisconsin Department of Transportation, Madison, Wisconsin. Correspondence dated August 19, 1975.

[118]Mr. John D. Quinn, Chief Engineer, United States Steel Corporation, Western Ore Operations, Lander, Wyoming. Correspondence dated December 19, 1975.

Although the required technology for the proper use of coal refuse has been well developed and documented by the British, there has been a noticeable lag in the application of this technology in the coal-producing areas of the United States. The political structure in Great Britain is such that the use of colliery spoil can be, and often is, mandated by the government. In this country however, untried materials proposed for a certain use must be judged capable of meeting established quality control requirements for that use. The mterial must also demonstrate a definite economic advantage to justify its use, particularly if it has been classified as a "waste" material.

Nevertheless, the success that the British have achieved in making use of large quantities of this material in a variety of applications has not yet resulted in a noticeable movement toward sustained uses of coal refuse in the areas of the United States where this material is most available. This is so despite the fact that in many cases use of this material would probably satisfy quality criteria for certain applications at a definite cost savings.

There have been isolated instances where coal refuse has been used in highway construction in the United States. The majority of these applications have proven to be successful. This section of the report will discuss known uses of coal refuse as a highway construction material. A distinction will be made between coal refuse and "red dog," which is the product of burning of a coal refuse bank.

It has been reported that "red dog" has been widely used in Alabama for open grading and road shoulders. It is noted, however, that this material is not used in road base work because it can "revert to its original form and apparently cause trouble from expansion and shrinkage."[119] There has been no reported use of coal refuse for highway purposes in Alabama.

In Colorado, the Fountain Sand and Gravel Company, a subsidiary of the C. F. & I. Steel Corporation, recently began operating a new lightweight aggregate plant which will eventually produce 200,000 tons (180,000 tonnes) per year

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[119] Mr. Alfred S. Chipley, Director, Division of Solid Waste, Alabama Department of Public Health, Montgomery, Alabama. Correspondence dated October 28, 1975.

of Fountain-Lite, a lightweight aggregate manufactured from the coal washery waste at the Pueblo coke plant, where more than 15 million tons (13.5 Mtonnes) of this material is reported to be stockpiled.[120]

Initially, marketing efforts for Fountain-Lite will emphasize the concrete block industry and the use of the aggregate in structural lightweight concrete. The Colorado Department of Highways has agreed to test this material for possible use as a skid-resistant aggregate in bituminous wearing surface mixtures. No committments have been made for incorporating this lightweight aggregate into Colorado State specifications.[121]

In Illinois coal mining wastes have been used to a limited extent. A portion of Interstate Route 57 in Franklin County was constructed on an embankment of coal refuse. Several refuse piles were located within the corridor of the Interstate and the material was used as fill rather than being removed and stockpiled at another site. Present evaluation of this section of Interstate Route 57 indicates that there has been no direct problems resulting from the use of coal refuse for embankment.[122]

Illinois is one of the major coal mining states and large amounts of coal refuse have accumulated, particularly in the southern portion of the state. There are vague references to the removal and subsequent use of up to 15 million tons (13.5 Mtonnes) of coal refuse, including about 20 percent "red dog," for use in road construction in Illinois.[123] This, however, has not been verified by the Illinois Department of Transportation, which states that "coal mining wastes are relatively plentiful in localized areas and have been used as fill material when feasible, but because of the heterogeneous mixture of the material has had a very limited variety of uses."[124]

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[120]Mr. William D. Rogers, Manager of Commercial Sales and Marketing, Fountain Sand and Gravel Company, Pueblo, Colorado. Correspondence dated December 4, 1975.

[121]Mr. James H. Bradish, Sales Manager, Fountain Sand and Gravel Company, Pueblo, Colorado. Correspondence dated March 30, 1976.

[122]Mr. Miles E. Byers, Engineer of Materials and Physical Research, Illinois Department of Transportation, Springfield, Illinois. Correspondence dated November 17, 1975.

[123]Report from Chief of Twin Cities Office of Mineral Resources to J. A. Corgan, Chief, Division of Environmental Activities, Washington, D.C., March 27, 1969.

[124]Mr. Miles E. Byers, Engineer of Materials and Physical Research, Illinois Department of Transportation, Springfield, Illinois. Correspondence dated August 19, 1975.

Practically all of the coal in Indiana is now surface mined. Most of the existing coal refuse banks are attributable to the cleaning of underground mined coal. Although a large percentage of the coal presently being produced is mechanically cleaned, refuse from surface mined coal is required to be returned to the open pit for burial and ultimate covering with overburden. Existing state legislation does not now permit the use of coal refuse for construction purposes, even on a temporary basis, due to the acid nature of the refuse.[125]

Several years ago, the Indiana State Highway Commission constructed two Interstate highways through strip mine areas. By undercutting and carefully selecting the backfill material from the mine strippings, it was possible to successfully utilize the coal overburden material in that area.[126] This use, of course, pertains to the overburden from strip mining and not to the coal refuse resulting from the cleaning and preparation of coal.

The use of coal refuse and/or "red dog" appears to have been very limited in Kansas. Aside from some occasional applications of refuse as a common embankment, no other use has been made of the material.[127] Some "red dog" may have been used in road surfacing in mining areas, although nothing more specific is known of any such use.[128]

Although Kentucky is now the leading coal-producing state in the United States, there is very limited use of preparation plant refuse for highway construction or any other use. Nevertheless, it was recently reported that refuse from a coal preparation plant in the town of Corbin, near the border of Knox and Whitley Counties in Eastern Kentucky, is being taken from the preparation plant and used by local and county road personnel as a sub-base material.[129]

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[125]Mr. Richard D. McNabb, Director, Division of Reclamation, Indiana Department of Natural Resources, Indianapolis, Indiana. Correspondence dated September 3, 1975.

[126]Mr. C. F. Hotler, Chief, Division of Materials and Tests, Indiana State Highway Commission, Indianapolis, Indiana. Correspondence dated August 14, 1975.

[127]Mr. C. W. Heckathorn, Assistant Engineer of Materials, State Highway Commission of Kansas, Topeka, Kansas. Correspondence dated August 15, 1975.

[128]Mr. Lawrence L. Brady, Chief, Kansas Geological Survey, Lawrence, Kansas. Correspondence dated September 18, 1975.

[129]Mr. Donald K. Cooper, Assistant Director of Coal Preparation, United States Steel Corporation, Pittsburgh, Pennsylvania. Personal communication.

The Kentucky Department of Transportation has made very limited use of coal refuse in highway applications. It has occasionally been used as aggregate for shoulders and pavement surfaces on very low-volume roads.[130]

It has been reported that a bonding agent has been developed and used with coal slurry from Eastern Kentucky to produce structural block of variable compressive strength, depending on the amount of bonding agent used. Although this bonding technique has not been demonstrated in the field, it has possible application as a stabilizer for use with coal refuse in base course construction.[131]

In eastern Ohio, coal refuse has been accepted for use in embankments for years, provided the materials conform to weight, compaction, and other requirements of the specifications. Coal refuse is considered as random material in the state specification.[132]

Some experimental work was done by the Pennsylvania Department of Transportation on the use of burned-out anthracite coal refuse ("red dog") as an aggregate for bituminous paving mixtures. Marshall stability values were in excess of 2200 pounds (998 kilograms). Nearly 1400 tons (1260 tonnes) of this material were used in the placement of four experimental paving projects in Luzerne County during 1970. (76) Some obvious distress was observed in the laboratory samples after 230 cycles of freezing and thawing, compared with more than 500 cycles in the conventional mixes. (126) Recent reports have indicated that the experimental sections did not wear very well under traffic. No further use has been made of the material for this purpose.[133]

The Pennsylvania Department of Transportaion has approved the use of "red dog" as an anti-skid material, provided it is properly crushed and graded. (18) This material has also been used as aggregate in the shoulders of the Northeast Extension of the Pennsylvania Turnpike. (4)

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[130]Mr. John E. McChord, Director of Division of Materials, Kentucky Department of Transportation, Frankfurt, Kentucky. Correspondence dated August 12, 1975.

[131]Mr. Don Hinkle, Director of Industrial Engineering, Island Creek Coal Company, Paintsville, Kentucky. Personal communication.

[132]Mr. John C. Dixon, Engineer of Tests, Ohio Department of Transportation, Columbus, Ohio. Correspondence dated August 18, 1975.

[133]Mr. Philip Butler, Pennsylvania Department of Transportation, Bureau of Materials, Testing and Research, Harrisburg, Pennsylvania. Personal communication.

More than 1.5 million cubic yards (1.14 million cubic meters) of anthracite coal refuse were used in the construction of a highway embankment for the Cross Valley Expressway in northeast Pennsylvania near Wilkes-Barre. This embankment forms part of the western approach to a bridge which crosses the Susquehanna River between Forty Fort and Kingston. The material from the refuse bank was first cleaned to remove its residual coal content and then placed in layers and thoroughly compacted to eliminate the possibility of spontaneous combustion and acid mine drainage. Instrumentation was installed during the construction of the embankment in order to monitor foundation response and ambient temperatures at various locations within the embankment. (15)

Anthracite coal refuse was also used to construct embankments 40 to 50 feet (12 to 15 meters) high for two sections of Interstate Route 81 near Hazleton in Luzerne County. The refuse was placed and compacted in five foot (1.5 meter) lifts and the outside slopes were covered with ten feet (3 meters) of soil (4).

Based on the success of these installations, the Pennsylvania department of Transportation is planning to utilize coal refuse in future highway projects. Several projects in the western portion of the state will incorporate processed bituminous coal refuse into construction as embankment material (15).

There has also been some very limited use made of "red dog" in the area of Montgomery County in southwestern Virginia, where it was used on at least one occasion to construct the base course on a secondary road project.[134]

In West Virginia, "red dog" is used as a sub-base aggregate and in maintenance work for shoulders and unpaved roads. In conjunction with a secondary road program some years ago, some laboratory and field work were performed with "red dog" mixed with portland cement. Although records of this work are not available, the addition of approximately 10 percent by weight of portland cement with "red dog" can form an excellent construction material.[135]

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[134]Mr. K. E. Ellison, State Materials Engineer, Virginia Department of Highways, Richmond, Virginia. Correspondence dated March 29, 1973.

[135]Mr. Garland W. Steele, Director of Materials Control, West Virginia Department of Highways, Charleston, West Virginia. Correspondence dated June 4, 1973.

Substantial amounts of "red dog" have been used in the past as fill for the construction of parking lots, industrial sites, and residential sites. Some tertiary county roads have also been topped with this material.[136] The use of "red dog" has also been observed in the driveways of private residences in the northern part of West Virginia.

There does not seem to be any documented use of coal refuse for highway construction purposes in West Virginia. It is interesting to note that a section of the Interstate Route 79 corridor just north of Morgantown was designed to pass through a rather large coal refuse bank. Instead of making use of this material, as was done in Illinois, the coal refuse was hauled away and borrow material was transported to the site for embankment construction.[137]

The Environmental Protection Agency arranged for a demonstration of coal refuse as base course material in the parking lot of its Mine Drainage Control Field Site at Crown, West Virginia near Morgantown. Three different base course mixtures were evaluated. The first mixture consisted of 12 inches (304.8 mm) of fly ash treated coal refuse (75 percent refuse - 25 percent fly ash). The second mixture consisted of a 6 inch (152.4 mm) layer of fly ash treated coal refuse overlain by a 6 inch (152.4 mm) layer of fly ash treated coal refuse mixed with five percent hydrated lime. The third mixture consisted of 15 inches (381 mm) of untreated coal refuse. All three base course mixtures were topped with three inches (76.2 mm) of asphalt base and one inch (25.4 mm) of asphalt wearing surface.

A drainage collection system was installed to monitor the quality and chemical composition of the leachate from each base course mixture. The leachate from the fly ash treated refuse had a neutral pH and was not found to be offensive in terms of the presence of harmful chemical constituents. However, the acidity and concentrations of certain metals from the third mixture were found to be excessive and steadily increasing. It has been concluded that the addition of fly ash and/or lime tends to neutralize the acidity and reduce the concentration of heavy metals from pyritic coal refuse discharge (129).

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[136] Mr. James E. Gilley, U.S. Bureau of Mines Liaison Officer for West Virginia, Charleston, West Virginia. Correspondence dated July 17, 1975.

[137] Mr. Alan Babcock, Ash Consultant, Monongahela Power Company, Fairmont, West Virginia. Personal communication.

The preceding examples constitute the known uses of coal refuse and/or "red dog" for highway construction purposes in the United States. It is possible that there have been other instances in which these materials have been used for public highway purposes, but such instances are probably isolated examples involving comparatively small quantities of material.

5.1.4 Metallurgical Slags

There are large contrasts in the utilization of metallurgical slags. On the one hand, the slags from the making of iron and steel have gained wide acceptance as construction material over the years, particularly slag from iron blast furnaces. On the other hand, the slags from heavy metal smelting operations have been utilized to a much lesser degree, although this is not to imply that these slag materials are necessarily inferior products. This section of the report will discuss the utilization of these two classes of metallurgical slags separately.

Iron and Steel Slags

The utilization of iron blast furnace slag has become widespread in areas where this material is produced. Although blast furnace slag is classified as a waste material or by-product in this study, it actually belongs in the category of an approved construction aggregate material.

Air-cooled blast furnace slag has been accepted and is presently known to be specified for use as highway construction material in a total of 20 states. Missouri is the only slag-producing state at the present time in which blast furnace slag is not specified and routinely used. It has been used there only on an experimental basis.

The known uses of this material in different areas of the United States are presented separately in Table 36. This table was developed from information received from slag processors, the National Slag Association, and numerous state transportation and environmental offices. A description of the different commercial uses of blast furnace slag is presented in "Iron Blast Furnace Slag: Production, Processing, Properties, and Uses " (57).

In addition to the three basic types of blast furnace slags described on page 96, a relatively new product known as pelletize blast furnace slag is also available. It is produced by a proces developed at National Slag, Ltd., in Hamilton, Ontario, Canada. This process involves pelletizing the liquid slag to produce

Table 36. States where air-cooled blast furnace slag is accepted for highway use.

State	Type of use	Remarks
Alabama	No reported uses	Approved as aggregate
California	Portland cement concrete Bituminous paving Aggregate base and sub-base Cement-treated base	Routinely used
Colorado	Bituminous paving	Routinely used
Delaware	No reported uses	Approved as aggregate
Florida	No reported uses	Approved as aggregate
Illinois	Approved aggregate in all quality classes	Routinely used. Removed from list of waste materials
Indiana	No reported uses	Approved as aggregate
Kentucky	No reported uses	Approved as aggregate
Louisiana	No reported uses	Approved as aggregate
Maryland	Bituminous paving	Routinely used
Michigan	Portland cement concrete Bituminous paving Base course construction	Routinely used
Mississippi	No reported uses	Approved as aggregate
Missouri	Bituminous paving	Use has only been experimental to date
New York	Portland cement concrete Bituminous paving	Routinely used
Ohio	Portland cement concrete Bituminous paving Base course construction	Routinely used

Table 36. States where air-cooled blast furnace slag is accepted for highway use (continued).

State	Type of use	Remarks
Pennsylvania	Portland cement concrete Bituminous paving Base course construction	Routinely used
Texas	No reported uses	Approved as aggregate
Utah	Bituminous paving Seal coat aggregate	Routinely used
Virginia	No reported uses	Approved as aggregate
West Virginia	Base course construction	Often blended with dry bottom boiler slag

a lightweight aggregate. This is accomplished by first expanding the molten slag under water sprays and then passing the expanded material over a rotating pelletizing drum, where spherical pellets are formed. These pellets are essentially spherical in shape and are in some gradation range as fine sand. The material is very promising for blending with air-cooled blast furnace slag in stabilized base course, but there has not as yet been any known use in the field for this purpose (31).

Because of variable chemistries and well-known expansive properties, the use of steel-making slags is not nearly as extensive as that of blast furnace slags. Most users of steel slag, recognizing the expansive character of this material, insist that it be properly aged prior to its use and avoid using it in confined applications.

The experiences gained by a number of state agencies in the use of steel slag for highway construction are related in the following paragraphs. Where possible, these accounts will note the type of steel furnace used to produce the slag being described.

The extent of the use of steel slag in Alabama is not well known. It is known, however, that the State Highway Department had some unsatisfactory results in the form of blow-ups resulting from the use of an open hearth slag as a base course aggregate. There is no indication of the extent of treatment, if any, of this slag material prior to its use.[138]

There have also been reports of the utilization of steel slag in asphalt paving work in the Birmingham and Gadsden areas, but changes in steel-making techniques are expected to reduce the future availability of steel slag in these areas.[139]

In California, the Department of Transportation requires in their specification that steel slag be control aged prior to use for a period of at least six (6) months under conditions that will maintain all portions of the stockpiled material at a moisture content in excess of six (6) percent of the dry weight of the aggregate. Individual stockpiles shall contain from 10,000 to 50,000 tons (9,000 to 45,000

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[138]Mr. W. F. McCullough, Assistant Materials and Tests Engineer, Alabama Highway Department, Montgomery, Alabama. Correspondence dated September 2, 1975.

[139]Mr. Alfred S. Chipley, Director, Division of Solid Waste, Alabama Department of Public Health, Montgomery, Alabama. Correspondence dated October 28, 1975.

tonnes) of steel slag and must be assigned a unique lot number. The state maintains a rigidly controlled system of inspection to assure proper quality control of the steel slag before approving it for use.[140]

There are from eighteen to twenty million tons (16.2 to 18 Mtonnes) of blast furnace and open hearth slag stockpiled in the vicinity of Fontana in southern California. Some 300,000 cubic yards (228,000 cubic meters) of mixed slag was incorporated into the embankments of Interstate Route 15 two miles (3.2 kilometers) from the steel plant. About 250,000 tons (225,000 tonnes) of open hearth slag are processed annually for use in embankments, sub-base, aggregate base, and asphaltic concrete.[141] Nevertheless, a slag processor in the area notes that "one of the difficulties in marketing slags is that we are in the center of the best natural aggregate deposits in California." He also points out that great resistance to the use of slag is provided by the aggregate producers in the area.[142]

Steel slag has been accepted as a skid-resistant aggregate in California. The Standard Special Revision M25 of the State specifications stipulate that no other type of aggregate can be used in asphalt mixtures in which steel slag aggregate is used.

Steel slag from the Pueblo works has been used in Colorado to make concrete that is highly resistant to abrasion. Since no tonnage figures are available, the use of steel slag in Colorado is probably limited, particularly when compared to the use of blast furnace slag.[143]

Steel slag is approved for seal coat and bituminous wearing surface use in Illinois. It is also approved "wherever else its adverse swelling characteristics permit."[144]

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[140]California Department of Transportation, Standard Special Provision M25, Section 8-1, Slag Aggregate, October 20, 1975.

[141]Mr. R. M. Collins, Engineering Services, California Department of Transportation, San Bernardino, California. Correspondence dated November 19, 1975.

[142]Mr. Fred C. Schaffner, Manager of Aggregate Sales, Heckett Slag Products, Fontana, California. Correspondence dated January 14, 1976.

[143]Mr. Anthony B. Rubner, Assistant Staff Materials Engineer, Colorado Department of Highways, Denver, Colorado. Correspondence dated September 5, 1975.

[144]Mr. Miles E. Byers, Engineer of Materials and Physical Research, Illinois Department of Transportation, Springfield, Illinois. Correspondence dated August 19, 1975.

Practically no information is available on amounts of steel slag produced and actually used for highway construction purposes in Illinois.

Steel slag production in Indiana is confined to the northwest corner of the state. It is used on a limited basis as an aggregate base material or in asphalt paving mixtures after it has been aged. Due to difficulties involved in controlling the material before its use, Indiana has chosen not to include steel slag in their Standard Specifications. Due to the possibility of recycling steel slag back to the blast furnace in some of the steel mills in the Gary area, the future availability of this material in Indiana is somewhat doubtful at this time.[145]

More than three million tons (2.7 Mtonnes) of blast furnace and steel slag are produced each year at Sparrows Point, Maryland. Although blast furnace slag is widely used in bituminous paving by the City of Baltimore (89), no definite information has been received regarding the nature or extent of steel slag use in specific projects.

The use of open hearth and basic oxygen furnace slags for highway construction in Michigan has been confined to base course applications on an experimental basis. Several experiences are noted in which untreated steel slag had been used, resulting in heaving and blistering of pavement surfaces (61). A slag processor in the Detroit area has successfully treated steel slag with spent pickle liquor (H_2SO_4) to accelerate expansion before use in base course construction (29).

In Missouri, the use of both blast furnace and steel slags are experimental at the present time. The experimental installations to date have been bituminous wearing surface projects in the St. Louis area using blast furnace and steel slags produced at Granite City, Illinois.

The first experimental steel slag overlay project in Missouri was inspected in conjunction with this research. This project was installed in 1973 over a 2.5 mile (4 kilometer) section of Natural Bridge Road near the Lambert International Airport in St. Louis County. The slag used was a basic oxygen furnace slag aged for a period of six months. The overlay was 1-1/2 inches (38.1 mm) thick and consisted of eighty percent by weight steel slag, twenty percent by weight river sand, and an asphalt content of 5.3 percent. No

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[145]Mr. C. F. Hotler, Chief, Division of Materials and Tests, Indiana State Highway Commission. Correspondence dated August 14, 1975.

problems were encountered during mixing at the plant or installation in the field. After three years of moderately heavy traffic, the pavement shows very little signs of wear.

The Missouri State Highway Commission has conducted periodic skid resistance measurements on this experimental pavement section using a locked wheel skid trailer. Skid resistance measurements on this section of the pavement are reported to be "holding up very well when compared with asphaltic concrete pavement surfaces of similar age and carrying similar amounts of traffic in the St. Louis area using local limestones as the primary coarse aggregate."[146]

Although a considerable amount of steel slag is produced in the Buffalo, New York area, the state of New York's Department of Transportation has not attempted to use this material. Because of volume expansion attributable to hydration of the free lime and magnesia, steel slags are considered unacceptable for use in confined areas or in Portland cement concrete. Department personnel are aware of some use of steel slag in Canada and elsewhere as aggregate in bituminous concrete pavements and as chipping for shoulders. But to date no use of steel slags in New York State is being contemplated.[147]

In Ohio, where extremely large accumulations of steel slag are found, the utilization of steel furnace slags in highway construction seems to be relatively low. Basic oxygen and/or open hearth slags must be properly conditioned prior to use. There are no specific projects on the use of steel slag as highway construction material, according to information received to date.

Although steel slag is produced and has accumulated in huge amounts in certain sections of Pennsylvania, reports of its use in highway construction are also somewhat limited. Open hearth slag was used experimentally on a cement-treated base course project in the Coatesville area several years ago, but expansion problems developed because the slag had not been properly treated before its use (77).

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[146] Mr. William L. Trimm, Division Engineer for Materials and Research, Missouri State Highway Commission, Jefferson City, Missouri. Correspondence dated April 6, 1976.

[147] Mr. Harry H. McLean, Director of Engineering Materials, New York Department of Transportation, Albany, New York. Correspondence dated September 9, 1975.

Processed open hearth slag was also used as base course aggregate in the construction of an interchange for Interstate Routes 82 and 283 with U.S. Route 322 in Harrisburg. The slag was screened and subjected to a controlled six-month aging process. No problems have developed since 1969 when the interchange was placed in service.[148]

Processed open hearth slag was used in a bituminous wearing surface installation near Zelienople, Pennsylvania. Workability of the mix was good, but some elongated steel particles and cuttings in the slag were noted to have caused tire damage. No definite reports on skid resistance values are available other than a brief note that the skid resistance for that section of pavement can be termed as adequate. (78)

It has been recently noted that 75,000 tons (67,500 tonnes) of stockpiled steel slag were used in the construction of a section of the Mid-County Expressway (Interstate Route 476) near Conshohocken, Pennsylvania, although the exact nature of its use is not known at this time.[149]

Some use has been made of open hearth slag from the Geneva plant in Utah as aggregate for bituminous paving mixtures. If properly aged, it was also found to be acceptable for use in Portland cement concrete, but the mixes were quite heavy and did not exhibit good workability. Processed open hearth slag was also used as fill material in the construction of Interstate Route 15.[150]

Large tonnages of basic oxygen furnace slag are being produced at Weirton, West Virginia. However, very little use has been made of this slag in highway construction. There is a report that some of this slag was placed and sprayed with asphalt on rural secondary roads carrying light traffic.[151] No other definite uses of steel slag in West Virginia are

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[148] Construction Methods, October, 1969, pp. 76-81.

[149] Mr. Bill Wilson, Slag Sales, International Mill Services, Philadelphia, Pennsylvania. Personal communication.

[150] Mr. Wade Bentensen, Materials Engineer, Utah Department of Highways, Salt Lake City, Utah. Personal communication.

[151] Mr. Garland W. Steele, Director of Materials Control, West Virginia Department of Highways, Charleston, West Virginia. Correspondence dated June 4, 1973.

reported, although it is possible that there may have been some experimental use of this material as base course aggregate.

The preceding discussion has noted in a general way the known usage of steel slag in highway construction, based on reports received during the course of this project from slag processors and state highway and transportation department engineers.

Heavy Metal Slags

The second category of metallurgical slags to be considered are by-products from the smelting of heavy metal ores. These slags are not produced in as great a tonnage as the iron and steel slags, and the percentage utilized is also correspondingly less. Nevertheless, where used, these materials appear to have performed satisfactorily. The purpose of this section of the report is to document the known applications of heavy metal slags in highway construction.

The largest amounts of copper slag are produced in Arizona, where seven of the country's fifteen domestic copper smelting operations are located. The Arizona Department of Transportation has approved the use of these slag materials as aggregates. A bituminous anti-skid wearing surface mix incorporating copper slag was designed and used, but the slag particles had a tendency to become dislodged by traffic, resulting in damage to windshields.[152] Regarding other uses of these slags in highway construction, the State has reported that "those tested are privately owned and we could not justify payment of the royalty requested."[153]

Granulated lead slag from the Kellogg smelter was used in Idaho as the fine aggregate for an asphalt binder course installed during the construction of Interstate Route 90 in Shoshone County.[154] This slag product is also being used locally as a bedding material for buried pipelines and as a frost barrier under concrete and asphalt slabs.[155]

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[152] Mr. Grant J. Allen, Engineer of Materials, and Mr. Rowan J. Peters, Assistant Engineer of Materials, Arizona Department of Transportation, Phoenix, Arizona. Personal communication.

[153] Mr. Grant J. Allen, Engineer of Materials, Arizona Department of Transportation, Phoenix, Arizona. Correspondence dated May 10, 1973.

[154] Mr. Richard N. Appling, Jr., Chief, U.S. Bureau of Mines, Western Field Operation Center, Spokane, Washington. Correspondence dated July 18, 1975.

[155] Mr. J. E. McKay, Vice President for Technical Services, Bunker Hill Company, Kellogg, Idaho. Correspondence dated November 6, 1975.

In southeast Idaho, phosphate slags from the Pocatello and Soda Springs areas are used in various phases of highway construction, including borrow, crushed base, or crushed aggregate for use in bituminous paving, seal coats, and Portland cement concrete mixtures. This material was recently used as coarse aggregate in a concrete pavement in the Montpelier area.[156]

In Michigan, copper reverberatory slag from the White Pine smelter was investigated by the Testing and Research Division of the Michigan State Highway and Transportation Commission for its suitabliity as an aggregate in highway construction. A number of standard evaluative tests were performed. The material was found to be suitable as aggregate for all types of highway construction with the exception of fine aggregate for Portland cement concrete. In addition, the investigation determined that this slag possessed much higher hardness (six to seven on the Mohs scale) than that of conventional aggregates used in Michigan. (36)

Both coarse and fine sized copper slags were used by the White Pine Copper Company to resurface the roads and parking areas around their entire plant site. Results were excellent, particularly in view of the fact that very heavy equipment operates in the area.[157]

Granulated lead smelter slag has been used as an antiskid material in eastern Missouri for a number of years by state and local highway departments. This practice has been recently discontinued because the Missouri Department of Natural Resources suspects that the slag contains significant amounts of lead. The concern of the Department is that in any application of this slag no lead be permitted to escape into the environment through leaching.[158]

Although no problems have arisen from past use of this slag and no data is available regarding the leaching characteristics of this material, the lead producers in Missouri have decided to withdraw the slag from the market and simply

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[156]Mr. Claude B. Humphrey, Materials Supervisor, Idaho Transportation Department, Boise, Idaho. Correspondence dated August 27, 1975.

[157]Mr. Richard H. Johnson, Senior Research Engineer, White Pine Copper Company, White Pine, Michigan. Correspondence dated November 21, 1975.

[158]Mr. Robert M. Robinson, Director, Solid Waste Management Program, Missouri Department of Natural Resources, Jefferson City, Missouri. Correspondence dated October 28, 1975.

dispose of it rather than contend with the adverse publicity being given to the possibliity of lead pollution.[159]

The Missouri State Highway Commission, however, is still making limited use of lead smelter slag in bituminous mixtures used by their maintenance forces for winter patching and spot sealing in the eastern part of the state.[160]

Large quantities of metallurgical slags are generated each year in Montana from the smelting of copper and lead and the production of elemental phosphorous. At this time, only phosphate slag is being utilized for any purpose as highway material. Nearly one million tons (0.9 Mtonnes) of phosphate slag have been used so far in highway construction in the vicinity of Butte, Montana. The main uses of this material have been as aggregate for base courses and in asphaltic concrete pavements. Because of its coarse nature, fine sand has been added in the form of mill tailings for both types of applications, but particularly in base course use, where the top surface of the base is often stabilized with emulsified asphalt. The material has no swelling or absorbing tendencies, has excellent adhesion to asphalt, and is considered to be one of the best sources of road building material in Montana.[161]

Phosphate slag has also been used extensively in highway construction for many years in Tennessee, where it is specified as a skid resistant coarse aggregate in bituminous wearing surfaces. Phosphate slag is utilized in even greater quantities for highway construction and other uses in Tennessee than in Idaho, where supplies of natural aggregate are more plentiful.[162]

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[159] Mr. J. W. Sherman, Division Manager, St. Joe Lead Smelting Division, Herculaneum, Missouri. Correspondence dated November 11, 1975.

[160] Mr. Clay Wester, District Maintenance Engineer, Missouri State Highway Commission, St. Louis, Missouri. Personal communication.

[161] Mr. Lehman B. Fox, Chief of Materials Bureau, Montana Department of Highways, Helena, Montana. Correspondence dated August 22, 1975.

[162] Mr. K. L. McQuivey, Market Manager, Phosphorous and Phosphorous By-Products, Monsanto Industrial Chemicals Company, St.Louis, Missouri. Correspondence dated December 9, 1975.

More than 100,000 cubic yards (76,000 cubic meters) of granulated copper slag from a secondary smelting facility in Carteret, New Jersey, were used as fill material in the widening and extension of the New Jersey Turnpike during 1967-68. Reference has also been made to other local uses of this material in highway construction.[163]

Small amounts of zinc smelter residue from Henryetta, Oklahoma, have been used as sub-base and bituminous base course materials. No estimate was made of the quantities involved.[164] It has also been reported that some zinc smelter wastes have been used as aggregate on unpaved local roads in Oklahoma. There are some claims, which are unsubstantiated at the present time, that cadmium has been leaching into ground water supplies as a result of the use of these residues.[165]

The nickel smelter at Riddle, Oregon, produces a granulated slag by-product that has been used to a limited extent in the southwest part of the state by the Oregon State Highway Division as sandblasting aggregate for removing traffic lane stripes. During the winter, moderate amounts of this slag are also used as anti-skid material. No use as yet has been made of this nickel slag in paving construction.[166]

Some of the zinc smelter residue generated in Pennsylvania has been used to a limited extent as highway material. Slag residue from a mechanical furnace in Palmerton, Carbon County, was used as base course material in the construction of Pennsylvania Route 209 near Lehighton. A contractor also processes some of the stockpiled residue from the Palmerton plant and markets it as an anti-skid material for use on local and state highways.[167] Slag residues from the zinc smelter located in Monaca, Beaver County, have been used in a variety of applications, including anti-skid materials,

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[163]Mr. R. N. Brown, Executive Vice President, United States Metals Refining Company, Carteret, New Jersey. Correspondence dated November 26, 1975.

[164]Mr. J. D. Telford, Assistant Materials Engineer, Oklahoma Department of Highways, Oklahoma City, Oklahoma. Correspondence dated August 13, 1975.

[165]Mr. Robert H. Arndt, U.S. Bureau of Mines Liaison Officer for Oklahoma, Oklahoma City, Oklahoma. Personal communication.

[166]Mr. John C. Jenkins, Engineer of Materials, Oregon State Highway Division, Salem, Oregon. Correspondence dated August 26, 1975.

[167]Mr. Tim Reilly, President, Aggregates, Inc., Pottsville, Pennsylvania. Personal communication.

aggregate for the paving of parking lots and driveways, base material for asphalt surfacing, and bedding for pipelines.[168] Aside from anti-skid use, there is probably no other application of this material on state highways in western Pennsylvania.

Since 1955, Monroc, Inc., Utah Sand and Gravel Division, has, under lease with Kennecott Copper Corporation, excavated, crushed, and sold approximately four million tons (3.6 Mtonnes) of air-cooled copper smelter slag produced at the Kennecott smelter facility in Garfield, Utah. Some of this slag was marketed as a select material for highway construction. Since 1968, the slag has been produced in a granular form which is not considered suitable for highway construction because it cannot be compacted. Construction of a new smelter will be completed in mid-1977 and the waste is expected to be in the form of a tailing from a flotation process instead of a slag.[169]

The Utah Department of Highways has used copper smelter slag in bituminous wearing surfaces and as a seal coat aggregate. The material is quite hard and extremely heavy, thereby making it more costly to transport. Although copper slag has performed very well in bituminous wearing surfaces and given high skid resistance, these pavements are more costly due to the heavier weight of the aggregate. Therefore, the Department of Highways feels that the most economical use of the material is as a seal coat aggregate. One small problem associated with seal coat usage is that the aggregate particles must be well seated or pieces could break off under traffic and, owing to the high unit weight, cause damage to windshields.[170]

Very little highway construction use has been made of the copper smelter slag produced in Tacoma, Washington. The product is crushed and marketed by a slag processor for use as a surfacing material in heavy equipment yards and private driveways, as well as a number of other uses.[171]

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[168]Mr. Charles D. Henderson, Manager, St. Joe Zinc Smelting Division, Monaca, Pennsylvania. Correspondence dated April 1, 1976.

[169]Mr. D. R. Cummings, Mill Superintendent, Kennecott Copper Corporation, Magna, Utah. Correspondence dated September 26, 1975.

[170]Mr. Wade Bentenson, Materials Engineer, Utah Department of Highways, Salt Lake City, Utah. Personal communication.

[171]Mr. Stan Bumgarner, Vice President and General Manager, Blackknight, Inc., Tacoma, Washington. Correspondence dated March 30, 1976.

5.1.5 Washery Rejects

Because of the physical state in which they are disposed, washery rejects are usually unsuitable for direct use as a highway construction material without at least some degree of dewatering and further processing. Unfortunately, some of these wastes still exhibit comparatively low solids contents after dewatering, making them unstable and difficult to handle. Therefore, their use in highway construction has been quite limited and will be only briefly recounted.

There is no evidence that alumina red mud has ever actually been used in highway construction. However, some experimental work has apparently been conducted on red mud for construction use. The material must first be neutralized, settled, filter dried, and finally kiln dried. In this form, it was reported to be suitable for concrete mixes.[172] There is also a reference to the experimental use of mud waste from an alumina reduction plant as paving material on a highway in Alabama.[173]

Of the solid wastes generated by the industrial phosphate industry, the only known material usage related to highway construction is that of phosphogypsum. This use was discussed earlier in the chapter.

There has been no use made of the tremendous volumes of phosphate slimes due to the fact that it is uneconomical at the present time to dewater these materials. Research aimed at finding practical uses for phosphate slimes and other mining and metallurgical wastes will be described at the end of this chapter.

A summary of the uses of mining and metallurgical wastes in highway construction is presented in Table 37. This summary represents all known and reported uses of these materials. There may be other highway uses of mining and metallurgical wastes which have not been reported, but which represent successful utilization of these materials.

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[172]Mr. J. M. Baretincic, Corporate Staff Engineer, Ormet Corporation, Hannibal, Ohio. Correspondence dated December 31, 1975.

[173]Mr. J. A. Branscomb, Reynolds Metal Company, Listerhill, Alabama. Correspondence dated August 20, 1975.

Table 37. Summary of mining and metallurgical waste use in highway construction.

State	Waste Material	Type of Use	Quantity Used	Remarks
Alabama	Open hearth slag	Base course aggregate	Not known	Unsatisfactory results due to expansion of the aggregate.
	Brown iron ore tailings	Aggregate	Not known	Work is experimental at this time.
	Incinerated coal refuse (red dog)	Grading and shoulders	Not known	Not recommended for road base due to expansion and shrinkage.
	Alumina mud	Paving material	Not known	Reported by Reynolds Aluminum. No further details available.
Arizona	Copper waste rock	Aggregate	Not known	Source used is now unavailable.
California	Gold dredge tailings	Embankment material Aggregate for bases Portland cement concrete, and bituminous concrete	Probably millions of tons over many years	Meets State specifications for sand and gravel material.
	Steel slag	Embankment material Aggregate for bases Portland cement concrete, and bituminous concrete	Over 250,000 tons (225,000 tonnes) per year	Aging process is strictly controlled by State specifications.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
California (continued)	Iron ore tailings	Aggregate in concrete structures for Interstate Route 10 and in bituminous mixtures for county roads	Not known	Coarse tailing product only was used.
	Asbestos tailings (asbestos shorts)	Additive to bituminous wearing surfaces	Not known	Screening is required to separate serpentine waste rock.
	Boron waste	Roadway surfacing around mine areas	Not known	Retrieval of material not considered possible at this time.
Colorado	Gold tailings and waste rock	Crushed as aggre- for highway construction	Not known	Used to build highway from Durango to Silverton in 1930's.
	Silver waste rock	Crushed as aggregate for road base use	Not known	Used in mining access roads and county roads adjacent to mines.
	Steel slag	Aggregate in concrete for abrasion resistance	Not known	Material has high hardness and is quite difficult to crush.
	Coal refuse	Fill material for state and county roads	Not known	C. F. & I. also producing lightweight aggregate from coal refuse for possible use as skid-resistant aggregate.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Florida	Phosphogypsum	Sub-base for in-plant roads and stabilized base material in Tampa area	10,000 tons (9,000 tonnes) per year as stabilized base course	Also reported to be used in paving ten miles (16 kilometers) of blacktop road.
Idaho	Phosphate slag	Borrow, crushed base, bituminous paving aggregate, and aggregate in concrete pavement	Not known	Material is very hard and dense and exhibits excellent skid-resistant properties.
	Silver-lead tailings	Embankment material in construction of Interstate Route 90	One million tons (0.9M tonnes)	Also used in the construction of a water impoundment dam.
	Gold dredge tailings	Road base fill and aggregate	Not known	Used in construction of a forest service road in Custer County.
	Granulated lead smelter slag	Bedding for buried pipelimes	Not known	Local use only. Also in concrete blocks.
		Fine aggregate for asphalt paving	Not known	Used in binder coarse of Interstate Route 90.
Illinois	Coal refuse	Embankment material in construction of Interstate Route 57 in Franklin County	Not known	Present evaluation by Illinois Department of Transportation indicates no direct problem from this use.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Illinois (continued)	Coarse lead-zinc tailings	Aggregate in bituminous paving mixtures	Over 100,000 (90,000 tonnes)	Have been used as aggregate for a number of years in applicable gradations and quality classes.
	Fluorspar tailings and waste rock	Crushed as aggregate	Not known	Have been used as aggregate for a number of years in applicable gradations and quality classes.
	Steel slag	Embankment and fill material	None	Research evaluation only except for approval in bituminous seal coats.
Indiana	Coal overburden from strip mining	Embankment material	Very limited	State legislation prohibits use of coal refuse in construction of transportation system due to the acid nature of the material.
	Steel slag	Base course and bituminous paving mixtures	Not known	Due to recycling of steel slag within the steel mills, future availability of the material is expected to decrease.
Kansas	Coarse lead-zinc tailings (chat)	Portland cement concrete, bituminous base and wearing surface aggregate	Not known	Also used as railroad ballast material.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Kansas (continued)	Incinerated coal refuse (red dog)	Road surfacing in mining areas	Not known	No use made of this material by the State highway Commission of Kansas.
Kentucky	Coal refuse	Sub-base and fill material	Not known	Used by local municipalities in vicinity of Corbin, Kentucky
		Aggregate for shoulders and bituminous wearing surfaces	Very limited	Used only on low volumes secondary roads.
Louisiana	Low grade iron ore	Aggregate for bituminous base course	Very limited	Used only on secondary roads in the northwest part of the state.
Maryland	Steel slag	Construction aggregate	Not known	No specific uses have been reported.
Michigan	Copper tailings (stamp sands)	Embankment and sub-base material for U.S. Route 41-Chassell South	Not known	Also used as aggregate in bituminous mixes and as anti-skid material.
	Copper waste rock	Embankment and sub-base material for U.S. Route 45-Military Hills	Not known	Also used by Keweenaw County as road base and sub-base material.
	Copper smelter slag	Aggregate for local and state roads	Not known	Also used to pave parking lot and access roads at White Pine Copper Company mine.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Michigan (continued)	Iron waste rock	Embankment, back-fill, and sub-base material for U.S. Route 2 - Ironwood	Not known	Also used as subgrade and fill material in swampy area.
	Steel slag	Aggregate for base course	Not known	Evaluated on an experimental basis at present.
Minnesota	Coarse taconite tailings	Skid-resistant aggregate in bituminous wearing surface mixes	Several hundred thousand tons	Very high skid resistance. Also used in bridge deck surfacings.
	Coarse taconite tailings	Aggregate in stone base, sub-base, and bituminous base course mixes	Not known	Also used as embankment and fill material. Must stabilize in base use due to lack of cohesiveness of fines.
Missouri	Coarse lead-zinc tailings (chat)	Portland cement concrete, bituminous base and wear-surface mixes	Not known	Also used as railroad ballast material.
	Barite tailings (tiff chat)	Road surfacing	Not known	Local road use only in east central Missouri.
	Iron waste rock (trap rock)	Portland cement concrete, bituminous mixes	Not known	Used routinely in bituminous mixtures and covered by Standard Specifications.
	Lead waste rock	Aggregate in bituminous mixtures	Not known	Fines are marketed as agricultural limestone.
	Steel slag	Aggregate in bituminous mixtures	Not known	Evaluated on an experimental basis.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Missouri (continued)	Granulated lead smelter slag	Anti-skid material	Not known	Recently discontinued due to concern over residual lead content.
Montana	Phosphate slag	Aggregate in base course and bituminous mixtures	One million tons (0.9 M tonnes)	Fines must be added for proper gradation. Has a high skid resistance.
	Copper smelter slag	Sandblasting of pavement markings	Not known	Very limited use to date. Millions of tons available. Has high iron concentration.
Nevada	Barite tailings (chert)	Resurfacing of Interstate Route 80 near Battle Mountain	Not known	Used - 3/4" (19.1 mm) material only.
	Asbestos tailings (asbestos shorts)	Additive in bituminous paving for Interstate Route 15 near Las Vegas	Not known	Also used as additive for resurfacing of playgrounds and parking lots.
New Jersey	Granulated copper slag	Fill material in construction and widening of New Jersey Turnpike	Over 100,000 (90,000 tonnes) tons used during 1968	Also used as abrasive grit material.
	Iron ore tailings	Dense aggregate in asphalt and concrete mixes	Not known	Mine no longer in operation.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
New Mexico	Molybdenum tailings and waste rock	Aggregate in bituminous mixtures	Not known	University of New Mexico presently studying characteristics of molybdenum tailings.
New York	Wastes from iron and titanium mining	Portland cement concrete, bituminous mixtures	Not known	Have been using these materials in pavements since 1930.
North Carolina	Phosphogypsum	Fill and sub-base material in swampy areas	100,000 tons (90,000 tonnes)	Also used in land reclamation.
	Feldspar tailings	Fill material	Not known	Material reported to have good compaction properties.
Ohio	Coal refuse	Embankment and fill material	Not known	Could probably be used within specifications as a random fill.
	Steel slag	Aggregate for base courses and bituminous mixtures	Not known	Permitted under State Specifications when properly conditioned prior to use.
	Alumina red mud	Aggregate for Portland cement concrete	Laboratory use only	Research indicates suitability if neutralized, settled, filtered, and dried.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Oklahoma	Coarse lead-zinc tailings (chat)	Portland cement concrete, bituminous mixtures	Not known	Also used as railroad ballast material.
	Zinc smelter residues	Aggregates for sub-base and bituminous base	Not known	Also used locally on unpaved roads.
		Bituminous mixtures	Not known	Experimental evaluation indicates potential for use.
Oregon	Granulated nickel slag	Road sandblasting, anti-skid material	Not significant	State Highway Division presently investigating possible use of this material as aggregate for paving.
	Granulated nickel slag	Bituminous mixtures	Not known	Adhesion to asphalt may need to be improved with anti-skid additive because of glassy surface.
Pennsylvania	Steel slag	Aggregate base course	Not known	Experimental use - expansion noted due to insufficient aging.
		Bituminous wearing surface	Not known	Experimental use.
	Anthracite coal refuse	Embankment material	1.5 million tons (1.35 M tonnes)	Performance currently being monitored by PennDOT. Material processed for removal of coal prior to placing in embankment.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Pennsylvania (continued)	Anthracite coal refuse	Shoulder material on northeast extension of Pennsylvania Turnpike	Not known	Not sure whether material was incinerated refuse (red dog).
	Anthracite coal refuse	Bituminous wearing surfaces for four test sections	Approximately 2,500 tons (2,250 tonnes)	Some refuse was red dog. Test sections reportedly not wearing well.
	Incinerated anthracite coal refuse (red dog)	Anti-skid material	Not known	Approved for anti-skid use by PennDOT.
	Iron waste rock	Bituminous wearing surface on Pennsylvania Turnpike	Not known	Also commercially marketed as aggregate material.
		Fill material	Not known	Waste rock has high unit weight.
	Zinc smelter residue	Sub-base material on Pennsylvania Route 209 at Lehighton	Not known	Also used as anti-skid material.
South Dakota	Gold waste rock	Seal coat resurfacing of State Highway 385 near Lead	Not known	Possible use in Portland cement concrete.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Tennessee	Phosphate slag	Aggregate in bituminous wearing surfaces	Not known	Material has high skid resistance.
	Zinc coarse tailings	Commercial aggregate	Not known	Marketed through American Limestone Co.
Utah	Copper Mill tailings	Embankment material in construction of Interstate Route 215 and mineral filler in bituminous mixtures	At least 5.5 million tons (4.95 Mtonnes) to date	Tailings are processed to recover coarse fraction for use in highway construction.
	Air-cooled copper slag	Granular fill material	Not known	Coarse slag (-3" or 76.2 mm size) used.
		Aggregate for seal coats and bituminous mixtures	Not known	Fine slag (-1/2" or 12.7 mm size) used. Possible uses in sandblasting and slurry seal coats.
Virginia	Incinerated coal refuse (red dog)	Base course aggregate	Not known	Secondary road use only.
	Crushed slate waste rock	Base course aggregate	85,000 tons (76,500 tonnes) per year	Used primarily in Buckingham and Cumberland counties.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Washington	Lead-zinc waste rock	Aggregate for subbase, base course and bituminous wearing surfaces	Not known	Used by city, county, and state agencies.
	Lead-zinc waste rock	Miscellaneous fill and aggregate for private driveways	Not known	
West Virginia	Incinerated coal refuse (red dog)	Aggregate for subbase, shoulders, and unpaved roads by state and local agencies	Not known	Also used as topping for county roads.
	Coal refuse	Blended with fly ash in base course of parking lot	Very limited	Experimental installation being monitored for leachate by EPA personnel.
	Basic oxygen furnace slag (steel slag)	Sprayed with asphalt for placement on light traffic rural secondary roads	Not known	Material not presently included in State Specifications.
Wisconsin	Iron ore tailings and waste rock	Aggregate in bituminouus mixture placed on U.S. Route 141 north of Milwaukee	Not known	Material crushed prior to mixing.
	Lead-zinc tailings	Aggregate for shoulders and surfacing of local roads	Not known	Used in southwestern part of Wisconsin.

Table 37. Summary of mining and metallurgical waste use in highway construction (continued).

State	Waste Material	Type of Use	Quantity Used	Remarks
Wyoming	Iron ore waste rock	Subgrade material for State Highway Route 270. Placed during late 1950's	Not known	Material has reddish color. State believes material is suitable for use in concrete.
	Iron ore tailings	Anti-skid material and maintenance patching	Not known	Coarse fraction separated for use. Also placed on mine haul roads.

5.2 OTHER USES

In addition to the possible or actual use of specific materials in highway construction, it is necessary to determine whether other uses exist or are feasible for these materials and whether development of such alternative uses will significantly reduce the amount of material that might be available for highway construction use.

5.2.1 Waste Rock

Many mining companies routinely consume a fairly high percentage of the waste rock generated at their operations for their own internal purposes, such as coarse material for tailing dams, construction of mine roads, fill material for possible subsidence areas, mine backfill, and, in some cases, the recovery of additional metal values from the waste rock. No other specific uses of waste rock have been noted at this time.

5.2.2 Mill Tailings

The only uses of mill tailings that appear to be feasible in any general sense are as fill material and in the reclaiming of possible additional mineral values. However, other uses have been developed for certain types and sources of mill tailings. Therefore, the format established in the preceding chapter will be followed and the tailings from basic mineral industry sources will be discussed individually.

<u>Copper</u>

The U.S. Bureau of Mines has successfully produced dry-pressed building bricks out of copper mill tailing samples from five sites in Arizona, Utah, and Montana. The bricks were produced in the laboratory and pilot plant and met ASTM requirements for compressive strength of building brick. (94) Stamp sands from the Upper Peninsula of Michigan have been reportedly used in the manufacture of building block, but the quantities used and resultant quality of the block are not known.[174] In addition to use of the coarse fraction for impoundments, the only other reported use of copper tailings is for mine sandfill material used in the backfill of underground copper mines.[175]

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[174]Mr. K. A. Allemeier, Engineer of Testing and Research, Department of State Highways and Transportation, Lansing, Michigan. Correspondence dated September 23, 1975.

[175]Mr. Joseph W. Murray, General Superintendent, Magma Copper Company, Superior, Arizona. Correspondence dated November 28. 1975.

Iron Ore and Taconite

Taconite tailings are used internally by the iron mining industry for dike and hard road construction and are also considered to have a very remote possibility as a low grade source of future iron units.[176] Natural iron ore tailings in Minnesota are considered a definite source of future units. There has also been some use of these tailings in the surfacing of mine roads.[177]

Lead-Zinc

Because many lead-zinc ores are found in limestone or dolomitic limestone formations, the tailings from the concentration of these ores are characteristic of crushed limestone. Tailings from lead production in Missouri have been sold for agricultural lime use, although "the market is limited due to transportation costs, so it ends up being more of a nuisance than a profit."[178] Fine tailings from zinc milling in Tennessee[179] and Pennsylvania[180] are also marketed as agricultural limestone, although the tonnages used represent a minor fraction of the total tailings produced.

The coarser fraction of the chat from the Tri-State mining district has been used for years as railroad ballast in sections of Kansas.[181] Similar use has probably also been made of this material in parts of Missouri and Oklahoma.

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[176]Mr. H. H. Vaughn, Chief Environmental Engineer, Eveleth Taconite Company, Eveleth, Minnesota. Correspondence dated January 20, 1976.

[177]Mr. John D. Boentje., President, Pittsburgh Pacific Company, Hibbing, Minnesota. Correspondence dated December 1, 1975.

[178]Mr. James B. Shannon, General Manager, Amax Lead Company of Missouri, Boss, Missouri. Correspondence dated November 12, 1975.

[179]Mr. J. H. Polhemus, Superintendent of Surface Operations, American Smelting and Refining Company, Mascot, Tennessee. Correspondence dated January 25, 1973.

[180]Mr. Prior, Mill Superintendent, New Jersey Zinc Company, Center Valley, Pennsylvania. Personal communication.

[181]Mr. Lawrence L. Brady, Chief, Kansas Geological Survey, Lawrence, Kansas. Correspondence dated September 18, 1975.

Gold-Silver

Steam-cured calcium silicate bricks have been produced in the laboratory from the gold gravels found in the Sierra Nevada gold fields of California. There is, however, no record of any commercial use of structural products from gold tailings. (47)

Local ranchers in Nevada have used some of the coarse tailing and waste rock from a nearby open pit gold-silver mining operation to construct earthen dams lined with riprap on their properties.[182] This use constitutes a very small fraction of the available material at this site. There are no other reported uses of tailings from gold or silver mining operations.

Phosphate

Phosphogypsum has been used as a soil conditioner or as land plaster by peanut farmers in central Florida. Due to the presence of deleterious fluorine and phosphoric acid, attempts to utilize this material as a gypsum substitute have thus far been unsuccessful. (108)

Bauxite

Pisolites, the sand-type waste from the processing of bauxite ore in Louisiana, has been used for tank foundations because of its excellent bearing characteristics. It will also be used in the near future as a landfill material.[183]

5.2.3 Coal Refuse

In addition to use as a highway material embankments, stabilized base courses, and asphalt paving, coal refuse has also been utilized as fill material and low-grade fuel for power generation.

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[182]Mr. J. P. McCarty, Resident Manager, Duval Corporation, Battle Mountain, Nevada. Correspondence dated November 18, 1975.

[183]Mr. J. W. Melancon, Works Manager, Kaiser Aluminum and Chemical Corporation, Baton Rouge, Louisiana. Correspondence dated December 5, 1975.

There has been very little use of coal refuse as a fill material in the United States, although it has probably been used occasionally for this purpose by private contractors. The primary reason for not using this material for fill has been its history of spontaneous combustion. However, experiences in the proper compaction of coal refuse used to construct dikes, dams, and industrial building sites in the Netherlands, Germany, and Great Britain have provided ample proof of the acceptability of coal refuse for fill purposes. Recent experiences in land reclamation projects in this country have confirmed that coal refuse is a suitable landfill material if proper compaction practices are followed during its use. (71)

It has been recognized for some time that coal refuse with low heating values can be burned as a source of power production. Direct burning of lean anthracite coal refuse has been well established in France for the past twenty-five years. Coal refuse with as little as 5,000 Btu heating value can be burned in specially designed, conventional boilers provided the waste is friable enough to permit economical grinding to a fine size. Some coal refuse is presently being blended with higher grade coal for utilization in existing power plants. (26) It has also been reported that the Allegheny Electric Power Company uses coal slurry, dried to thirty percent moisture content, as fuel in its coal fired power producing boilers.[184]

There are desirable chemicals among the trace elements in coal refuse. One of these desirable elements is alumina. Since the United States presently imports ninety percent of the bauxite ore used to produce alumina, it may be economically feasible to consider the use of coal refuse as a source of alumina. The North American Coal Company constructed a six-million dollar plant in Ohio for this purpose and it is possible that some of the major aluminum companies in the United States are considering the possibility of processing coal refuse in order to extract alumina value.[185]

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[184]Mr. Ray Henderson, Vice President, Consolidation Coal Company, Christopher Division, Osage, West Virginia. Personal communication.

[185]Mr. Donald W. Cooper, Assistant Director of Coal Preparation, United States Steel Corporation, Pittsburgh, Pennsylvania. Personal communication.

Coal refuse has also been used as a source of lightweight aggregate for the concrete block industry. Since 1959, the Clinchfield Coal Company in Virginia produced 200,000 tons (180,000 tonnes) a year of rotary kiln fired lightweight aggregate product called "Clinch-Lite." This material was made from crushed bituminous coal shale refuse. Unfavorable market and cost conditions forced closure of the plant in 1975.[186]

Bituminous coal refuse from the Truax-Traer Coal Company in West Virginia was also processed into a lightweight aggregate product beginning in 1955. The refuse was crushed to passing 1/4 inch (6.35 mm) size, pelletized and burned on a chain grate stoker. The sintered product met the requirements of ASTM Designation C-130 for lightweight aggregate, but production was discontinued around 1960. (82)

Anthracite coal refuse also has been used as a source of lightweight aggregate. The By-Lite Corporation in Pennsylvania has continued manufacturing a lightweight travelling grate product called "By-Lite." This product is also used primarily in block manufacture with some additional use in lightweight concrete.[187]

Other possible uses for coal refuse include use with fly ash as raw material for brick manufacture, backfill material to prevent underground mine subsidence, and as a miscellaneous soil conditioner. (69)

5.2.4 Metallurgical Slags

Other uses of metallurgical slags will be considered in two separate categories: (1) iron and steel slags and (2) heavy metal slags.

Iron and Steel Slags

More than sixty percent of the blast furnace slag processed each year, or approximately twenty million tons (18 Mtonnes), is used in highway construction. The remainder is used

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[186]Mr. J. B. Steele, Clinchfield Coal Company, Dante, Virginia. Correspondence dated March 3, 1976.

[187]Mr. John Connells, President, By-Lite Corporation, Wilkes-Barre, Pennsylvania. Personal communication.

principally for railroad ballast and in the manufacture of concrete block, cement, mineral wool, and roofing cover material.

Nearly half of the steel slag processed each year, or approximately five million tons (4.5 Mtonnes), is used in highway construction. The remainder is used mainly as miscellaneous fill material, railroad ballast, and in agriculture.[188] It has been noted that most of the agricultural use occurs in Alabama, where the iron ores contain phosphorous, so that open hearth slags in Alabama are used as a source of phosphate fertilizer, making these slags somewhat scarce for use as aggregate.[189]

It has also been noted previously that, at some integrated steel plants, steel slag is used as feed material for the blast furnaces. In addition, approximately twenty percent of processed steel slag is magnetic material, which is separated from the slag and sold by the slag processor. These uses reduce the amount of material available for possible utilization in highway construction.

Heavy Metal Slags

A number of uses have been developed for copper smelter slag. It has been used as a source of iron in the manufacture of portland cement, as roofing granules on composition shingles, as grit material for sandblasting, and as fill and ballast for log-hauling yards.[190] Most of the marketed slag product from smelters in Arizona and other western states is used for railroad ballast.[191]

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[188] "Slag-Iron and Steel." U.S. Department of Interior, Bureau of Mines, Preprint from the 1974 Minerals Yearbook.

[189] Professor Reynold Q. Shotts, Department of Civil and Mineral Engineering, University of Alabama, University, Alabama. Correspondence dated October 14, 1975.

[190] Mr. C. H. Randt, Assistant Manager, American Smelting and Refining Company, Tacoma, Washington. Correspondence dated November 17, 1975.

[191] Mr. Lee C. Travis, General Manager, American Smelting and Refining Company, Salt Lake City, Utah. Correspondence dated November 14, 1975.

Copper smelter slag from Tennessee is sold commercially as a source for high early strength portland cement.[192] Magma Copper Company is presently conducting some experimental work in conjunction with the use of its smelter slag as partial replacement for cement in mine sandfill.[193] Anaconda Company considers that some metallic values are present and recoverable from its slag material,[194] although there is no indication that attempts have been made to recover these values.

Granulated lead smelter slag has been used as bedding for buried pipelines, mixed with sand as material for production of decorative concrete blocks, and as sandblasting grit.[195] The coarse lead smelter slag produced at East Helena, Montana, is sold to a local cement plant for their iron requirements.[196] At least one producer in Missouri considers that there is a sufficient amount of zinc in their slag to partially recover it at some future date and at least one process for this removal is now under study.[197]

The only reported non-highway use of zinc smelter residue is as a bedding material for pipelines,[198] although it can also make a well-compacted fill material. Granulated nickel slag has been used for sandblasting purposes in Oregon.[199]

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[192] Mr. R. D. Estes, Supervisor for Environmental Control, Cities Service Company, Copperhill, Tennessee. Correspondence dated December 8, 1975.

[193] Mr. Joseph W. Murray, General Superintendent, Magma Copper Company, Superior, Arizona. Correspondence dated November 28, 1975.

[194] Mr. Jack B. McCoy, Metallurgist, Anaconda Company, Anaconda, Montana. Correspondence dated December 3, 1975.

[195] Mr. J. E. McKay, Vice President for Technical Services, Bunker Hill Company, Kellogg, Idaho. Correspondence dated November 6, 1975.

[196] Mr. Lee C. Travis, General Manager, American Smelting and Refining Company, Salt Lake City, Utah. Correspondence dated November 14, 1976.

[197] Mr. J. W. Sherman, Division Manager, St. Joe Minerals Corporation, Herculaneum, Missouri. Correspondence dated November 11, 1975.

[198] Mr. Charles D. Henderson, Manager, St. Joe Minerals Corporation, Monaca, Pennsylvania. Correspondence dated April 1, 1976.

[199] Mr. Walter E. Lewis, U.S. Bureau of Mines, Liaison Officer for Oregon, Salem, Oregon. Correspondence dated July 14, 1975.

These are the only known non-highway uses of metallurgical slags. Most are not of sufficiently large volume to consume a very sizable percentage of the available material.

5.2.5 Washery Rejects

Very little use has been made to date of washery rejects from the alumina and phosphate producing industries. Known attempts to find applications for these materials will be briefly described.

Alumina red mud has been used to a very limited extent as a soil stabilizer and is reportedly suitable as a feed material for steel furnaces.[200] However, for all intents and purposes, no practical uses have been developed for this material.

Due to the lack of an economical dewatering method, there has been no report of any commercial use of phosphate slimes at the present time. The only use made of material in the holding ponds in central Florida has been land reclamation of some of the older ponds for agricultural purposes. (115)

5.3 RESEARCH PROGRAMS

An awareness of research in the area of mining and metallurgical wastes is needed in order to obtain a full perspective of all possibilities for utilizing these materials. This section of the report will discuss known research programs in this area.

At the end of 1975, Midwest Research Institute completed a study for the Environmental Protection Agency entitled "A Study of Solid Waste Generation Treatment, and Disposal in the Metals Mining Industry." This study identifies and describes the land-disposed solid wastes produced by primary metal mining industries, such as copper, lead, zinc, mercury, and uranium. A report on the findings of this study should be available during the early part of 1976.

A number of other research activities have been undertaken, dealing with potential uses for specific mining and metallurgical wastes. The following paragraphs will identify the nature of these programs.

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[200]Mr. J. A. Branscomb, Reynolds Metals Company, Listerhill, Alabama. Correspondence dated August 20, 1975.

5.3.1 Mill Tailings

A National Science Foundation contract has been awarded to the University of Arizona to conduct a study of the use of copper mill tailings as a possible highway construction material. Dr. Hassan Sultan of the Civil Engineering Staff is the principal investigator. This study will determine the engineering properties of copper tailing samples from Arizona, Utah, and Idaho. Particular attention will be focused on such engineering parameters as shear strength, California bearing ratio, moisture-density relationships, and the laboratory performance of these materials in bituminous and portland cement concrete mixtures.

Canadian researchers studying possible uses for mineral wastes have found that mill tailings from metal mines were of little value due to their high metallic sulfide contents, but that phosphogypsum showed some promise as a substitute for gypsum. (20) Other researchers in Canada have thoroughly studied the strength development of cement-stabilized nickel mine tailings for use as mine backfill material. (125)

For the past six years, the University of Missouri at Rolla has been engaged in a study of the environmental aspects of trace contaminants associated with the lead-producing industry in Missouri. This work has been conducted with the help of a grant from the National Science Foundation (130).

The mining industry reportedly is considering joint sponsorship of research to be done by the University of Missouri, Rolla, College of Agriculture, to demonstrate that the trace metals contained in lead tailings are not hazardous or detrimental. However, there is some doubt that this work will begin in the near future.[201]

The University of New Mexico will be conducting a study of the properties of molybdenum tailings from the northern part of the state and determining the suitability of these tailings for various uses in highway construction.[202]

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[201]Mr. T. J. Planje, Dean, School of Mines and Metallurgy, University of Missouri, Rolla, Missouri. Correspondence dated October 20, 1975.

[202]Mr. J. E. Martinez, Professor of Civil Engineering, University of New Mexico, Albuquerque, New Mexico. Correspondence dated October 8, 1975.

North Carolina State University has studied possible uses for feldspar tailings. An evaluation of potential highway applications for these materials has indicated that coarse tailings can be used in asphalt paving mixtures and that fine tailings can be stabilized with portland cement or a mixture of lime, fly ash, and portland cement for use as a stabilized base material (106).

Another study was conducted at North Carolina State University to determine whether useful products could be developed from the overburden and sand tailings from phosphate mining. Ten percent sodium carbonate was added to the minus 14 mesh plus 100 mesh tailings and the mixture was sintered into an aggregate product which, when used as aggregate in asphalt test cylinders, was found to be superior in frictional resistance to commercial aggregates (98).

A process was developed at Oak Ridge National Laboratory for incorporating radioactive waste sands and slimes from uranium milling into asphalt. The waste slurry or solids were mixed with commercial emulsified asphalt or molten base asphalt and the temperature raised to evaporate the waste fluid. The concentrated slurry was evaporated while the waste was neutralized with lime to precipitate radium and sulfates. Possible uses are for roofing materials and road surfacing (8).

The U.S. Bureau of Mines recently published a Report of Investigations entitled, "Radium Removal from Uranium Ores and Mill Tailings," which describes various techniques used in the laboratory to remove radium from tailings and ore samples by acid leaching. (10) An earlier Bureau of Mines report discussed the leaching of vanadium and uranium from uranium mill tailings. High percentages of recovery were found using sulfuric acid as the leaching medium (24).

The U.S. Department of Health, Education, and Welfare has studied the levels of radiation exposure associated with proximity to various uranium mill tailings deposits. Several reports have been published on this subject (112, 113). Dr. Hilding G. Olson of the Mechanical Engineering Department at Colorado State University has investigated the levels of radiation associated with using uranium tailings as fill material.

Several studies have been made into possible ways for utilizing spent oil shale. One study concluded that the most promising markets for this material were lightweight aggregate used in structural concrete and cement production (22). Another study indicated that asphalt mixtures using spent oil shale possessed high stability and resistance to stripping, but further evaluation is needed of the effects of durability and weathering in the field (44).

5.3.2 Coal Refuse

A number of past studies of anthracite coal refuse utilization have been performed and published by Pennsylvania State University. Operation Anthracite Refuse was aimed at developing new ways to utilize this material. This study recommended that anthracite refuse be used as anti-skid material, aggregate in bituminous mixtures, and as a soil-less medium for plant growth (17).

Another study evaluated anthracite refuse as an aggregate for highway construction. Although some physical properties such as Los Angeles abrasion were satisfactory, high percent losses in the sodium sulfate soundness test justified rejection of the material by the Pennsylvania Department of Transportation as aggregate for base courses and sub-base. This study concluded that anthracite coal refuse should be used in shoulders and embankments (69).

A study was performed at the University of Kentucky to investigate the feasibility of coal refuse and "red dog" as aggregate in bituminous paving mixtures using asphalt cutbacks, coal tars, and emulsions. It was concluded that mixtures containing these materials have insufficient retained strength to meet immersion-compression criteria and may fail when exposed to water. Low air voids and degradation of aggregate are other problems associated with these mixtures (50).

Dr. Jerry Rose of the Civil Engineering staff at the University of Kentucky has been actively engaged in research to determine the most technically and economically feasible uses of coal refuse, with particular emphasis on refuse disposal problems in the State of Kentucky.

A more recent study performed at West Virginia University identified a large number of engineering properties associated with coal refuse. Although a wide range of variability was found in the properties of these materials, the results essentially confirmed the findings of the British National Coal Board evaluations of colliery shale (81).

Two related research projects were conducted for the Environmental Protection Agency, involving the use of carbonate binding techniques to stabilize coal refuse and taconite tailings in place for use as structural fill or in road base construction. Some field demonstrations of these techniques were proposed, but it is not known at this time whether any such demonstrations were ever conducted (64,65).

A research project conducted several years ago by the Franklin Institute determined that the use of minus 100 mesh coal washing fines improved the resistance of concrete block to water penetration while maintaining adequate compressive strength (49).

5.3.3 Metallurgical Slags

A great deal of research has been performed over a period of many years into the use of blast furnace slag as aggregate in portland cement concrete and bituminous mixtures, resulting in the widespread acceptance of blast furnace slag for these uses.

Dr. John J. Emery of McMaster University in Hamilton, Ontario, Canada, has been conducting a considerable amount of recent research on the utilization of blast furnace and steel slags, sponsored in part by National Slag, Limited, of Canada. Much of this research has dealt with the use of steel slag in bituminous wearing surfaces (29,30).

The use of copper reverberatory slag as an aggregate for highway construction was evaluated by the Michigan Department of State Highways. A thorough investigation of this material was made using many evaluative tests. This slag is now approved for all aggregate uses, except as fine aggregate for portland cement concrete (36).

The potential use of zinc smelter wastes as highway construction material was evaluated in a study conducted several years ago at Oklahoma State University in cooperation with the Oklahoma Department of Highways. Four (4) types of smelter residues were tested for possible use in sand-asphalt paving mixtures, portland cement concrete mixtures, and stabilized base course mixtures. The materials were judged to be satisfactory for use as aggregate in asphalt and stabilized base mixtures, but are not recommended for use in portland cement concrete because of alkali-aggregate reactivity (51).

A number of years ago, the University of Tennessee evaluated several sources of phosphate slag for use as fine aggregates. As a result of this study, phosphate slags produced by Monsanto at Columbia, Tennessee, were found to be acceptable for use in portland cement concrete and in bituminous mixtures (128).

5.3.4 Washery Rejects

Batelle Columbus Laboratories recently completed a study for the Environmental Protection Agency entitled "An Assessment of Technology for Possible Utilization of Bayer Process Muds." This report has been submitted in draft form and is not yet available for public review.[203]

Several research studies were performed by the Illinois Institute of Technology Research Institute on the possiblity of utilizing alumina red mud and phosphate slime as lightweight building materials. One study concluded that lightweight building materials can be produced from foamed and sintered compositions containing alumina red mud, clay, and various additives (54). Another study was made in which the production of lightweight aggregate from phosphate slime was found to be technically feasible. Tests were run on concrete mixtures using these lightweight aggregates. With proper proportioning, these lightweight concrete mixtures were found to generally conform to applicable ASTM strength and density requirements (55).

Two other investigations were also made into the use of phosphate slimes as lightweight aggregate. Srini Vasan recommends the use of lightweight aggregate produced from dried phosphate slimes in a rotary kiln. Twenty-eight day compressive strengths using these aggregates were between 3000 and 4000 psi (210 to 280 kg/cm^2) (121). The University of Florida also investigated the drying and firing of phosphate slimes and concluded that these materials will produce excellent lightweight aggregates (103).

The National Science Foundation is presently sponsoring research into the dewatering of phosphate slimes. This work has as its objective to develop an effective and economically

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[203]Mr. A. A. Rambikur, Aluminum Company of America, Point Comfort, Texas. Correspondence dated March 22, 1976.

feasible method of increasing the solids content of phosphate slimes to a level where the material is workable and can be utilized in a practical manner.[204]

This work is presently being conducted at the University of Florida. It involves a study of seepage dewatering by a combination of processes which are designed to take maximum advantage of natural gravity forces. Several Florida phosphate mining companies are also conducting field scale research programs on a variety of different techniques for mixing sand tailings with phosphate slimes in an effort to dewater the slimes (115).

In addition to the research programs noted above, the U.S. Bureau of Mines has for years been conducting a comprehensive program aimed at developing new and improved ways to stabilize, reclaim, or utilize mineral wastes. A large number of reports have been published as a result of this research, many of which are included in the list of references for this report.

It should also be noted that most state highway or transportation departments conduct investigations of new material sources on a continuing basis. Many of these agencies regularly evaluate mineral wastes in their respective states, either on their own initiative or at the request of private industry.

Table 38 presents a summary of the present state-of-the-art of highway use of mining and metallurgical wastes.

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[204]Mr. Charles J. Johnson, Program Manager, Advanced Energy and Resources Research and Technology, National Science Foundation, Washington, D.C. Correspondence dated December 9, 1975.

Table 38. Summary of state-of-the-art of highway use of mining and metallurgical wastes.

			Present state-of-the-art of highway use		
Mineral Industry	Type of Waste	None	Laboratory Evaluation	Field Investigation	Routine Construction
Alumina	Red & brown muds		X [1]		
	Pisolites			X	
Asbestos	Tailings			X	
Barite	Tailings				X
Copper	Waste rock	X			
	Tailings		X		
	Smelter slag			X	X
Feldspar	Tailings		X		
Fluorspar	Waste rock				X
	Tailings	X			
Gold	Waste rock				X
	Dredger tailings				X
	Placer tailings				X
	Lode tailings	X			
Gypsum	Tailings	X			
Iron	Waste rock				X
	Tailings	X			

Footnote placed at end of table, p. 201.

Table 38. Summary of state-of-the-art of highway use of mining and metallurgical wastes (continued).

Mineral Industry	Type of Waste	None	Present state-of-the-art of highway use: Laboratory Evaluation	Field Investigation	Routine Construction
Lead & Zinc	Waste rock	X			
	Coarse tailings (chat)				X
	Fine tailings	X			
	Lead smelter slags			X	
	Zinc smelter residues			X	
Molybdenum	Tailings				X
Nickel	Smelter slag			X	
Phosphate	Sand tailings	X			
	Slimes	X			
	Phosphogypsum			X	
	Furnace slag				X
Silver	Tailings			X	
Slate	Mine waste				X
Taconite	Waste rock	X			
	Tailings				X
Uranium	Tailings	X			

Table 38. Summary of state-of-the-art of highway use of mining and metallurgical wastes (continued).

Mineral Industry	Type of Waste	Present state-of-the-art of highway use			
		None	Laboratory Evaluation	Field Investigation	Routine Construction
Anthracite Coal	Red dog			X	
	Coarse refuse		X	X	
	Washery silt	X			
Bituminous Coal	Red dog			X	
	Coarse refuse		X	X	
	Washery silt	X			
Iron & Steel	Blast furnace slag				X
	Steel slag			X	X
Oil shale	Spent shale		X		

[1]X denotes that a material has reached a certain stage of development. For example, alumina red and brown muds have been evaluated for highway use in the laboratory.

6. EVALUATION OF MINING AND METALLURGICAL WASTES

The physical properties, chemical compositions, and previous uses of mining and metallurgical wastes were used for their evaluation as highway construction material.

The objectives of this evaluation were to determine:

1. The specific materials that could be used in highway construction with minimal processing.

2. Needed research on particular aspects of some wastes in order to assess their potential for use in highway construction.

Technical, environmental, and economic factors were considered in the evaluation. Each will be discussed separately in this chapter of the report.

6.1 TECHNICAL EVALUATION

The technical evaluation was based on the following information:

1. The physical and chemical nature of the material.

2. Published information on composition and engineering properties.

3. Performance record as used in highway construction or related applications.

Representative samples of mining and metallurgical wastes were obtained. A total of eighty-five different material samples were collected, representing a well distributed cross-section of waste materials and geographical regions.

Table 39 summarizes the samples received according to industrial source of material. A total of eighteen different basic material sources are represented. Several sources also involve samples of different waste classifications. Table 40 summarizes the samples received according to different states in which they are produced. Samples were received from a total of twenty-eight different states. Due to proximity of sources, the greatest number of samples (19) were obtained from Pennsylvania.

The mining and metallurgical waste samples collected during this study are quite representative of the various classifications of materials which were evaluated. Never-

Table 39. Summary of mining waste samples by source of material.

	Source	Types of Materials	Number of Samples
1.	Aluminum	Muds, Tailings	10
2.	Anthracite Coal Refuse	Refuse, Slurry	5
3.	Bituminous Coal Refuse	Refuse, Aggregate	5
4.	Blast Furnace Slag	Air-Cooled, Granulated	4
5.	Boron	Tailing	1
6.	Copper	Tailings, Slags	15
7.	Gypsum	Tailing	1
8.	Iron	Waste Rock, Tailings	6
9.	Lead	Tailings, Slag	7
10.	Molybdenum	Tailing	1
11.	Nickel	Granulated Slag	1
12.	Phosphorous	Phosphogypsum, Slimes, Slags	4
13.	Spent Oil Shale	Coarse and Fine Tailings	2
14.	Steel Furnace Dust	Fine Dusts	2
15.	Steel Slag	Air-Cooled Slags	4
16.	Taconite	Coarse and Fine Tailings	5
17.	Uranium	Tailings	5
18.	Zinc	Tailings, Residues	7
		TOTAL	85

Table 40. Summary of mining waste samples by state.

	State	Sources of Waste(s)	Number of Samples
1.	Alabama	Alumina mud, iron ore tailing	3
2.	Arizona	Copper tailings and slag	5
3.	Arkansas	Alumina mud	1
4.	California	Iron ore and boron tailings	2
5.	Colorado	Uranium tailings, spent oil shale	4
6.	Florida	Phosphate slimes, phosphogypsum	3
7.	Idaho	Phosphate slag	1
8.	Illinois	Iron and steel slags, lead-zinc tailings	4
9.	Indiana	Gypsum tailings	1
10.	Louisiana	Alumina muds	2
11.	Maine	Copper tailings	1
12.	Michigan	Iron, steel, and copper slags	4
13.	Minnesota	Taconite tailings	5
14.	Missouri	Lead tailings and slags, iron tailings	6
15.	Montana	Copper and lead smelter slags	2
16.	Nevada	Copper tailings	1
17.	New Jersey	Granulated copper slag	1
18.	New Mexico	Copper, uranium, and molybdenum tailings	3
19.	Ohio	Aluminum smelter residue	1
20.	Oklahoma	Zinc smelter residues	2
21.	Oregon	Granulated nickel slag	1
22.	Pennsylvania	Coal refuse, tailings, slags, and zinc residues	19
23.	Texas	Alumina muds	3
24.	Utah	Copper and uranium tailings	3
25.	Virginia	Aggregate from coal refuse	1
26.	Washington	Uranium mill tailings	2
27.	West Virginia	Coal refuse, alumina waste	3
28.	Wyoming	Uranium mill tailing	1
		TOTAL	85

theless, individual variations in rock formations, ore deposits, and beneficiation techniques within the same industrial source make it impossible to draw completely general conclusions regarding these sources of materials.

The technical evaluation was performed by a team composed of two soils engineers, a geologist, an asphalt paving specialist, and a portland cement concrete specialist. Each of these individuals independently inspected material samples, reviewed applicable literature, and read correspondence pertaining to mining wastes.

Inspection of waste material samples was concerned mainly with the following characteristics: nominal particle size, gradation, particle shape, hardness, mineral composition, and physical appearance. The review of literature and correspondence was aimed at determining the composition and engineering properties of specific waste materials and their performance record in various highway applications.

A principal task within the technical evaluation was a rating of each waste relative to its immediate use in highway construction. For the purpose of this rating, all materials were considered in their "as is" condition or their condition after minimal processing.

All mining and metallurgical wastes classified in this study were evaluated for potential highway construction use in each of five application categories: waste fill, structural fill, base or sub-base, bituminous mixtures, and concrete mixtures. Table 41 indicates the technical properties used in this evaluation and their relevance to these highway applications.

The technical properties shown in Table 41 are outlined and defined in a report published by the National Cooperative Highway Research Program entitled, "Promising Replacements for Conventional Aggregates for Highway Use." (73) Each of these properties was considered of equal importance in the evaluation. There was no weighting of individual properties.

Each material was evaluated for each relevant highway application. A numerical rating was assigned to each property applicable to the particular use (for instance, wear resistance was rated when the material was considered for bituminous mixtures). Numerical ratings were assigned on a scale from 1 (poor) to 5 (outstanding). For example, taconite tailings were given a rating of 5 for wear resistance when used in bituminous mixtures because of the exceptional serviceability and improved skid resistance attributed to this material.

Table 41. Material properties used in technical evaluation.

		TYPES OF HIGHWAY USES				
Category	Property	Waste Fill	Structural Fill	Base or Sub-base	Asphalt Mixtures	Concrete Mixtures
General	Deleterious Substances	X[1]	X	X	X	X
	Uniformity		X	X	X	X
Physical	Gradation	X	X	X	X	X
	Particle Shape		X	X	X	X
	Maximum Particle Size		X	X	X	X
	Porosity and Pore Structure		X	X	X	X
	Surface Texture		X	X	X	X
Mechanical	Hardness		X	X	X	X
	Soundness		X	X	X	X
	Particle Strength	X	X	X	X	X
	Wear Resistance			X	X	X
	Mass Stability		X	X	X	X
	Resistance to Degradation from Applied Loading		X	X	X	X

Footnote placed at end of table, p. 207.

Table 41. Material properties used in technical evaluation (continued).

		TYPES OF HIGHWAY USES				
Category	Property	Waste Fill	Structural Fill	Base or Sub-base	Asphalt Mixtures	Concrete Mixtures
Chemical	Solubility	X	X	X	X	X
	Chemical Reactivity	X	X	X	X	X
	Resistance to Chemical Attack	X	X	X	X	X
	Volume change due to Wetting & Drying	X	X	X	X	X
	Resistance to Degradation from Freezing & Thawing	X	X	X	X	X
	Resistance to Degradation from Wetting & Drying		X	X	X	X
	Oxidation and Hydration Reactivity		X	X	X	X
Thermal	Coefficient of Thermal Expansion		X	X	X	X
	Integrity during heating			X	X	
Visual	Reflectivity				X	X

(1) X denotes that a property is applicable to a particular type of highway use. For example, the presence of deleterious substances is a property that must be considered when evaluating a material for possible use as waste fill.

There are cases where a particular application of a certain material represents a poor or uneconomical use of that material. An example of this would be the use of blast furnace slag as waste fill. Although the material would probably perform well in such an application, the evaluation team considered cases like this to be misuse of a resource and did not evaluate such applications.

A summation of individual property values for each type of highway application was made for every material. These total values were tabulated and compared to determine which materials were most highly rated for specific applications. As a result of this evaluation, individual materials were placed in one of three categories: recommended, usable, or unacceptable.

The results of the technical evaluation are summarized in Table 42 for each highway application. This table indicates the degree of acceptability of different mining and metallurgical wastes for general highway construction use. Table 42 also indicates the suitability of each material for specific applications.

The evaluation is also summarized in Table 43 in terms of those more general indicators most influential in recommending mining and metallurgical wastes for use in highway construction. The following indicators were considered:

1. Current highway acceptance
2. Notable physical properties
3. Principally used in highway construction
4. Minimal processing required
5. Other related uses

This table essentially confirms the recommendations made in Table 42. Materials with the most technical factors recommending their immediate use are steel slag, gold gravels, phosphate slag, coarse taconite tailings, copper slag, lead-zinc chat, nickel slag, lead slag, and waste rock from the mining of copper, fluorspar, gold and iron ores.

Many of the materials rated as useable in this evaluation require more extensive processing in order to compete with conventional materials. Most of the otherwise suitable finer grained materials can be agglomerated and fired into a synthetic aggregate product which could be used in some phase of highway construction. However, the cost of producing such synthetic aggregates was considered uneconomical when compared to the cost of conventional aggregates presently used in highway construction. Therefore, the potential for using mining and metallurgical wastes as

Table 42. Results of the technical evaluation of mining and metallurgical wastes for highway use.

		Type of Highway Application				
Category	Waste Material	Waste Fill	Structural Fill	Base or Sub-base	Asphalt Paving	Concrete Paving
Recommended	Blast furnace slag			X (1)	X	X
	Copper slag			X	X	X
	Fluorspar waste rock			X	X	X
	Gold gravels		X	X	X	X
	Iron ore waste rock		X	X	X	X
	Phosphate slag			X	X	X
	Steel slag		X		X	
	Taconite tailings (2)		X	X	X	X
Usable	Asbestos tailings				X	
	Barite tailings (2)				X	X
	Boron tailings				X	X
	Coal refuse	X	X			
	Copper tailings (2)	X	X			

Footnotes placed at end of table, p. 211.

Table 42. Results of the technical evaluation of mining and metallurgical wastes for highway use (continued).

Category	Waste Material	Type of Highway Application: Waste Fill	Structural Fill	Base or Sub-base	Asphalt Paving	Concrete Paving
Usable (continued)	Copper waste rock		X			
	Feldspar tailings	X	X	X	X	X
	Fluorspar tailings		X			
	Gold waste rock	X	X	X		
	Iron ore tailings (2)			X	X	
	Lead-zinc tailings (2)			X	X	X
	Lead-smelter slag		X	X	X	
	Molybdenum tailings (2)	X		X		
	Nickel slag		X	X	X	
	Phosphogypsum	X	X	X		
	Pisolites	X	X			
	Red dog	X	X	X	X	
	Silver tailings	X	X			
	Spent oil shale (3)	X			X	
	Zinc smelter residues		X	X	X	

Table 42. Results of the technical evaluation of mining and metallurgical wastes for highway use (continued).

Category	Waste Material	Type of Highway Application				
		Waste Fill	Structural Fill	Base or Sub-base	Asphalt Paving	Concrete Paving
Unacceptable	Alumina muds					
	Coal slurry	X				
	Copper tailings (4)	X				
	Gold lode tailings (4)	X				
	Iron ore tailings (4)	X				
	Lead-zinc tailings (4)	X				
	Phosphate slimes					
	Uranium tailings	X				

(1) X denotes that a material is suitable for a certain type of highway application. For example, blast furnace slag is recommended as suitable in base or sub-base, asphalt or concrete paving.

(2) Only the coarse fraction of these tailing materials is considered usable.

(3) Spent oil shale is considered usable based on prior research only. To date, there has been no use of this material in highway construction.

(4) The unseparated tailings from these sources are not recommended for highway construction use.

Table 43. Technical summary of use indicators for mining and metallurgical wastes for highway construction.

Mineral Industry	Type of Waste	Has Current Highway Acceptance	Has Notable Physical Properties	Principally Used in Highways [1]	Minimal Processing Required	Has Other Related Uses
Alumina	Red & brown muds					X
	Pisolites				X	X
Asbestos	Tailings (shorts)	X [2]	X	X	X	
Barite	Tailings (tiff chat)	X		X	X	
Copper	Waste rock	X	X	X	X	
	Tailings	X		X	X	X
	Smelter slag	X	X		X	X
Feldspar	Tailings				X	
Fluorspar	Waste rock	X	X	X	X	
	Tailings				X	
Gold	Waste rock	X		X	X	X
	Dredge tailings	X	X	X	X	X
	Placer tailings	X	X	X	X	X
	Lode tailings					
Gypsum	Tailings				X	
Iron	Waste rock	X	X	X	X	
	Tailings				X	

Footnotes placed at end of table, p. 214.

Table 43. Technical summary of use indicators for mining and metallurgical wastes for highway construction (continued).

Mineral Industry	Type of Waste	Has Current Highway Acceptance	Has Notable Physical Properties	Principally Used in Highways (1)	Minimal Processing Required	Has Other Related Uses
Lead & Zinc	Waste rock				X	
	Coarse tailings (chat)	X		X	X	X
	Fine tailings				X	X
	Lead smelter slags		X	X	X	X
	Zinc smelter residues		X	X	X	
Molybdenum	Tailings	X		X	X	
Nickel	Smelter slag		X	X	X	X
Phosphate	Sand tailings				X	X
	Slimes					
	Phosphogypsum	X			X	X
	Furnace slag	X	X	X	X	
Silver	Tailings	X		X	X	
Slate	Waste rock	X		X	X	
Taconite	Waste rock				X	
	Tailings	X	X	X	X	
Uranium	Tailings					

Footnotes placed at end of table, p. 214.

Table 43. Technical summary of use indicators for mining and metallurgical wastes for highway construction (continued).

Mineral Industry	Type of Waste	Has Current Highway Acceptance	Has Notable Physical Properties	Principally Used in Highways(1)	Minimal Processing Required	Has Other Related Uses
Anthracite Coal	Red dog	X		X	X	
	Coarse refuse		X			X
	Washery silt				X	X
Bituminous Coal	Red dog				X	
	Coarse refuse		X			X
	Washery silt				X	X
Iron and Steel	Blast furnace slag	X	X	X	X	X
	Steel slag	X	X	X	X	X
Oil shale	Spent shale				X	X

(1)For materials having a number of uses, but with the largest amounts used in highway construction.

(2)X denotes that the indicator is satisfied for this material, i.e., asbestos tailings (shorts) have current highway acceptance.

synthetic aggregate in highway construction was not considered in this evaluation.

Some general comments are offered next concerning the relative suitability or unsuitability of specific mining and metallurgical wastes for use in highway construction, based on an examination of their physical properties.

6.1.1 Factors Beneficial to Use

Many mining and metallurgical wastes are as good as, or in some cases better than, conventional materials now being used for highway construction. Because of a good performance record and notable physical properties, some materials are highly recommended for highway construction use. Outstanding examples of such materials are gold gravels from California, coarse taconite tailings, blast furnace slag, steel slag, phosphate slag, and waste rock from iron ore mining.

These materials all have several attributes in common: relatively high hardness, good range of particle sizes, fairly angular particle shape, wear resistance, and a general chemical stability.

Many waste rock sources derived from igneous or metamorphic rocks would probably make good aggregate, provided they have not been severely altered by the formation of the ore deposits. Crushing and sizing would be the only processing required in order to use such waste rock.

Generally, the coarser, sand-size fractions of most tailings make acceptable construction materials, as long as there are no harmful or reactive chemical components contained in the tailings, such as the pyrites in some zinc tailings and residual radium in uranium tailings. The relatively fine size of tailing materials make them good candidates for blending with coarse materials, such as gravel, to increase the fines content into an acceptable range.

Coal refuse and red dog have both been used succesfully in many cases as a structural fill. These materials are usually well graded and can be compacted into a dense, stable mass. In fact, a recent report to the Appalachian Regional Commission has concluded that "coal refuse is nonplastic and a better grade fill material than many acceptable natural soil materials." This report further states that "if properly utilized, coal refuse can be a good engineering material " (4).

Metallurgical slags require little in the way of processing except for crushing and sizing. Because of their hardness, these materials have excellent wear resistance and impart high levels of skid resistance when used in surface mixtures. They also possess excellent drainage characteristics when used in base courses because of their open gradation.

Unfortunately, some mining and metallurgical wastes possess characteristics which do not highly recommend them for highway construction use. These will also be discussed as part of the technical evaluation.

6.1.2 Factors Detrimental to Use

There are factors associated with certain waste materials which present problems regarding their use in highway construction. These problems can be divided into two categories:

1. Problems that can be readily solved by the use of special processing or construction techniques.

2. Problems that are either very difficult to solve with present technology, or, because of environmental, legal, or economic constraints, are practically unsolvable at this time. Such problems are serious enough to prevent use.

PROBLEMS THAT CAN BE SOLVED BY SPECIAL PROCESSING OR CONSTRUCTION TECHNIQUES

Mill Tailings

One of the detrimental features of mill tailings is the presence of an excessive amount of fines (minus #200 mesh) material. It has been fairly recognized that fines in excess of twenty-five percent by weight will result in low shear strengths.[205] The fineness of some tailings has been cited as a reason for concluding that these materials are unsatisfactory for highway construction. In some cases this is true. For example, the lead-zinc tailing from the Bunker Hill Company in Washington are reported as one hundred percent minus 200 mesh.[206]

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[205] Mr. Karl Dean, Mining Consultant, Salt Lake City, Utah. Correspondence dated November 5, 1975.

[206] Mr. L. M. Kinney, Mine Manager, Bunker Hill Company, Metaline Falls, Washington. Correspondence dated December 12, 1975.

However, in other instances, the removal of a portion of the fines can result in a fine aggregate with an acceptable gradation. Proven methods of separating coarse from fine tailings are available and have been used by the Eveleth Taconite Company and U.S. Steel Corporation in Minnesota and Kennecott Copper Corporation in Utah. Available methods include cyclones (centrifugal separators), hydro-separators, and magnetic separators. In many tailing ponds, a natural separation also occurs in the deposition of the tailing.

Another common disadvantage of most tailing materials is their lack of cohesion, even in the very fine fractions. This problem was identified earlier in this report in the case of taconite tailings by Mr. R. M. Canner of the Minnesota Department of Highways who noted that "the lack of cohesiveness of the material... results from the cleanness and non-plastic nature of the fines."

A visual inspection of copper mill tailings at the Copper Cities operation, Miami, Arizona, showed a weak cementitious bond between the particles. It can be expected that the use of these tailings as an embankment or sub-base material would exhibit similar characteristics as the taconite tailings.

The lack of cohesion or cementitious bond between particles also points to a high potential for slope erosion. Such erosion was evident along the berms of tailing dams at the Copper Cities site and at New Jersey Zinc Company's Friedensville mine in Center Valley, Pennsylvania. Slope erosion is also identified as a problem in the use of classified copper mill tailing from Kennecott Copper Corporation as embankment material in Utah. However, such problems are not new to the highway construction industry and can be solved by paying strict attention to established erosion control procedures during construction and protecting final slopes with an adequate cover of topsoil.

Most of the tailing samples inspected by the evaluation team exhibited a tendency toward dusting. Reference was made to the problem of dusting in an indirect way in some of the correspondence that was received from state highway personnel. This tendency toward dusting is no different than that experienced in the handling and use of fly ash and can be solved by proper moisture control of the material during construction.

Coal Refuse

In the past, the principal objections to the use of coarse coal refuse in highway construction have been:

1. Its carbonaceous content and tendency toward ignition by spontaneous combustion.

2. Its pyritic composition and acid nature, resulting in the production of acidic leachate.

There are several solutions to these problems. The most practical solution during construction is to properly compact the refuse when it is used as embankment or sub-base material. Compaction of the refuse in relatively thin layers (8 inches or 203.2 mm maximum) to at least 97 percent of its maximum dry density decreases the void ratio, thus reducing the internal circulation of air and the permeability of the material. This eliminates, for all practical purposes, the threat of spontaneous combustion, oxidation of pyrites, and acidic leachate. At the same time the shear strength of the material is improved. A cover of several feet of natural soil is also recommended over the slopes of coal refuse embankments (15).

Other remedial measures can be taken to reduce the potential problems traditionally associated with the construction use of coal refuse. Butler notes that, if the coal content of a refuse bank equals or exceeds fifteen percent, the bank is considered an economically attractive source of coal. The "cleaning" of refuse banks to recover their coal content will reduce or almost eliminate the hazard of spontaneous combustion. The anthracite refuse used in the embankment construction of the Cross Valley Expressway was a processed refuse that had been "cleaned" prior to its use (15).

The acidic nature of coal refuse can be effectively neutralized by the use of fly ash. Lime and/or cement used as a binding agent reacts chemically with the fly ash, producing a pozzolanic reaction and imparting added strength and durability to the mixture.

Another problem with the use of coal refuse is its tendency toward weathering. This is particularly evident in bituminous coal refuse, which is composed in part of poorly consolidated siltstones and mudstones with high clay content, which disintegrate in a fairly short time as a result of exposure to frost, wind, water, temperature changes, and cyclic wetting and drying (4).

It is advisable not to allow weathering to occur over long periods of time because the mechanical properties of the refuse could be severely altered. However, it is common practice to permit initial weathering of this material, perhaps for a period of one to two weeks, prior to its placement in a controlled fill.[207] The most logical place to use aged or weathered coal refuse would be as a capping material for an embankment prior to the placement of topsoil.

Steel Slag

Many engineers are hesitant to use steel slag in any application because of its expansive nature. Hydration of the free calcium and magnesium oxides in the steel slag causes this objectionable volume expansion. Lack of recognition of the expansive tendency of steel slag in the past has resulted in pop-outs, heaving, and pavement break-up on a number of highway projects (61).

It is now well recognized that the problem of expansion can be controlled by properly aging the steel slag for a time period of at least six months under controlled moisture conditions. This will effectively permit hydration of the free calcium and magnesium oxides and allow most, if not all, of the expansion to occur prior to using the material. In some steel mills, the slag is neutralized with pickle liquor (H_2SO_4) as an alternative means of inhibiting undesirable volume expansion (29).

The use of steel slag as aggregate in bituminous concrete mixtures is sometimes avoided because of concern for expansion of the steel slag. Properly aged steel slag should present no expansion problems when used in bituminous mixtures. Steel slag usually expands because of hydration; if water is kept from coming in contact with the steel slag particles, no expansion should occur. It has been reported that at least one midwest slag processor has not aged any steel slag used in bituminous mixtures and has never had any problems due to expansion.[208]

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[207]Mr. John Stevens, Superintendent, Consolidation Coal Company, Humphrey Cleaning Plant, Osage, West Virginia. Personal communication.

[208]Mr. Donald W. Lewis, Chief Engineer, National Slag Association, Alexandria, Virginia. Personal communication.

PROBLEMS THAT PROBABLY PREVENT USE IN HIGHWAY CONSTRUCTION

Mill Tailings

In cases where the coarse fraction of a tailing product is not separated and recovered, the excessive amount of fines in most tailings will probably restrict or prevent their effective use as a construction material.

The chemical and mineralogical composition of some tailings precludes their use as a mineral filler in bituminous mixtures, even though in many cases the tailings may satisfy gradation requirements. As noted in the previous chapter, the use of classified copper mill tailings as a mineral filler in Utah has resulted in premature age hardening of the asphalt in the bituminous mixtures. Although this problem is under study, there are no firm explanations at the moment for this behavior.[209]

The use of some tailings present major environmental problems. An example of this is the residual radiation associated with uranium mill tailings. In some states it is illegal to use these tailings in any type of construction. Environmental effects will be discussed in more detail in the following section of this chapter.

Coal Refuse

The oxidation of the pyrite and marcasite contained in coal refuse is detrimental to its use in portland cement concrete. These minerals are deleterious and produce an acid discharge upon contact with water.

The strength development of concrete mixtures using coal refuse is comparatively low. The inherently low strength of the individual refuse particles, the clay content normally associated with this material, and its tendency toward weathering all combine to assure low resistance to wearing when refuse is used in bituminous mixtures. Therefore, the use of coal refuse in bituminous and portland cement concrete mixtures is not recommended.

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[209]Mr. Wallace J. Stephenson, Engineer of Materials and Tests, Utah Department of Highways, Salt Lake City, Utah. Personal communication.

Steel Slag

As noted earlier, the expansive nature of steel slag precludes its use in confined applications where exposure to water is likely, such as base courses. It is possible that well-aged steel slag could be used in a base course, but some small additional expansion may occur in prolonged contact with moisture.

The alkaline nature of steel slag is a factor that does not make it highly suitable for use in portland cement concrete mixtures, due to the possibliity of alkali-aggregate reaction. Moreover, the water in the cement paste would offer a further opportunity for hydration of the steel slag with the possibility of slight, but still objectionable, long-term volume expansion.

6.1.3 Relationship of Mining and Metallurgical Wastes to Specification Requirements

The use of a specific material in highway construction depends on a number of factors. One of the most influential of these factors is the ability of the material to meet existing specification requirements for a particular use.

Each state adopts its own specifications in order to establish desired quality criteria for materials and workmanship. Quality criteria for materials are generally based on requirements developed by national specifying agencies (ASTM, AASHTO). Highway material criteria are sometimes modified by different states in order to more closely reflect differences in climatic conditions and local material quality in those states.

Some mining and metallurgical wastes do not possess the same properties as conventional materials. Coal refuse is a good example of such a material. Simply because a material is unable to meet existing quality criteria does not necessarily mean that material will not perform satisfactorily when used in highway construction.

With this in mind, materials engineers from state highway and transportation departments in thirty-five principal mining states were contacted and asked the following questions:

1. Do your specifications forbid the use of any specific mining and/or metallurgical wastes?

2. Can your specification requirements be modified to permit the use of a material which does not meet existing criteria, but which has demonstrated acceptable performance in the field?

Responses were received from twenty-six states. Generally, most state specifications do not prohibit by reference the use of specific wastes in highway construction. However, most state specifications stipulate precisely which materials are permissable for use. Therefore, a material not included among those specifically mentioned would not be permitted for use in highway construction without special permission.

There are some examples of mining and metallurgical wastes which are presently included in state spacifications. These include steel slag in California and Michigan and chat in Illinois and Missouri. There are also a few instances in which certain wastes are prohibited for specific uses. These include copper mill tailings as aggregate in portland cement concrete in Arizona and steel slag in applications where expansion might be detrimental (nearly all applications) in West Virginia.

Generally, mining and metallurgical wastes which can meet existing specification requirements will probably be approved for use. Many of these materials, particularly waste rock and tailings, are very similar to natural aggregate or borrow materials.

Since most states specify different classes of materials for different levels of use, it is quite possible that a number of mining and metallurgical wastes could meet specification requirements for at least one class of material, although possibly not the highest class.

In order to be considered for highway construction use, a waste material must demonstrate adequate laboratory and field performance and be economically competitive with conventional materials. If a material were to meet these criteria, most state materials engineers felt that specification requirements could then be modified to permit this material to be used in a specific application.

A number of states handle approval of materials not meeting specification requirements by a special provision written into the contract for certain projects in which the waste or by-product material is proposed for use. These special provisions normally define the allowable use of the material and establish expected performance levels for the use of the material.

Most state materials engineers are usually quite receptive to considering the use of new materials sources, including wastes or by-products, for highway construction. The main concern is that a material source be economical and of sufficient quality to provide the desired level of performance.

6.2 ENVIRONMENTAL EVALUATION

The purpose of this evaluation is to determine:

1. The existing environmental effects caused by disposal of mining and metallurgical wastes, and

2. The possible environmental effects that may result from the use of these wastes in highway construction.

6.2.1 Environmental Effects Caused by Disposal of Mining and Metallurgical Wastes

A general evaluation was made of the adverse environmental effects of mining and metallurgical wastes. The purpose of this general evaluation is to identify those wastes that are most damaging to the environment in their present state. The following indicators were used in this evaluation:

1. Health and safety

2. Pollution of air and/or water

3. Aesthetic blight

4. Proximity to populated areas

5. Public nuisance

The findings of this evaluation are summarized in Table 44. This evaluation considered each mineral industry as a whole. Deviations within a specific industry are not reflected. For example, uranium mill tailings were considered as not being located close to populated areas. However, a few uranium mills are located within or close to comparatively small populated areas.

Mining and metallurgical wastes having the most adverse effects on the environment are coarse and fine coal refuse, phosphate slimes, uranium mill tailings, alumina muds, and heavy metal slags from the smelting of lead and zinc ores. The stabilization or utilization of these materials should receive a higher priority than that of other mineral wastes because of the greater damaging effects on the environment.

Table 44. Summary of environmental effects of the disposal of mining and metallurgical wastes.

Mineral Industry	Type of Waste	Health and Safety	Air or Water Pollution	Aesthetic Blight	Proximity to Populated Areas	Public Nuisance
Alumina	Muds		X[1]	X	X	X
	Pisolites					
Asbestos	Tailings	X	X			
Barite	Tailings		X			
Copper	Waste rock					
	Tailings		X	X		
	Smelter slag					
Feldspar	Tailings		X			
Fluorspar	Waste rock					
	Tailings		X			
Gold	Waste rock					
	Dredge tailings				X	
	Placer tailings				X	
	Lode tailings		X			
Gypsum	Tailings					
Iron	Waste rock					
	Tailings		X	X		

Footnote placed at end of table, p. 226.

Table 44. Summary of environmental effects of the disposal of mining and metallurgical wastes (continued).

Mineral Industry	Type of Waste	Health and Safety	Air or Water Pollution	Aesthetic Blight	Proximity to Populated Areas	Public Nuisance
Lead and Zinc	Waste rock					
	Coarse tailings (chat)					
	Fine tailings		X	X		
	Lead smelter slags	X	X	X	X	
	Zinc smelter residues	X	X	X	X	
Molybdenum	Tailings		X			
Nickel	Smelter slag					
Phosphate	Sand tailings			X		
	Slimes	X	X	X	X	X
	Phosphogypsum			X	X	X
	Furnace slag				X	
Silver	Tailings		X			
Slate	Waste rock					
Taconite	Waste rock					
	Tailings	X	X			X
Uranium	Tailings	X	X			

Table 44. Summary of environmental effects of the disposal of mining and metallurgical wastes (continued).

Mineral Industry	Type of Waste	Health and Safety	Air or Water Pollution	Aesthetic Blight	Proximity to Populated Areas	Public Nuisance
Anthracite Coal	Red dog			X	X	
	Coarse refuse	X	X	X	X	
	Washery silt	X	X	X	X	
Bituminous Coal	Red dog			X	X	
	Coarse refuse	X	X	X	X	X
	Washery silt	X	X	X	X	
Iron and Steel	Blast furnace slag		X		X	
	Steel slag				X	
Oil shale	Spent shale					X

(1) X denotes that the material is a problem where indicated. For example, alumina muds do contribute to air or water pollution.

6.2.2 General Environmental Effects and those Attributable to Highway Use of Mining and Metallurgical Wastes.

There are several possible ways in which the use of mining and metallurgical wastes in highway construction could have an adverse effect upon the environment:

1. The material may contain a soluble toxic or harmful substance. If such substances are leached into ground water supplies, they could result in dangerous concentrations of undesirable chemicals causing water pollution and potentially serious health effects.

2. The material may have a chemical composition that includes a toxic or harmful substance. If such particles become airborne and are inhaled or ingested into the human body in large enough doses over a period of time, serious health problems could result.

3. The material may contain some residual radioactivity in large enough concentrations to be considered harmful for prolonged human exposure. Radioactive particulates may also become airborne and present a health hazard.

These environmental effects will be described in a general fashion. Environmental concerns will then be discussed relative to the highway construction use of specific mining and metallurgical wastes. This will include a discussion of the possible environmental effects of using the materials recommended in the technical evaluation.

GENERAL ENVIRONMENTAL EFFECTS

Water Pollution

Substances which constitute undesirable elements in ground water supplies include heavy metals, sulfides (which react with water to form sulfuric acid), and residual leaching material, such as cyanide from gold extraction. The levels of concentration (usually expressed in parts per million) of such substances in the water supply are extremely important. In some cases, trace amounts of certain components in a soluble form may be sufficient to adversely affect drinking water quality and safety.

The composition of the material, its solubility, and its opportunity for exposure to moisture and subsequent leaching must be considered. The amount of annual rainfall, the percent of infiltration of the rainfall, the proximity of the ground water table to surface, and the extent to which ground water supplies are used for public consumption are also important variables to consider when assessing potential ground water pollution effects. There are certain areas of the United States where extra caution should be exercised when using materials with possible leaching effects. Several examples are discussed in the following paragraphs.

In Arizona, the state experiences approximately 20 inches (508 mm) of precipitation per year in the more populous southeast portion. Huge volumes of copper mining wastes are located throughout this area. In general, the runoff is comparatively low, indicating high infiltration. Since 53 percent of the state's water supply is from ground water, extreme caution should be exercised against heavy metal contamination of the ground water.

In northeast Minnesota, where huge deposits of taconite tailings exist, average annual precipitation is from 25 to 30 inches (635 to 762 mm). Average runoff is 5 to 10 inches (127 to 254 mm) per year, indicating a large percentage of infiltration. Since 14 percent of the water supply is derived from ground water sources, care must be taken to avoid possible pollution of these sources.

Central Colorado has average precipitation of 15 to 20 inches (381 to 508 mm) per year, of which from 1 to 10 inches (25.4 to 254 mm) is runoff. The balance presumably goes to recharge ground water supplies, which make up 17 percent of the state's water usage. Infiltration of heavy metals and other injurious components should be carefully avoided in ground water supplies.

In northern Idaho, the average annual precipitation is approximately 40 inches (1016 mm) per year with about 30 inches (762 mm) of runoff. There are a number of aquifers in the northern portion of the state, where large deposits of tailings from silver-lead-zinc mining are located. Up to 16 percent of the entire state's water supply is derived from ground water sources, presumably from these areas with a large portion used in northern Idaho.[210]

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[210] "Water Atlas of the United States." Water Information Center, Inc., Second Edition, 1963, Port Washington, New York.

Air Pollution

The single most harmful element from the standpoint of inhalation of airborne particles is asbestos. This element may assume several forms. It is now well recognized that inhalation of asbestos fibers can cause lung cancer. Therefore, the presence of asbestos fibers in mining wastes must be recognized and steps must be taken to control dusting of such materials.

Radiation

Materials remaining after the processing of radioactive ores may contain a certain of amount of residual radioactivity which could be harmful when present at sufficiently high levels in proximity to populated areas. These materials emit low level radiation, which in some cases may exceed allowable levels defined by the U.S. Surgeon General. In such cases, it is essential to identify the level of radiation of different material sources and to relate this information to the porposed use and expected degree of exposure of the material.

SPECIFIC ENVIRONMENTAL EFFECTS RELATED TO HIGHWAY CONSTRUCTION USE

There are several materials which present environmental problems when used in certain highway construction applications. These will be discussed in terms of the environmental consequences noted above.

Water Pollution

Chemicals or minerals (such as pyrite or pyrrhotite) contained in some tailings can corrode and destroy buried pipes or culverts on contact.[211] Similarly, chemicals or minerals (particularly heavy metals) can become soluble and leach into ground water supplies if exposed to water in uses such as fill, base, or sub-base construction.

One of the most obvious examples of harmful leachate is the acidic drainage resulting from oxidation of pyrite and marcasite in coal refuse. The runoff from coal mines is referred to as acid mine drainage and results from the same chemical process.

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[211] Mr. Karl Dean, Mining Consultant, Salt Lake City, Utah. Correspondence dated November 5, 1975.

Tailings from sulfide ores are often high in pyritic content. A good example is the zinc tailing from New Jersey Zinc Company in Gilman, Colorado, which is reported as 65 to 75 percent pyrite (FeS_2). This pyrite content is so high that the company reports the tailing "could be used for the production of sulfuric acid if sulfur became scarce." They also state "it is doubtful that there is any hope of use as a highway material because of the high pyrite content."[212]

Another example of undesirable pyrite is the tailing from Climax Molybdenum Company in Climax, Colorado. Regarding this material, a company official has stated "we do not recommend the use of our tailing as a fill component due to the particle size and decomposition of the pyrite which lowers pH and causes electrolysis with metal."[213]

As mentioned earlier, there is concern in Missouri regarding the presence of residual lead and zinc in lead smelter slag and the possibility that these metals could become soluble and leach into the environment or become airborne and respirable.[214]

There are also unsubstantiated reports that cadmium has leached into ground water supplies in Oklahoma as a result of using zinc smelter residues in local road construction.[215]

Tailings resulting from cyanide extraction process to remove gold from its ore have been found to contain low concentrations of cyanide. However, these concentrations have not been considered dangerous enough to restrict the use of this material in highway construction.[216]

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[212] Mr. R. C. Osborne, Manager, New Jersey Zinc Company, Gilman, Colorado. Correspondence dated October 1, 1975.

[213] Mr. James A. Brown, Environmental Control Engineer, Climax Molybdenum Company, Climax, Colorado. Correspondence dated October 28, 1975.

[214] Mr. James H. Long, Supervisor, Air Quality Control Program, Missouri Department of Natural Resources, Jefferson City Missouri. Correspondence dated December 10, 1975.

[215] Mr. Robert H. Arnt, U.S. Bureau of Mines Liaison Officer for Oklahoma, Oklahoma City, Oklahoma. Personal communication.

[216] Mr. Harvey H. Collins, Supervising Engineer, Waste Management Unit, California Department of Health, Sacramento, California. Correspondence dated November 7, 1975.

There are at least two mining wastes which contain asbestiform particles. There is concern about the possible escape of these particles into the air where they could become respirable.

One of these materials is asbestos shorts, the tailings remaining after separation of asbestos fibers. This material contains some very short asbestos fibers (less than 1/8 inch or 3.175 mm long) which could become airborne at the asphalt plant when used in bituminous paving mixtures.

More publicized is the concern that presently exists in the state of Minnesota over the use of taconite tailings. The tailings from the Reserve Mining Company concentrator at Silver Bay are presently being disposed of in Lake Superior. This practice has created an environmental controversy because asbestiform fibers have been discovered in these tailings. The city of Duluth takes water from Lake Superior for drinking water use.

There has been an investigation into the composition of taconite tailings from different sources in Minnesota. This investigation has revealed that the ore source at the Reserve mine in Babbitt, Minnesota, which is concentrated at Silver Bay, Minnesota, is geologically unique. This is the only known taconite ore containing asbestiform fibers.

The policy of the Minnesota Department of Highways regarding the use of taconite tailings in highway construction is as follows:

> "Only taconite tailings from Eveleth Taconite at Forbes, Minnesota, U.S. Steel at Virginia, Minnesota, or Butler Taconite (Hanna Mining) at Nashwauk, Minnesota, will be permitted to be used on this project unless the contractor obtains prior approval to use other sources from the State Highway Materials Engineer."[217]

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[217] Mr. B. F. Himmelman, Materials Engineer, Minnesota Department of Highways, St. Paul, Minnesota. Correspondence dated April 26, 1976.

Radiation Hazards

A number of mining companies, state environmental officials, and state highway materials engineers were contacted regarding the possible use of uranium mill tailings in highway construction. The response from these individuals was nearly unanimous in recommending that these tailings not be considered because of their residual radioactivity in the isotopic form of radium. On the average, uranium tailings contain up to 70 percent of the radioactivity originally contained in the ore.[218]

There is sufficient radioactivity in these tailings to create a weak field of gamma ray emission in the immediate vicinity of the tailings. The radioactivity in the tailings will remain nearly constant for thousands of years (119).

Because of the unsuccessful use of uranium mill tailings as fill material in Grand Junction, Colorado and their potential as a health hazard, most agencies no longer consider this material to be usable.[219] An additional negative aspect of the tailings is that the residual radium ultimately decays into radioactive particulates which become respirable.[220]

The Public Health Service of the U.S. Department of Health, Education, and Welfare conducted studies to determine the levels of radioactivity (from radon) associated with wind transport of airborne uranium tailings particles. These levels were then compared with recommended minimum levels.

Standards for allowable radiation exposure are not stable, but have been adjusted downward in recent years. Even so, the smallest general dose of radiation has an associated risk (112).

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[218] Mr. R. G. Beverly, Director of Environmental Control, Union Carbide Corporation, Grand Junction, Colorado. Correspondence dated December 16, 1975.

[219] Mr. Anthony Rubner, Assistant Staff Materials Engineer, Colorado Department of Highways, Denver, Colorado. Correspondence dated September 5, 1975.

[220] Mr. Paul B. Smith, Regional Representative, U.S. Environmental Protection Agency, Denver, Colorado. Correspondence dated October 15, 1975.

The International Commission on Radiological Protection (ICRP) has developed criteria for individuals occupationally exposed to radon. In addition, the ICRP recommends that annual radiation dose limits for members of the public shall be one-tenth of the corresponding annual occupational values for continuous exposure. A value of 1 picocurie per liter is recommended as the maximum allowable concentration for continuous radiation exposure to individuals in the general population, over and above the natural background levels. Federal regulations generally permit average concentrations of up to 3 picocuries per liter at boundaries of a restricted area. (113) These values refer to the presence of radon concentrations in a given space.

Borrowman and Brooks state that the problem of setting an acceptable level of radiation exposure is very difficult because a dose-effect relationship has never been established for low-level radiation. They note that an upper level of 20 picocuries of radium per gram of mill tailings appears acceptable to some authorities. Unfortunately, none of the methods used by the Bureau of Mines to reduce the radium content were able to produce tailings meeting this value. (10)

The United States Surgeon General has published guidelines for radiation exposure levels in dwellings constructed on or with uranium mill tailings.[221] These guidelines are expressed in terms of milli-Roentgens per hour, which refer to radiation intensity and are not compatible with picocuries per liter.

Since radiation exposure along a highway is quite temporary compared with the length of exposure received in a dwelling, a measure of radon concentration is probably more applicable to the use of uranium tailings in highway construction.

A study was made of radon levels at selected locations in the vicinity of four uranium tailings piles in Colorado and Utah. Measurements of radon concentrations were made at these locations. A total of 57 sampling stations were located in relation to the directions of the prevailing winds at each site. All average background concentrations of radiation were measured. It was found that average radon concentrations were less than the allowable 1 picocurie per liter at all but two of the sampling locations. Measured concentrations were also found to be lower in the vicinity

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[221]Dr. Hilding G. Olson, Department of Mechanical Engineering, Colorado State University, Fort Collins, Colorado. Correspondence dated December 2, 1975.

of the stabilized tailing pile. These results indicate that there is no significant radiation exposure to the public from the tailings piles which were studied (113).

There is also a remote concern with the level of radiation from phosphate mining wastes. It has been noted that radium-226 is also an unwanted by-product from the processing of phosphate ores. There is no specific data to support the degree of radiation associated with these materials. However, it has been reported that an experience similar to that at Grand Junction, Colorado occurred in Polk County, Florida, resulting from the use of phosphate wastes as a fill material.[222]

6.24 ENVIRONMENTAL ASSESSMENT OF MINING AND METALLURGICAL WASTES RECOMMENDED FROM THE TECHNICAL EVALUATIONS

This evaluation also addresses the possible effects of using materials recommended in the technical evaluation.

Blast Furnace Slag

Blast furnace slag is recommended for use as structural fill, sub-base or base, waste fill, bituminous paving, Portland cement concrete. Blast furnace slags are basically complex silicate glasses, which present no environmental hazards from leaching or airborne dust. These slags have been widely used for many years in highway construction with no reports of adverse environmental effects.

Copper Smelter Slags

These materials are recommended for use as structural fill, sub-base or base, waste fill, bituminous paving, and portland cement concrete. Copper smelter slags from sulfide ores are ferrous silicates which may contain some residual metallic sulfides and some metallic copper. Under conditions in which acid water contacts the slag, copper ion could be liberated and leached from the mass. These slags should be tested to determine if copper leaching occurs. Copper slags from a direct process in which the metal is in a native state are complex silicates and present no environmental hazards. Slags containing some residual metallic sulfides

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[222]Mr. Paul B. Smith, Regional Representative, U.S. Environmental Protection Agency, Denver, Colorado. Correspondence dated October 15, 1975.

and metallic copper should be used only in bituminous paving or portland cement concrete in order to avoid harmful leaching.

Gold Gravels

Gold gravels from hydraulic and dredge mining are recommended for uses as structural fill, sub-base, waste fill, bituminous paving, and portland cement concrete. Gold gravels from dredging and placer mining are essentially crystalline rock, usually igneous or sand stone. They present no environmental hazards if they have not been used for gold extraction by the cyanide process. In such cases, the absence of residual cyanide should be demonstrated before use. Gold gravels have been extensively used in California for highway construction. They are considered to be an acceptable source of aggregate in areas where they occur.

Phosphate Slags

Phosphate slags are recommended for use as structural fill, sub-base or base, waste fill, bituminous paving, and Portland cement concrete. Phosphate furnace slags are silicate type glasses, with calcium silicate as the principal ingredient. Calcium silicate is sparingly soluble and should present no problem from leaching. The dust of the material, on long exposure, can lead to silicosis as would any fine size silicate.

Steel Making Slags

Slag from the making of steel is recommended as structural fill and bituminous paving material. Steel slags are a variable combination of oxides, principally calcium, iron, silicon, magnesium, and aluminum. Volume expansion from hydration of free calcium and magnesium oxides has been identified as a problem from the technical evaluation.

In some cases, hydration of open hearth slag used in bituminous mixtures has produced areas of whitish powder or efflorescence from the leaching of material undergoing hydration. A chemical analysis of leachate from open hearth slag in Michigan shows a pH of 10.2 with 70 mg./liter of sulfate. Such effluents would probably cause only slight corrosion (61).

Waste Rock from Feldspar Mining

Waste rock from feldspar mining is recommended for use in portland cement concrete. The feldspar group of minerals are complex silicates of aluminum with potassium, sodium, calcium, and, rarely, barium. The associated rocks are usually pegmatites and as such present no environmental hazard.

Orthoclase, a feldspar mineral, undergoes alteration when subjected to waters carrying carbon dioxide. A soluble potassium carbonate is formed which could cause problems with vegetation in the immediate runoff or leaching area.

Waste Rock from Fluorspar Mining

Waste rock from fluorspar mining is recommended for use in portland cement concrete and bituminous paving.

The mineral fluorite (fluorspar) is generally worked in veins associated chiefly with limestone and dolomites as well as igneous rocks and pegmatites. None of these associated rocks would offer environmental hazards from leaching or by airborne contamination.

It should be noted that in areas of Southwestern United States, fluorite exists in conjunction with heavy metal sulfides, e.g. galena. The use of fluorite rock from such areas should be restricted to non-wearing surfaces, unless it can be shown that the heavy metal sulfides are not worn down to enter the environment as dust or leachate.

Waste Rock from Gold Mining

Waste rock from gold mining is recommended for use as structural fill, sub-base or base, waste fill, and in Portland cement concrete. This source of waste rock will generally be of the silicic-igneous type and will present no environmental hazard. Since gold may be associated with other heavy metals, the absence of such metals, e.g. selenium and tellurium, should be demonstrated.

Waste Rock from Iron Mining

Waste rock from iron mining is recommended for use as structural fill, sub-base or base, waste fill, bituminous paving, and in Portland cement concrete. Waste rock from high grade iron ore mining can be from many rock types, but is often a limestone or rhyolite. As such, no environmental hazard is presented. If iron sulfides are present, the oxidation of the sulfide would lead to a leachate containing iron and sulfuric acid. In such cases, sealing against air and moisture would be required.

Waste rock from iron mining operations in the California, Missouri, New York, Pennsylvania, and Wyoming areas have been used in highway construction. There have been no reports of adverse environmental effects related to such uses.

Several guidelines are offered as a means of identifying and avoiding serious environmental problems that could occur from using mining and metallurgical wastes in highway construction. These guidelines are:

1. The material should give a pH of between 6 and 8.

2. Materials containing sulfides or heavy metals should be approached with caution. However, the concentration of sulfides or heavy metals in the leachate is of much greater significance than their mere presence.

3. Materials which are predominantly silicates can generally be considered acceptable for any use.

4. Dusting and air pollution should be minimized when using most mining and metallurgical wastes. Standard construction procedures should be adequate.

6.3 ECONOMIC EVALUATION

The economic analysis was separated into two phases:

1. An assessment of "economic potential" for each of the wastes based largely on the quantities available and their location with respect to market areas.

2. A study of the cost factors that would determine the cost of the material in place in the highway.

6.3.1 Assessment of Economic Potential

It is readily apparent that small quantities of a given waste located many miles from a point of use would virtually eliminate the use of the material. Such a waste has been assessed in this study as having a low "economic potential." Several examples are cited to illustrate the meaning of this concept.

Reynolds Metals Company produces a waste material from their alumina reduction process which is called silica fines. This material is a fine-grained, amorphous silica dust which can be pelletized. It is produced at the rate of 27 tons (21.6 tonnes) per day or about 8,000 tons (7,200 tonnes) per year. The material is also reportedly not suitable for stockpiling, which further reduces its value as highway construction material.[223]

With respect to location, an official at the Climax mine in Climax, Colorado does not recommend the use of their molybdenum tailing because "our deposit is removed from any construction potential by up to 120 miles of mountain roads."[224]

A Nevada mining company noted the following in a discussion of the tailing material from their open pit copper mine: "Being as this entire area is composed of thousands of square miles of material such as we have here, there would be little incentive to use this material unless it was for a road in the immediate vicinity."[225]

The following indicators were used as evidence of "economic potential":

1. Material available in large quantities
2. Located near market areas
3. Located near aggregate shortages
4. Located in areas with growth potential.

Each of these indicators requires some definition.

A production of 500,000 tons (450,000 tonnes) per year at an individual location is considered to be a large quantity. Where production has ceased, a large quantity would consist of at least 500,000 tons (450,000 tonnes) available for use.

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[223]Mr. J. A. Branscomb, Reduction Research Division, Reynolds Metals Company, Listerhill, Alabama. Correspondence dated October 6, 1975.

[224]Mr. James A. Brown, Environmental Control Engineer, Climax Molybdenum Company, Climax, Colorado. Correspondence dated October 28, 1975.

[225]Mr. J. P. McCarty, Resident Manager, Duval Corporation, Battle Mountain, Nevada. Correspondence dated November 18, 1975.

Wastes located within 50 to 100 miles (80 to 160 kilometers) of major metropolitan areas are considered as being near potential markets. This criterion depends on the validity of several assumptions: (1) most new highway construction and substantial improvement projects will be close to metropolitan areas, (2) the Interstate System will be virtually complete prior to any significant highway use of the wastes, and (3) the uncertainty of future energy supplies will dictate against any big program for the construction of inter-city highways.

Many states have reported a shortage of natural aggregate supplies in certain areas. Correspondence with state highway materials engineers has identified a number of general areas throughout the United States where present shortages of desired quality aggregate have been noted. These areas are essentially quite similar to those indicated by Miller and Collins (79) and described by Witczak[226] and others.

Figure 42 denotes the location of areas in which aggregate shortages have been reported. These are areas where the greatest potential probably exists for using mining and metallurgical wastes. Generally, most large metropolitan areas are or will be experiencing some shortages in aggregate supplies. Mining and metallurgical wastes located in or within 50 to 100 miles (80 to 160 kilometers) of aggregate shortage areas are considered as located near aggregate shortages.

Areas that are expected to have the highest rate of population and economic growth in the future are the Northeast, Southwest, Great Lakes region, and the Far West regions. (2) Since population shifts have been toward the big cities, all major metropolitan areas can also be expected to continue their growth. Population and economic growth are generally accompanied by increased construction activity. Therefore, mining and metallurgical wastes located in or near the above areas will probably have greater opportunity for use as a construction material.

A number of mining and metallurgical wastes have value for other uses, including mineral or fuel values. However, most of these wastes exist in large enough quantities that

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[226] Witczak, Matthew W., Lovell, C. W., Jr., and Yoder, E. J. "A Generalized Investigation of the Potential Availability of Aggregate by Regional Geomorphic Units within the Conterminous Forty-Eight States." Highway Research Record No. 353, 1971, pp. 31-42.

Figure 42. Locations of aggregate shortage areas.

a sufficient amount of material would still be available for possible highway construction use.

The existance of competing uses was not considered to be a significant enough factor to eliminate the use of mining and metallurgical wastes for highway construction.

Table 45 summarizes the findings of this assessment of "economic potential." Each mineral industry was considered as a whole. Exceptions within a specific industry are not reflected. For example, bituminous coal refuse was not considered to be located in areas of potential growth. Although there are large amounts of this material located relatively close to the Pittsburgh metropolitan area, most of the bituminous coal refuse is located in the Appalachian region, which is not a potentially high growth area.

Mining and metallurgical wastes having the most favorable "economic potential" are gold gravels, iron ore waste rock and tailings, phosphate sand tailings, phosphogypsum, phosphate slag, taconite waste rock and tailings, anthracite coal refuse, blast furnace slag, and steel slag.

6.3.2 Economics of Obtaining, Processing, and Transporting Mining and Metallurgical Wastes

The cost of any product must be considered when its use in highway construction is contemplated. The elements that combine to influence the cost of the material, in place, are; F.O.B. price, transportation cost, and the cost of construction. For the purposes of this discussion, processing costs are assumed to be included in the F.O.B. price. In addition, no meaningful data are available on the cost of construction with mining wastes. This cost element, for the time being, must be left unresolved and a subject for future determination.

In many cases, the most costly of these elements will be the transportation cost. It undoubtedly will be the controlling factor in determining the extent of use of a particular mining or metallurgical waste in those instances where all other considerations show the material to be acceptable.

<u>F.O.B. Price</u>

The price that an owner would seek for his material would depend on a number of factors; including but not necessarily limited to, the following:

1. The value of the material for its particular use (largely determined by the cost of competitive materials).

Table 45. Economic summary of quantity and location indicators for mining and metallurgical wastes.

Mineral Industry	Type of Waste	Material Available in Large Quantities	Located Near Market Areas	Located Near Aggregate Shortages	Located in Area of Potential Growth
Alumina	Muds	X[1]	X	X	X
	Pisolites				
Asbestos	Tailings				X
Barite	Tailings				
Copper	Waste rock	X			
	Tailings	X			
	Smelting Slag	X			
Feldspar	Tailings				
Fluorspar	Waste rock			X	
	Tailings			X	
Gold	Waste rock				
	Dredge tailings	X	X	X	X
	Placer tailings	X	X	X	X
	Lode tailings				
Gypsum	Tailings				
	Waste rock	X	X		X
Iron	Tailings	X	X		X
	Waste rock				
Lead and Zinc	Coarse tailings (chat)	X			
	Fine tailings	X			
	Lead smelter slags		X		X
	Zinc smelter residues		X		X
Molybdenum	Tailings	X			
Nickel	Smelter slag	X			

Footnote placed at end of table, p. 243.

Table 45. Economic summary of quantity and location indicators for mining and metallurgical wastes (continued).

Mineral Industry	Type of Waste	Material Available in Large Quantities	Located Near Market Areas	Located Near Aggregate Shortages	Located in Area of Potential Growth
Phosphate	Sand tailings	X[1]	X		X
	Slimes	X	X		X
	Phosphogypsum	X	X		X
	Furnace slag	X		X	X
Silver	Tailings	X			
Slate	Waste rock		X		X
Taconite	Waste rock	X	X		X
	Tailings	X	X		X
Uranium	Tailings	X			
Anthracite Coal	Red dog		X	X	X
	Coarse refuse	X	X	X	X
	Washery silt	X	X	X	X
Bituminous Coal	Red dog		X	X	
	Coarse refuse	X	X	X	
	Washery silt	X	X	X	
Iron and Steel	Blast Furnace Slag	X	X	X	X
	Steel Slag	X	X	X	X
Oil Shale	Spent Shale				

[1]X denotes that the material satisfies the criteria for a particular indicator. For example, alumina muds are available in large quantities.

2. The market demand.

3. The profit margin and market demand for other uses of the same material.

4. Disposal costs assuming no further use.

5. Stockpiling costs assuming further use.

6. The cost of retrieving from a stockpile-access and loading.

7. The cost of any special processing needed to satisfy a user's requirements.

The F.O.B. prices of various mining and metallurgical wastes were found to range from $.35 per ton ($.386 per tonne) to $6.00 per ton ($6.61 per tonne). The price of asbestos tailings (shorts) is one notable exception. This material has been reported to cost between $50 and $60 per ton ($55 and $60 per tonne).[227]

For most of the by-products evaluated in this study, the cost of processing will essentially involve some form of size control. If the material is too coarse, it will probably have to be crushed and screened. If the material is too fine, the coarser fraction must be separated. Material with a sizeable iron fraction should have this component removed by magnetic separation in order to recover this metal value. Some of the fine-grained wastes are so wet that de-watering is necessary. No current estimates of costs for any of these processing steps are presently available. Miller and Collins noted in a previous report that the average cost of crushing and sizing a slag was approximately $.75 per ton ($.83 per tonne) (79).

Table 46 summarizes information received from a number of industrial sources concerning the selling price of different mining and metallurgical wastes. Nearly all of these materials are metallurgical slags. For the most part, these materials are selling at between $2.00 and $3.00 per ton ($2.20 and $3.31 per tonne). Many are sold F.O.B. plant with loading included. A number of companies have reported that their prices are negotiable.

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[227] Mr. Irving F. Moore, President, Wheeler Properties, Inc., Reno, Nevada. Correspondence dated January 12, 1976.

Table 46. Selling price of mining and metallurgical wastes.

Company	Location	Waste Commodity	Reported Cost
A.S.A.R. Co.	Hayden, Arizona	Copper Smelter Slag	$4.50/ton ($4.96/tonne)
Atlas Asbestos	Coalinga, California	Asbestos Tailing (shorts)	$50-60/ton ($55-66/tonne)
Heckett	Fontana, California	Blast Furnace Slag	$1.25/ton ($1.38/tonne)
		Steel Slag	$.70/ton ($.77/tonne)
Bunker Hill	Kellogg, Idaho	Lead Smelter Slag	$2.00/ton ($2.20/tonne)
Monsanto	Soda Springs, Idaho	Phosphate Slag	$.35-$.40/ton ($.39-$.44 /tonne)
Bethlehem	Burns Harbor, Indiana	Blast Furnace Slag	$2.30/ton ($2.54/tonne)
Black Trap	Iron Mountain, Missouri	Iron Ore Waste Rock-3/8" aggregate	$5.75/ton ($6.34/tonne)
		Iron Ore Waste Rock-sand size	$4.00/ton ($4.41/tonne)
A.S.A.R. Co.	East Helena, Montana	Lead Smelter Slag	$4.25/ton ($4.68/tonne)
Bethlehem	Buffalo, New York	Blast Furnace Slag	$2.50/ton ($2.76/tonne)
Bethlehem	Bethlehem, Pennsylvania	Blast Furnace Slag	$2.50/ton ($2.76/tonne)
Bethlehem	Johnstown, Pennsylvania	Blast Furnace Slag	$2.60/ton ($2.87/tonne)
Crucible	Midland, Pennsylvania	Steel Slag	$1.60/ton ($1.76/tonne)
St. Joe Mineral	Monaca, Pennsylvania	Zinc Smelter Residue	$2.50/ton ($2.76/tonne)

Table 46. Selling price of mining and metallurgical wastes (continued).

Company	Location	Waste Commodity	Reported Costs
New Jersey Zinc	Center Valley, Pennsylvania	Zinc tailing-damp	$2.00/ton ($2.20 /tonne)
		Zinc tailing-dry	$6.00/ton ($6.61 /tonne)
Cities Service	Copperhill, Tennessee	Copper Smelter Slag	$6.00/ton ($6.61 /tonne)
Monsanto	Columbia, Tennessee	Phosphate Slag	$.60-$.75/ton) ($.66- $.83 /tonne)
Kennecott	Garfield,	Copper Smelter Slag	$1.00/ton ($1.10/tonne)
Black Knight	Tacoma, Washington	Copper Smelter Slag	$1.00-$2.00/ton ($.1.10-$2.20/tonne)

Several companies have reported on the estimated cost of retrieval for mining and metallurgical wastes. Amax Lead Company estimates a cost of $2.00 per ton ($ 2.20 per tonne) for retrieval of lead smelter slag, including screening and loading.[228] Retrieval and loading of copper smelter slag has been estimated at a cost of $3.00 per ton ($ 3.31 per tonne).[229] Ormet estimates that it would cost approximately $2.40 per ton ($ 2.65 per tonne) for a drag line operation to reclaim alumina red mud waste, with processing and loading additional costs.[230]

If a waste material could be recovered prior to disposal, it is possible that it could be obtained at a relatively low cost. The cost associated with the disposal of waste would probably be reduced. This saving could be substantial and would influence the determination of the selling price.

An example of such a situation is coal refuse. If the refuse can be hauled away from the preparation plant, most coal companies would realize a significant reduction in the cost of operation. On the other hand, once the refuse has been disposed of in a stockpile or controlled fill area, the coal company has incurred a disposal cost for this material. The charge to a potential user in the latter case, would be higher.[231]

There are other problems associated with obtaining or recovering mining and metallurgical wastes. This is particularly the case with respect to coal refuse. There would have to be an agreement made between the company and the union local having jurisdiction at a particular mine, permitting non-union or other union labor to perform any kind of work on mine property.

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[228]Mr. Harvey L. Rowland, Chief Engineer, Amax Lead Company, Boss, Missouri. Correspondence dated November 12, 1975.

[229]Mr. R. N. Brown, Executive Vice-President, U.S. Metals Refining Company, Carteret, New Jersey. Correspondence dated November 26, 1975.

[230]Mr. Joseph Baretincic, Corporate Staff Engineer, Ormet Corporation, Hannibal, Ohio. Correspondence dated December 31, 1975.

[231]Mr. Al Holtz, Plant Superintendent, United States Steel Corporation, New Eagle, Pennsylvania. Personal communication.

Thus far, the discussion of economics has centered around costs associated with the material itself. The remainder of this evaluation will focus on an analysis of the costs involved in transporting mining and metallurgical wastes.

Transportation Economics

On a national average it has been reported that transportation accounts for 50 percent or more of the delivered cost of construction materials. If long hauls are involved, the cost of transportation will dictate the overall economic value of a material (59).

The general consensus of opinion among knowledgeable personnel in the mining industry and in state highway or transportation departments is that transportation costs are the single factor most responsible for limiting the use of mining and metallurgical wastes.

The cost of shipping these materials is often substantially higher than comparable shipping costs for conventional materials. This section of the report will analyze the present state-of-the-art for determining haul rates for truck, rail, and barge transport. Rates will be quoted for hauling certain mining or metallurgical wastes in specific areas by each of these modes.

Truck Transport

Highway shipments of bulk materials are most often made by open type dump trucks. Regardless of the type of vehicle used, approximately 90 percent of bulk materials such as aggregate are shipped by truck, mostly within a hauling distance of 50 miles (80 kilometers) or less (59).

Truck carriers can be broadly classified into two categories: common carriers and contract carriers. The basic difference between the two is that common carriers are licensed to make regular hauls of a number of commodities between established points while contract carriers negotiate haul rates for special point to point moves of certain commodities.

Common carriers are subject to price regulations for the goods that they haul. If the hauls are interstate (across state boundaries), the tariffs are published by the carrier and filed with the Interstate Commerce Commission. If the hauls are intra-state (within a state boundary), the tariffs are then filed with the state Commerce Commission or Public Utility Commission.

The tariffs used by each common carrier are issued by the carrier or his agent for the specific use of that particular carrier. The tariff defines very rigidly the scope of the carrier's operating authority in terms of the commodities he is permitted to haul, the specific points to and from which he may haul these commodities, the rate or rates that are to be charged for these hauls, and the sizes of vehicles which can be used. Generally, a number of additional rules and regulations accompany these tariffs.

There are two basic types of rates available from common carriers: class rates and commodity rates. Published class ratings and minimum weights are listed in the National Motor Freight Classification 100-C according to commodity description. Very few mining and metallurgical wastes are included among these commodities. Slag (without mineral value) and chat (lead or zinc mine refuse) are both listed under motor classification Class 35 with a minimum weight of 60,000 pounds (27,216 kilograms). Class 35 is the classification normally assigned to bulk materials, which describe most mining and metallurgical wastes.

When using a tariff, a point to point move of a specific commodity may be assigned a rate (commodity rate) or a distance rate chart may be used instead to determine rates for bulk commodities (class rates). For the movement of bulk commodities using general distance or class rates, a good rule of thumb would be to figure on a rate of $.75 per ton ($.83 per tonne) for the first mile (1.6 kilometers) and $.05 per ton ($.055 per tonne) for every mile (1.6 kilometers) thereafter. However, a rate would still be quoted on the basis of the origin and destination of the move.

In some cases, a haul rate will be increased to take into account any tolls that might be involved or reduced if the haul can be made in less time using limited - access routes. It is also possible that initial and per-mile charges will vary somewhat in different parts of the country or among different common carriers, but these figures are fairly representative of truck haul rates now being used by common carriers in Pennsylvania.

For example, a 90 mile (144 kilometer) haul of a bulk material would involve a class rate of approximately $5.20 per ton ($5.73 per tonne) using the rule of thumb. If a specific move were made with sufficient frequency and involved sizeable quantities, a tariff could be issued which would probably result in a commodity rate for that movement at a lower rate than the class rate.

If the move were only being made for a temporary time period, a shipper could negotiate a more favorable rate with a contract carrier. However, contract carrier rates are usually for at least a year and tonnage may have to be guaranteed.

Although any common carrier may negotiate a shipping contract as a contract carrier, most contract carriers are construction haulers whose main business is hauling aggregate.

If interstate commerce is involved, a copy of the contract and schedule must be on file with the Interstate Commerce Commission. If a regulated common carrier normally reports to the Interstate Commerce Commission, a commodity rate will be the lowest permissible rate that can be negotiated.

No filing of a negotiated hauling contract is normally necessary if only an intra-state movement is involved. However, a state permit will probably be required for any negotiated contract. Therefore, it is recommended that the state Commerce Commission or Public Utility Commission be contacted in advance of any negotiation with a contract carrier.

A company could even haul its own materials in intra-state and interstate commerce without a certificate from the Interstate Commerce Commission. However, periodic checks are conducted to make sure that only company materials are being hauled.

Figure 43 shows the relationship of truck carriers and the rates associated with each type of carrier. A number of examples concerning the range of truck costs for some hypothetical market situations are presented in Table 47. These rates are compared with rail rates for the same movements.

Rail Transport

Any discussion of rail transportation rates must be prefaced with the statement that this is an extremely complex and detailed subject. To thoroughly research all aspects of rail hauling for mining and metallurgical wastes would necessitate a separate study in itself.

Nevertheless, an investigation was made of the various rates available for transporting mining and metallurgical wastes in bulk by rail. As in truck hauling, there are two basic types of rates which apply to rail hauling: class rates and commodity rates. Commodity rates may be either commodity column rates or specific commodity rates. Class rates generally apply to shipments in small volume and to

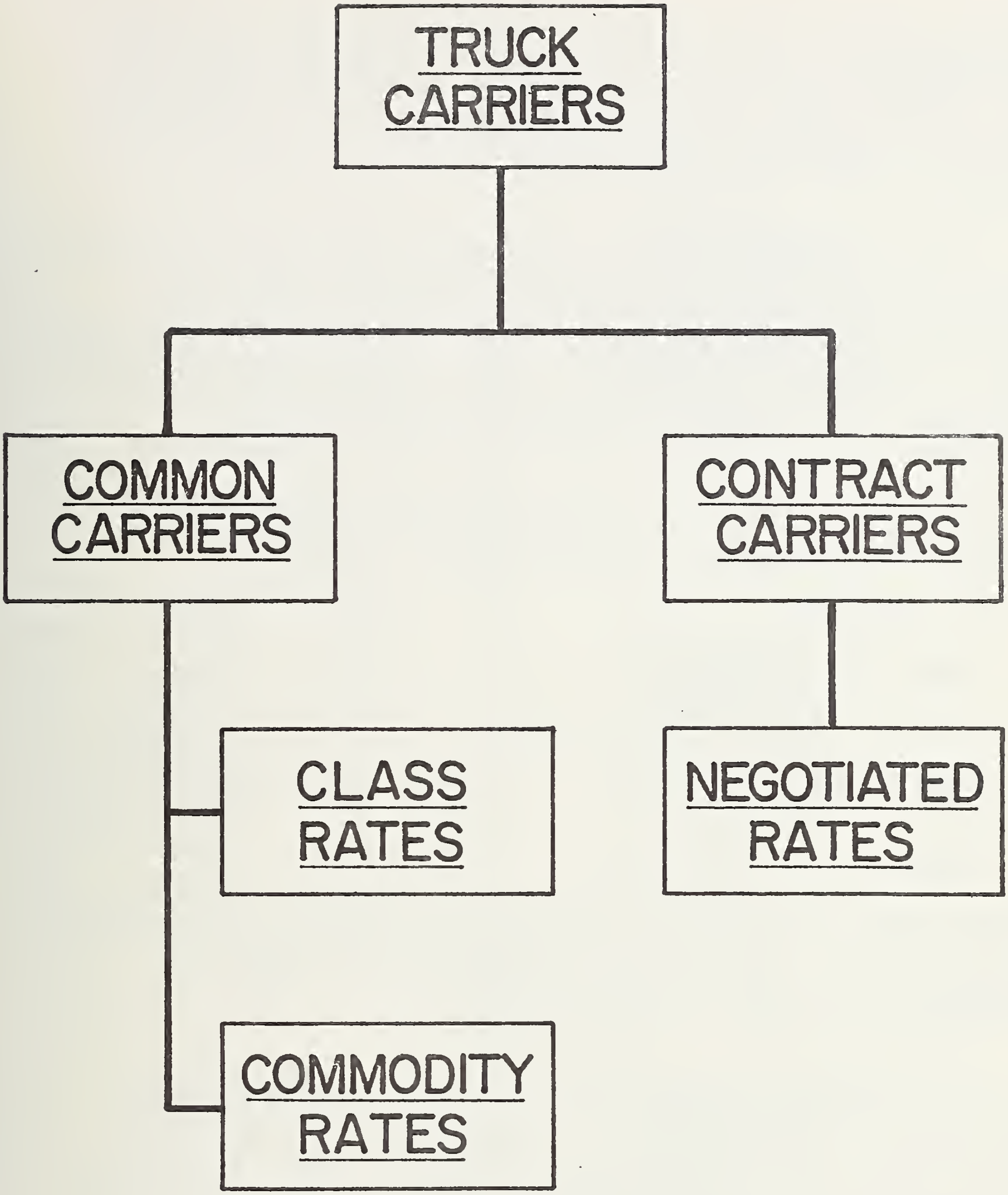

Figure 43. Options for truck hauling rates

and from points not generating sufficient tonnage or requiring movements on an irregular basis. Commodity rates apply to those movements of a specific commodity that usually move on a regular basis between established points in sufficient volume to justify a rate lower than a class [illegible] (100) Figure 44 illustrates the various rates [illegible] by rail.

With few exceptions, the only applicable rates for moving mining waste in bulk at the present time are class rates. Each raw material is classified according to a Standard Transportation Commodity Code number and listed in the Ratings, Rules, and Regulations of the Uniform Freight Classification No. 12, which was established by the Uniform Classification Committee. These material classifications are based upon the nature of the material and its end use or value.

An examination of the Uniform Freight Classification index to articles indicates that the following commodities would qualify as mining or metallurgical waste:

Article	Item	Class
Coal waste, anthracite	28660	17-1/2
Coal waste, bituminous	28660	17-1/2
Chat (lead or zinc mine refuse)	47390	13
Slag, granulated or lump	47470	13

These classifications are based on the shipment of the materials in bulk. The slag classification includes granulated or lump slag which is without commercial value for the extraction of metals. Slag carrying mineral value is subject to the classification ratings for ore.

It is possible that some mining wastes could be classified as a gravel or sand (not otherwise indexed by name), in which case they would fall under Items 47420 and 47460, respectively, and would also be listed as class 13 material, which is one of the lowest class ratings. The class rating is a carload rating which indicates the percentage of first class shipping costs for each material.

For each of the above classifications, the Uniform Classification Code stipulates the minimum carload weight and type of car required to qualify for a particular class rating. Once the class rating has been determined, the haul rate can be

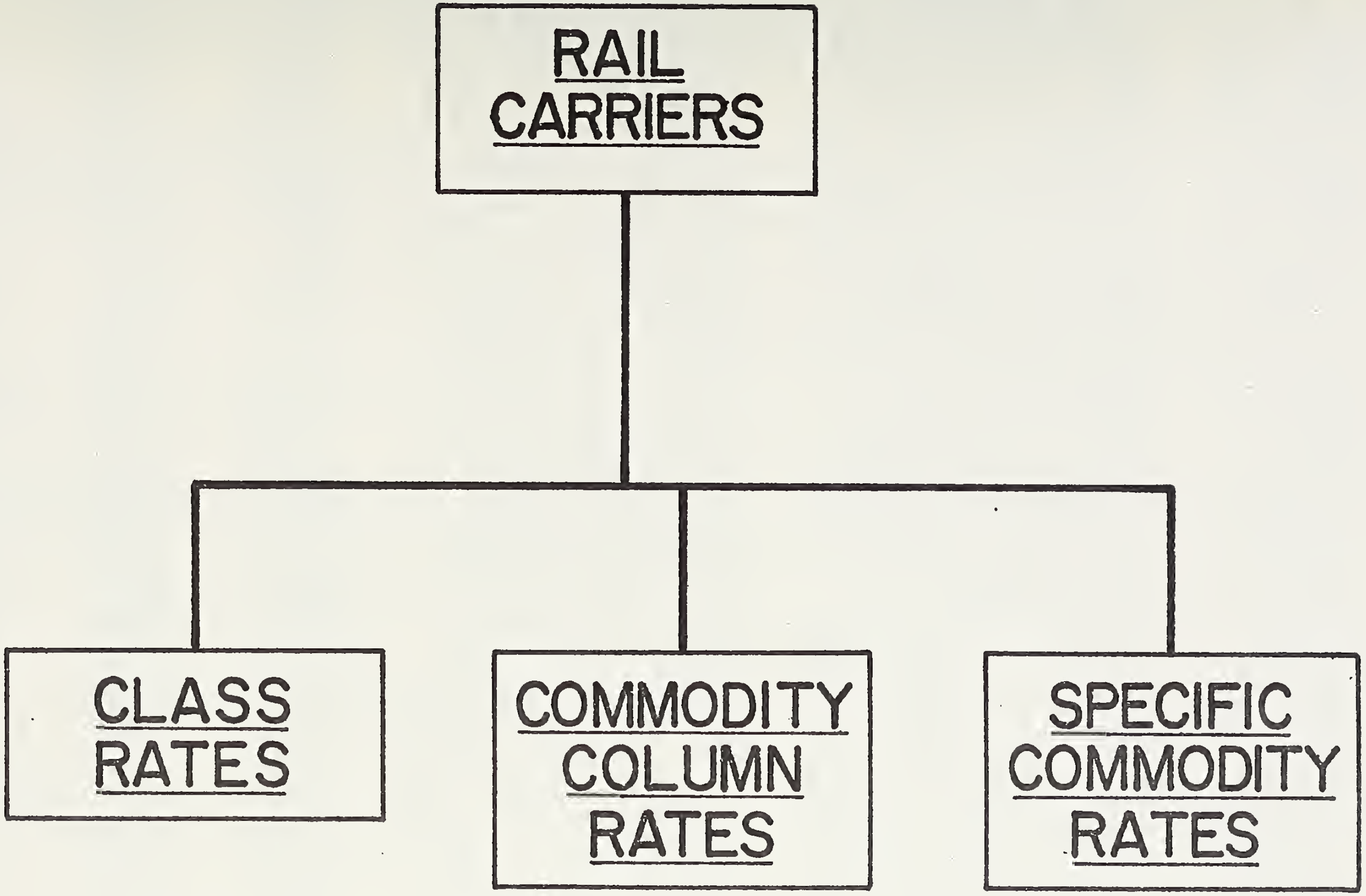

Figure 44. Option for rail hauling rates

established from the applicable tariff, based on the haul distance, points of origin and destination and the class rating.

Rail freight tariffs are established by various groups of railroads which have banded together to publish rates. There are five territories established by the Interstate Commerce Commission - the New England, the Official (or Northeast), the Western, the Southern, and the Mountain Pacific and Trans territories.

Different tariffs have been established for interstate rail movements within or between these territories, based on an analysis of the costs incurred by the railroads in these territories, the type of available train service, and type of equipment provided. Tariffs for intrastate rail movements are established by the carriers based on approval by the state Commerce Commission or Public Utility Commission. The Interstate Commerce Commission may overrule a state Commission if the rates are in variance. Individual states often take longer in adopting ex parte increases, so the rates for intrastate movements may be slightly lower than those for interstate movements.[232]

It must be understood that a rail hauling rate can be established only by requesting a rate from an individual railroad company. Tariff rates are expressed in terms of cents per hundred weight or ton and are tabulated according to class rating and rate base number. The origin, destination, and route of a particular movement would have to be known in order to determine the rate, since in some tariffs a conversion from rate base number to distance must be made. Factors such as topography, type of equipment, number of rail lines involved, turnaround time, and percentage of empty backhaul may enter into the process of rate determination, even for a class rate.

Table 47 presents an analysis of the computed rail and truck hauling rates for eight selected hypothetical moves of various mining and metallurgical wastes. All rates were computed using the class rates published in the respective tariffs.

It can readily be seen from this table that the use of class rates makes it uneconomical to consider rail transportation of these materials unless commodity column or specific

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[232]Mr. Gus Barnett, Louisville and Nashville Railroad. Freight Rate Department, Louisville, Kentucky. Personal communication.

Table 47. Comparison of truck and rail haul rates for selected movements of mining and metallurgical wastes.

Commodity	Rate	To	Miles	Class Rating (1)	Rail Class Rate ($ per cwt)	Rail Class Rate ($ per ton)	Truck Class (2) Rate ($ per ton)
Taconite Tailings	Mt. Iron, Minn.	Minneapolis, Minn.	204	13	.59	11.80	10.90
Steel Slag	Pueblo, Colo.	Denver, Colo.	117	13	.46	9.20	6.55
Coal refuse	Wilkes-Barre, Pa.	Harrisburg, Pa.	135	17-1/2	.66	13.20	7.50
Lead-zinc tailings	Miami, Okla.	Tulsa, Okla.	90	13	.42	8.40	5.20
Copper Slag	Copperhill, Tenn.	Knoxville, Tenn.	109	13	.46	9.20	6.15
Coal refuse	Harlan, Ky.	Lexington, Ky.	180	17-1/2	.74	14.80	9.70
Phosphate slag	Soda Springs, Idaho	Twin Falls, Idaho	180 (3)	13	.65	13.00	7.75
Copper Tailings	Hayden, Arizona	Phoenix, Arizona	97 (3)	13	.49	9.80	5.20

(1) Class 13 and 17-1/2 ratings require bulk hauling in open cars with a minimum carload weight of 80,000 pounds.
(2) Determined on the basis of $.75 per ton for first mile and $.05 per ton for each additional mile.
(3) Rate base numbers expressed for movements in Western territory.

commodity rates can be negotiated. Although truck class rates are less than railroad class rates, hauling by truck would also be uneconomical for these movements. Contract carrier rates would have to be negotiated for long truck hauls.

In order to obtain a commodity column rate or a specific commodity rate, the applicant must first write to the pricing officer of the rail carrier that serves the origin of that particular commodity movement. A copy of the letter should also be sent to the pricing officer of the destination carrier. It is not necessary to contact the Interstate Commerce Commission or any state Commerce Commission or Public Utility Commission when applying for a commodity rate.

The negotiations with railroad companies should be handled personally. A typical railroad company employs staff personnel who develop costs for existing and proposed freight traffic. Therefore, all applicable information on costs, tonnages, and mileages should be developed in advance before proposing a rate, including knowledge of the railroads' fixed cost and equipment costs.

Specifically, railroad companies need a very complete description of the commodity involved, giving reference to the Item Number of the Uniform Freight Classification, if possible. The description of the material should include an estimate of its value per ton or 100 pounds (45 kilograms). The origin(s) and destination(s) should be specific and should indicate if there is track served and by what carrier(s). The estimated volume of movement is most important. It must be noted whether the proposed movement is to be a one-time move or would involve continuous volume. Also required is the kind of equipment needed to handle the movement.[233]

The length of time involved in a rate determination can vary considerably depending on the merits of the rate. Once an agreement has been reached with the railroads, the proposed tariff must be taken before the Territorial Rate Commission for approval. Normally, the negotiated rate will not become published and effective for a period of at least 90 to 120 days after it has been proposed to the Territorial Rate Commission.

Several of the rates computed in Table 47 were checked with the railroad companies and were also compared with transportation rates provided by individual mining companies.

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[233]Mr. J. E. McDaniel, Director of Marketing, Louisville and Nashville Railroad, Louisville, Kentucky. Correspondence dated April 8, 1976.

The Duluth, Mesabi, and Iron Range Railway Company has obtained a commodity column rate to haul taconite tailings for a distance of 100 miles (161 kilometers) between mill and mine locations in the iron range of Minnesota. This rate is quoted in Western Trunk Lines Commodity Tariff No. 417-F, Item 2520, Supplement 10, which is thirty-two (32) percent of a Class 17-1/2 rate based only on a 100-mile (161 kilometer) point-to-point haul.[234]

A study was conducted for the Reserve Mining Company, Silver Bay, Minnesota by Arthur D. Little, Inc., to evaluate the possibility of utilizing taconite tailings as a raw material for the construction industry in Great Lakes ports. Part of this study involved a determination of rail rates for transporting taconite tailings from Silver Bay, Minnesota to Chicago. A detailed analysis was presented of the cost accounting procedures developed by the Interstate Commerce Commission and used by the railroads to compute fixed costs and out-of-pocket costs in order to determine a rate for a specific freight movement. The calculated specific commodity rate of hauling taconite tailings from Silver Bay to Chicago (600 miles or 965 kilometers) was $5.25 per ton ($ 5.79 per tonne), which compares very closely with a quoted rate of $5.28 per ton ($ 5.82 per tonne) to haul iron ore for the same movement. (67)

Table 48 presents a comparison of the class, commodity column, and specific commodity rates for a hypothetical 100 mile rail haul of taconite tailings. This would closely correspond to a rail haul from the Mesabi range to the Duluth - Superior area. The class rate was computed from the rates quoted in Western Trunk Lines Commodity Tariff No. 1001-A, Section 68. The commodity column rate was determined on the basis of thirty-two (32) percent of a Class 17-1/2 rate as quoted by the Duluth, Mesabi, and Iron Range Railway Company. The specific commodity rate for a 100 mile haul distance was developed by extrapolation from Figure VII (railroad out-of-pocket and fully distributed cost per ton) of the Arthur D. Little report to Reserve Mining Company. By comparing these rates it is obvious that substantial savings in transportation costs can be effected through the negotiation of a commodity rate.

A further check on rail hauling rates was conducted by contacting the Louisville and Nashville Railroad to obtain a rate quotation for transporting coal refuse from Harlan to

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[234]Mr. R. T. Bennett, Marketing Manager, Duluth, Mesabi, and Iron Range Railway Company. Personal communication.

Table 48. Comparison of railroad hauling rates for movement of taconite tailings.

	Computed Class Rate	Commodity Column Rate	Commodity Class Rate
Method of Calculation	Determined by Valley Forge Laboratories based on existing tariff	Based on 32 percent of Class 17-1/2 rate as quoted by Duluth, Mesabi, and Iron Range Railway	Extrapolation of rates from Figure VII of Arthur D. Little report to Reserve Mining Company
Rate	$.43 per cwt $8.60 per ton ($ 9.48 per tonne)	.32 x $.59 per cwt = $.19 per cwt $3.80 per ton ($ 4.19 per tonne)	$2.40 per ton ($2.65 per tonne)
Percent of Class Rate	100	44.2	27.9

NOTES:

1. Rates based on haul distance of 100 miles or 161 kilometers.
2. Computed Class rate for truck haul by common carrier is $5.70 per ton ($ 6.28 per tonne), based on $.75 per ton ($.83 per tonne) for first mile (1.6 kilometers) and $.05 per ton ($.0 55 per tonne for each additional mile (1.6 kilometers).
3. The above rates do not include charges for loading and unloading.

Lexington, Kentucky and for transporting copper slag from Copperhill to Knoxville, Tennessee. These rates were compared with the rate for hauling aggregate over the same distance.[235] The findings of this investigation are shown in Table 49. Also shown in this table is the haul rate quoted by the Cities Service Company for the movement of their granulated copper smelter slag from Copperhill to Knoxville.[236] This rate applies to "slag, expanded or water granulated, carload, in open-top cars, minimum weight marked capacity of car, except when car is loaded to full cubicle or visable capacity, actual weight shall govern, but in no case less than 80,000 lbs.," as published in Table 5 of the Southern Freight Territory Bureau Tariff 388-L.[237]

After reviewing the figures, the advantages of entering into negotiations with the railroad companies for more favorable hauling rates are readily apparent. A good illustration of this is the point-to-point commodity rate negotiated by the New Jersey Zinc Company for hauling granulated zinc smelter residue 92 miles (147.2 kilometers) from their smelter in Palmerton, Pa., back to their Ogdensburg mine in Sussex County, New Jersey for use as mine backfill. The zinc ore is hauled from the mine to the smelter and the residue is hauled back to the mine in the otherwise empty cars for the return portion of the movement.

The rate agreed upon for hauling the zinc smelter residue from the smelter to the mine is a per car rate of $120 per railroad car. Since each car is rated at 75 tons (68 tonnes) the haul rate is $.08 per hundred weight (cwt) or $1.60 per ton ($1.76 per tonne), as noted in the Central New Jersey Tariff No. 59. Since the Central New Jersey Railroad is now part of the new Conrail system, this rate may have to be re-negotiated.[238]

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[235] Mr. Gus Barnett, Marketing Division, Louisville and Nashville Railroad, Louisville Kentucky. Personal communication.

[236] Mr. R. D. Estes, Supervisor of Environmental Control, Cities Service Company, Copperhill, Tennessee. Correspondence dated December 8, 1975.

[237] Mr. H. E. Robins, Jr., Senior Traffic Analyst, Cities Service Company, Atlanta, Georgia. Correspondence dated April 8, 1976.

[238] Mr. Will Smith, New Jersey Zinc Company, Transportation Department, Bethlehem, Pa. Personal communication.

Table 49. Comparison of railroad hauling rates for movements of coal refuse and copper slag within the Southern Territory.

COAL REFUSE

Origin	Destination	Distance
Harlan, Kentucky	Lexington, Kentucky	180 miles (290 kilometers)

Computed Class Rate	Quoted Class Rate (1)	Quoted Commodity Rate for Aggregate (1)
$14.80 per ton ($ 16.31 per tonne)	$14.60 per ton ($ 16.09 per tonne)	$3.78 per ton ($ 4.17 per tonne)

COPPER SLAG

Origin	Destination	Distance
Copperhill, Tennessee	Knoxville, Tennessee	90 miles (144 kilometers)

Computed Class Rate	Quoted Class Rate (1)	Quoted Commodity Rate (2)	Quoted Commodity Rate for Aggregate (1)
$9.20 per ton ($ 10.14 per tonne)	$9.20 per ton ($10.14 per tonne)	$2.90 per ton ($ 3.20 per tonne)	$2.94 per ton ($ 3.24 per tonne)

(1) Quoted rates from Louisville and Nashville Railroad.

(2) Quoted commodity rate for this movement provided by Cities Service Company, Copperhill, Tennessee.

Although this rate is a per car rate for a somewhat unique situation and cannot be directly compared with the hauling of a basic commodity, it does serve to illustrate what can be accomplished in the way of negotiating with a railroad company for a specific commodity rate.

There may also be other possible measures for improving rail transportation rates for construction materials. In the past railroads have established special rates for the movement of cement from cement plants to portable ready-mix concrete plants located near highway construction projects.[239] Similar arrangements could possibly be negotiated for the movement of mining or metallurgical wastes, provided the material source and the proposed highway project are located reasonably close to rail facilities.

The unit train concept involves a train with up to as many as 140 identical hopper cars hauling one commodity between a single origin and destination with a minimum of delivery stops. The unit train concept was initially developed in 1959. Coal is practically the only commodity using unit trains; in fact, about 70 percent of all the coal mined in the United States is hauled by unit train. The shuttle train is a further refinement of the unit train concept in which the entire train stays connected and returns immediately to its point of origin for reloading (42).

These concepts are also applicable to hauling of other bulk materials such as aggregates. The Chicago and North Western Railway initiated a unit train movement of sand and gravel from South Beloit, Illinois to Des Plaines, Cragin, and Elmhurst, northwest of Chicago. These trains, called "Commoditrains," resulted from agreements between the railroad and labor unions to effect work rule changes that speeded up delivery time at lower cost. A single car rate of $1.73 per ton was used for a 189 mile (304 kilometer) round trip (59).

A Colorado paving contracting firm with asphalt plants in the Denver area recently developed a company-owned unit train system using 100 ton (90.7 tonne) aggregate cars for hauling 3,000 tons (2,700 tonnes) of gravel per day over a one-way haul distance of 43 miles (69.2 kilometers). In this instance, no cost figures were given (41). It may be also possible to establish a unit train rate for hauling specific

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[239] Mr. T. Bernard, Southern Railway System, Marketing Division, Washington, D.C. Personal communication.

mining and metallurgical wastes, but large quantities and sustained use of the material are necessary.

From the preceding discussion, it appears at this time that it is not economical to consider the use of railroad hauling of mining and metallurgical wastes unless significantly lower rates can be negotiated or unless a unit or shuttle train service could be established.

Barge Transport

In areas of proximity to navigable waterways, barge is the least expensive form of transportation for bulk commodities. This mode of transport presents the best potential for very high tonnage movement of material at the most reasonable rates.

The inland waterway system is a network of more than 25,000 miles (40,000 kilometers) of navigable waterway, nearly half of which is comprised by the Mississippi River system. Included in this mileage are the Great Lakes and the Atlantic and Gulf Intercoastal waterways, which include approximately 3,000 miles (4,800 kilometers). All told, with planned channel improvements authorized by the Congress, there will eventually be more than 29,000 miles (46,400 kilometers) of navigable waterways throughout the United States.[240]

Coal is presently the largest commodity movement on the inland waterways system, with mining products (including aggregate) ranking second. Most of the hauling by water is done using river barges and towboats, although ore hauling in the Great Lakes is handled by larger ore boats.

The standard open-top coal barge is rated at 1,000 tons (900 tonnes), but usually carries about 900 tons (810 tonnes) of coal. Most barges being built today are called jumbo barges. These barges are rated at 1,400 tons (1,260 tonnes) and are well suited to the locks on the Ohio and Mississippi Rivers. Barges are most often moved in tows of from six to as many as thirty barges, depending on the size of the locks and the towing restrictions of the waterway.[241]

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[240] American Waterways Operators, Inc., Compiled from information supplied by the U.S. Army Corps of Engineers.
[241] 1975 Keystone Coal Industry Manual, Mining Informational Services, McGraw-Hill Mining Publications.

The ore carrying vessels servicing the Great Lakes are considerably larger than river barges, with typical carrying capacities of from 10,000 to 15,000 tons (9,000 to 13,500 tonnes). There are a number of ore vessels which have recently increased their capacity into the 25,000 to 30,000 ton (18,500 to 27,000 tonne) range and there are a few so-called super carriers with capacities between 50,000 and 60,000 tons (45,000 to 54,000 tonnes).[242]

The Arthur D. Little, Inc., report to the Reserve Mining Company estimated that taconite tailings could be shipped by ore carrier from Duluth or Silver Bay, Minnesota to lower lake ports such as Chicago, Cleveland, Detroit, and Toledo for $2.08 per ton, including loading costs. Ocean-going barges and tugs do not ordinarily service the Great Lakes; therefore, freight costs for such shipments are unknown (67).

For practical purposes, the scope of this investigation was confined to river barges because there are a large number of river transportation or barge companies in service. Comparatively small tonnages (1,000 to 1,500 tons or 900 to 1,350 tonnes minimum) can be moved by barge. Extremely high volume movements of a commodity would be needed in order to consider the use of ore carrying vessels.

As with other transport modes, the Interstate Commerce Commission grants licenses to river transportation companies to haul commodities within designated movements. Rate determinations for specific movements of specific commodities are published in tariffs, the same as with motor and rail transport.

Any commodity that cannot be counted, such as ores or aggregates, is considered as a bulk commodity. In transporting a bulk commodity for which there is no published tariff, barge companies are permitted to charge what is known as a column 1 rate or all-commodity rate. Barge companies consider all bulk commodities to be fairly similar and would charge practically the same rate for all of them. Basically, it does not make any difference what the commodity is as long as it is an aggregate. When its value changes, then the hauling rate will change.[243]

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[242]"North American Iron Ore." Engineering and Mining Journal, November, 1974. pp. 69-70.
[243]Mr. David Ruffner, District Sales Manager, Valley Line Company, Chicago, Illinois. Personal communication.

Rates for commodities such as mining or metallurgical wastes would be determined by the barge company on the basis of the nature and quantity of the commodity, the points of origin and destination, distance, whether the haul is upstream or downstream, lock and channel limitations, and any applicable local regulations. Up river hauls are usually higher in cost than down river hauls. Barge rates may also vary in different parts of the country (53).

For hauls of non-regulated bulk commodities involving interstate movements, there is no need to file the tariff with the Interstate Commerce Commission. Illinois is the only state which tariffs for hauling such commodities must be filed.

A rate was obtained from the River Transportation Division of Consolidation Coal Company for transporting coal refuse approximately 70 miles (112 kilometers) from Morgantown, West Virginia to Pittsburgh in standard coal barges at a cost of $1.00 to $1.50 per ton ($1.10 to $1.65 per tonne). Since coal refuse is heavier than coal, somewhat less refuse would be hauled per barge than the rated weight of coal. The rate quoted was for towing only, assuming that loading and unloading facilities are available. Loading and unloading costs would be additional and could range from $.50 to $1.00 per ton ($.55 to $1.10 per tonne) to load and to unload.[244]

The rate given was a down-river tow and was quoted as a variable rate because of possible weather delays and other conditions. It was felt that this rate was competitive with other barge haulers on the Monongehela River. It would not be necessary to contact the Interstate Commerce Commission in order to establish this rate.

Rates were obtained from the Valley Line Company in Chicago, Illinois for hauling steel slag on the Ohio River and the Mississippi River. The rates were all based on down-river hauls using jumbo barges with a 1,400 ton (1,260 tonne) minimum shipment.

Steel slag can be hauled from Aliquippa, Pennsylvania (northwest of Pittsburgh) to Cincinnatti, Ohio, a distance of 450 miles (724 kilometers) down the Ohio River for $2.65 per ton ($2.92 per tonne). From Aliquippa to Louisville, Kentucky, a distance of 584 miles (940 kilometers), the same material can be hauled for $3.02 per ton ($ 3.33 per tonne).

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[244]Mr. David Kreitzer, Consolidation Coal Company, River Transportation Division, Elizabeth, Pennsylvania. Personal communication.

Steel slag can be hauled from Granite City, Illinois (across the Mississippi River from St. Louis) down river to Memphis, Tennessee, a distance of 403 miles (648 kilometers) for $2.61 per ton ($2.88 per tonne). From Granite City to Vicksburg, Mississippi, a distance of 602 miles (968 kilometers), the same material can be hauled for $3.07 per ton ($ 3.38 per tonne).[245]

It has been reported that 2,500 tons (2,268 tonnes) of copper smelter slag was barged from Tacoma to Seattle, Washington (30 miles or 48 kilometers) for $.90 to $1.00 per ton ($. 99 to $1.10 per tonne), barge rent included, and that 4,000 tons (3,629 tonnes) of copper slag was also towed from Tacoma to Vancouver, British Columbia (144 miles or 231 kilometers) for $1.40 per ton ($1.54 per tonne), barge rent included. An additional cost of $.50 per ton ($.55 per tonne) for unloading was also involved in each movement.[246]

The above examples indicate that, whenever possible, the use of barge transport should be investigated as a desirable alternative in the transport of bulk commodities such as mining and metallurgical wastes.

Combination of Modes

Transporting mining or metallurgical waste over a substantial distance (100 miles or more) will probably involve more than one mode of transportation. In order to analyze such a possibliity, a hypothetical example was developed, based on an actual attempt to negotiate the movement of chat (lead-zinc tailings) from a waste dump in Picher, Oklahoma to Tulsa, Oklahoma by truck and shipment by barge from Tulsa to Vicksburg, Mississippi for ultimate use as aggregate.

The total cost of moving the chat from its origin to destination is shown in Table 50. This cost involves not only the transportation charges for truck and barge movements, but also the port handling charges for loading and unloading. The port handling charges were found to be $.30 per ton for loading at Tulsa and $.30 per ton for unloading in Vicksburg. The motor carrier rate was a negotiated commodity rate with a contract carrier. The barge rate was determined from a published tariff, based on a minimum load of 1,300 tons.

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[245]Mr. David Ruffner, District Sales Manager, Valley Line Company, Chicago, Illinois. Personal communication.

[246]Mr. Stan Bumgarner, Vice President, Black Knight, Inc., Tacoma, Washington. Correspondence dated March 30, 1976.

Table 50. Combination mode movement of chat from Picher, Oklahoma to Vicksburg, Mississippi.

1. Material Cost

Estimated cost of material is approximately $.25 per ton ($.276 per tonne).

2. Transportation Cost-Expressed in dollars per ton (dollars per tonne)

Anticipated transportation modes are:
- Picher, Oklahoma to Tulsa, Oklahoma by truck
- Tulsa, Oklahoma to Vicksburg, Mississippi by barge

Total Transportation Cost = A + B + C + D where:

A = Motor hauling cost
B = Port handling charge for loading barge
C = Barge hauling cost
D = Port handling charge for unloading barge

Item	Description	Location	Cost	Distance
A	Motor Hauling Cost	Picher, Oklahoma to Tulsa, Oklahoma	$3.00 ($3.31)	95 miles (153 kilometers)
B	Port Handling Charge	Tulsa, Oklahoma	$ .30 ($.33)	
C	Barge Hauling Cost	Tulsa, Oklahoma to Vicksburg, Miss.	$4.50 ($4.96)	485 miles (780 kilometers)
D	Port Handling Charge	Vicksburg, Mississippi	$ .30 ($.33)	

Total Transportation Cost $8.10 per ton ($ 8.93 per tonne)

The total cost per ton from origin to destination, including loading and unloading charges, was found to be $8.10 for a movement of 580 miles (933 kilometers).[247] This example illustrates the potential for shipping materials over great distances at comparatively economical rates, provided sufficient effort is expended in advance to research transportation alternatives and negotiate the most favorable rates.

[247]Mr. Sam Dryer, Transportation Consultant, Montgomery, Alabama. Personal communication.

7. CONCLUSIONS AND RECOMMENDATIONS

The information presented in this report was analyzed and used to develop conclusions and recommendations.

7.1 CONCLUSIONS

The conclusions derived from this research are presented in two forms:

1. Conclusions pertaining to the overall production and utilization of mining and metallurgical wastes.

2. Conclusions pertaining to each specific category of mining and metallurgical waste.

Regarding the overall production and utilization of mining and metallurgical wastes, we conclude the following:

1. Between 1.6 and 2 billion tons (1.44 to 1.8 Gtonnes) of mining and metallurgical wastes are produced and disposed of in this country each year. Total accumulations of identifiable mining and metallurgical wastes in the United States are on the order of 20 billion tons (18.0 Gtonnes).

2. Growing demands for metals and minerals, together with the mining of lower grade ores, will result in a steady increase in the future generation of these by-product materials.

3. The total amounts of mining and metallurgical wastes produced annually are so large that it is impossible, as well as impractical, to use all or even a large percentage of these materials. Nevertheless, usable mining and metallurgical wastes are available in sufficiently large quantities to constitute a significant source of highway construction material in certain areas.

4. The mining industry has been routinely using its own waste materials for many years to construct access roads, haul roads, impoundments, and fill areas. In most cases, such materials have performed quite satisfactorily for these purposes.

5. Many sources of mining and metallurgical wastes have demonstrated excellent past performance as a highway construction material. Other sources, although essentially untried, do offer promise for use in some form of highway construction.

6. Certain mining and metallurgical wastes possess unique and beneficial properties which merit their consideration or further use as highway construction material. These properties should be recognized and emphasized, so that appropriate personnel in the highway industry realize their value and utilize such materials in the most suitable manner.

7. Before a particular source of material can be utilized, rightful ownership of the material must be established. While this may appear to be fairly obvious, it may often be a complicated and time-consuming process because of inadequate information. Consequently, any such investigation should be initiated well in advance.

8. Many states have experienced local shortages in the available supply of high quality aggregate materials. Significant quantities of mining and metallurgical wastes exist in many of these states. These materials are often located close to such shortage areas and should be considered alternative supply sources.

9. It is presently uneconomical to transport mining and metallurgical wastes over long distances, particularly if class rates are used. It will be necessary to negotiate more favorable transportation rates in order to more fully utilize these materials. To qualify for such rates, large quantities of specific materials must be involved and definite movements proposed.

10. The volume of new highway construction in the future is uncertain. Because of changing transportation priorities, energy concerns, and inflation, future highway construction will probably involve an increasing percentage of maintenance and improvement of existing facilities.

The following conclusions have been formulated regarding specific categories of mining and metallurgical wastes:

<u>Waste Rock</u>

1. There are basic differences in the nature of rock formations and ore deposits. These differences can result in wide variations in the composition and structure of waste rock from different mining industries.

2. In many cases, waste rock from the mining of igneous rock types is useful as an aggregate source for highway construction. Certain metamorphic and sedimentary rock types are also suitable for highway construction use.

3. Waste rock from the mining of copper, fluorspar, gold, and iron ore has been successfully used in highway construction material in a number of states. Some waste rock sources are being successfully marketed as high quality construction materials.

Mill Tailings

1. A number of different mineral processing techniques are used to separate minerals from host rock. Regardless of the separation techniques employed, the resultant tailings almost always occur as very finely graded materials.

2. In most cases, the coarse or sand-sized fraction of tailings must be separated from the remaining material in order to be potentially useful as a highway construction material. The majority of tailing materials used thus far in highway construction have been the coarse fraction of tailings from the milling of copper, taconite, lead-zinc, iron ore, and molybdenum ores.

3. It is absolutely necessary to identify the chemical composition of any material proposed for highway construction use. This is particularly true of mill tailings because of their fine particle size. Potential users of mining and metallurgical wastes must also be aware of the presence of trace elements and their potential solubility.

4. Recovery of mineral value from waste rock or tailings can result in a residue of harmful leaching material. This will depend on the nature of the processing operation.

Coal Refuse

1. The utilization of coal refuse in the United States has developed at a slower rate than in Europe, particularly in Great Britain, where this material is used extensively in highway construction.

2. Because this material has demonstrated its usefulness in construction, it should now be considered as a potential resource instead of an unwanted waste.

3. Fly ash can be used advantageously with coal refuse to neutralize the acidic nature of the refuse, modify the gradation, and impart some pozzolanic properties. This will help to alleviate two waste disposal problems while producing a useable construction material.

4. Coal refuse has been successfully used as embankment material in several highway construction projects in Pennsylvania and other states. It has also been successfully used in cement stabilized base applications in Europe. The key to the successful use of this material is in proper compaction.

<u>Metallurgical Slags</u>

1. Blast furnace slag has been widely accepted and successfully used for a number of years as an all-purpose construction material. Therefore, this material should be considered as an aggregate source instead of as a by-product or waste material.

2. Steel slags, depending on their chemistry, require an aging period of at least six months prior to use. This allows for volume expansion to occur due to hydration of the free lime and magnesium in these slags. Once aged, these materials make an excellent skid-resistant and wear resistant aggregate, particularly for bituminous mixes.

3. Metallurgical slags from the smelting of heavy metal ores have been successfully used in highway construction. In particular, phosphate slag has proven to be an excellent source of aggregate. However, more information is needed concerning the solubility and possible leaching effects of copper, lead, zinc, and nickel smelter slags.

<u>Washery Rejects</u>

1. To date, no suitable uses have been developed for alumina muds or phosphate slimes. Research is continuing into beneficiation and utilization possibilities for these materials.

2. The most difficult problem with developing possible uses of phosphate slimes is dewatering of the material. There has not as yet been any method found for dewatering these materials that is economically feasible.

3. Alumina muds and phosphate slimes have both demonstrated potential in the laboratory for the production of lightweight aggregate and lightweight building products.

7.2 RECOMMENDATIONS

After analyzing and evaluating all the information concerning mining and metallurgical wastes and their possible use in highway construction, a number of recommendations were developed. These recommendations are based upon the findings of the technical evaluation. Environmental and economic factors were also considered. The recommendations resulting from this study are presented in three forms:

1. General recommendations

2. Specific recommendations for highway use

3. Specific recommendations for needed research.

General Recommendations

1. Mining and metallurgical wastes that have demonstrated acceptable performance in highway construction should be more widely used wherever possible. This is preferable to creating larger excavations for construction material while suitable alternate sources are already stockpiled and available for use.

2. There are variations that may occur in physical properties and chemical compositions between different sources of the same material. Therefore, each source of mining and metallurgical waste should be carefully evaluated on a case-by-case basis for possible use in highway construction.

3. Where possible, potential users of mining or metallurgical wastes should try to obtain these wastes before their ultimate disposal. By so doing, they may reduce the cost of the material through avoidance of all or part of the producer's disposal costs.

4. Each state in which there is mining activity should inventory the available quantities and locations of mineral wastes within its borders. The purpose of such an inventory would be to assess the feasibility of using these materials. The information contained in Volume 2 is intended to facilitate this type of investigation.

5. In conjunction with this work, states with aggregate shortages should also study the geological nature of rock deposits in various metal and nonmetal mining areas of their state. This type of study would be valuable in helping to identify waste rock sources with potential value as aggregate.

6. States experiencing aggregate shortages should review their material specifications to determine whether certain requirements are too restrictive to permit the use of otherwise acceptable nonspecification materials. During such a review, a comparison should be made between state specification requirements and similar requirements outlined by national (ASTM, AASHTO) specifying agencies.

7. Uses of mining and metallurgical wastes for highway construction should be developed at the local level, if at all possible. The advantages of use by county or municipal road personnel are the steady utilization of material, development of a performance record, and approval of material for use with minimal delay.

8. As noted in the conclusions, more favorable transportation rates must be negotiated for hauling mining and metallurgical wastes. Truck movements should be made by contract carrier if quantities and/or distances warrant it. Prospective users of waste commodities should work closely with railroad lines to obtain commodity rates or to initiate "Commodi-train" service to potential use areas. Where possible, water transportation should be investigated.

Specific Recommendations for Highway Use

1. The waste rock from the mining of copper, fluorspar, gold, and iron ore should continue to be used where it has provided satisfactory performance in the past. Other waste rock sources from these industries should be investigated, particularly waste rock from the mining of iron ore.

2. Coarse tailings from the processing of copper, iron ore, lead-zinc, molybdenum, and taconite ores should continue to be used. In particular, taconite tailings from approved sources are an excellent skid resistant aggregate and should be more widely used for this purpose.

3. More use should be made of the gold gravels located in Northern California. These materials are considered an acceptable source of construction aggregate and exist in very large quantities.

4. Coal refuse is recommended for use in a number of applications. This material has already demonstrated its capability as a structural fill and opportunities to use it in this manner should be developed wherever possible.

5. Coal refuse is also recommended to be blended with fly ash (and possibly lime and/or cement) and used in sub-base, base course, and shoulder work. Experimental sections should be arranged and constructed in several coal mining states (such as Illinois, Kentucky, Ohio, Pennsylvania, and West Virginia) to demonstrate the potential usefulness of this concept.

6. Air-cooled blast furnace slags are an excellent all-purpose construction material. This material is highly recommended for use wherever it occurs and it should be given priority in the highest type uses, such as aggregate for asphalt and concrete mixes. However, the use of ferro-manganese slags is not recommended.

7. Steel slags, once they have been adequately aged, are highly recommended as an aggregate for bituminous paving mixtures. They are particularly recommended for use in bituminous wearing surfaces, where they have exhibited superior performance as a skid-resistant aggregate.

8. Like blast furnace slag, phosphate slags are also an excellent source of aggregate and should be widely used wherever available. These slags should also be used primarily in higher type applications.

9. The use of copper smelter slag is highly recommended in areas where it occurs and is economically competitive with other materials. These slags have excellent properties and have been successfully used

as railroad ballast and highway aggregate in the past.

10. Slags from the smelting of lead, zinc, and nickel ores are recommended for use in bituminous paving mixtures on an experimental basis. These materials appear to have promise for such use and data is needed on their field performance.

11. Pisolites produced from the smelting and refining of bauxite ore at Baton Rouge, Louisiana should be used as a sub-base material on an experimental basis. This material has already demonstrated excellent bearing properties when used as structural fill for tank foundations.

12. Phosphogypsum should be more widely used as a select fill or sub-base material. It is available in large quantities and has been used successfully in the past in these applications.

Specific Recommendations for Needed Research

1. A feasibility study is needed to develop means of improving rail and/or barge hauling rates for the movement of mining and metallurgical wastes with the best potential for highway construction use. This study should have as its primary objective the negotiation of hauling rates for specific commodities that are comparable to those in effect for conventional aggregate materials.

   Mining and metallurgical wastes of immediate interest are taconite tailings, gold gravel, steel slag, phosphate slag, lead-zinc chat, coarse copper tailings, copper smelter slag, and coal refuse. A possible secondary objective of this study could be to investigate negotiated truck rates from contract carriers, although this would probably be better handled as part of a local marketing analysis.

2. Processes for the separation of coarse and fine tailings should be studied. Facilities where some form of separation is presently employed should be identified and the coarse material from each separation process evaluated for possible use as highway construction material. Of particular interest would be a comparison between wet and dry methods of separation and the coarse products resulting from these methods.

Such a study would encompass the economics of the separation process itself, the suitability of the coarse fraction for highway construction use, methods of disposal of the residue or slurry, environmental considerations involved in the separation and disposal process, and an overall economic evaluation of the separation and disposal operation.

3. Taconite tailings, steel slag, and phosphate slag have all demonstrated excellent skid resistant properties. The potential usefulness of other mining and metallurgical wastes for skid resistant applications should also be studied. Candidate materials for such an investigation would include, but not necessarily be limited to, waste rock and coarse tailings from sources noted in the conclusions, gold gravel, red dog, and slags from the smelting of copper, lead, nickel, and zinc.

   The objective of such a program would be to determine relative differences in skid resistance between mining and metallurgical wastes and representative conventional aggregate materials from selected geographical areas. This should involve the development of suitable wearing course mixtures in the laboratory and a field evaluation program to demonstrate the anti-skid characteristics of materials with the best laboratory performance.

4. A number of mining and metallurgical wastes are not presently considered for use because they contain undesirable components such as lead, zinc, or other heavy metals. The extent of solubility of these components is generally not well known. There is a need to investigate the leaching characteristics of coarse tailings and metallurgical slags from the processing and smelting of heavy metal ores.

   The primary purpose of this research would be to determine the environmental effects of using these materials in various phases of highway construction. Concentrations of heavy metals, pyrites, and other undesirable or toxic elements would be identified in the leachate from these materials. Such concentrations would be compared with applicable water quality control standards established by state and federal environmental agencies. This research would develop recommendations concerning environmentally acceptable applications for these materials.

Methods of neutralizing hazardous environmental effects (such as decomposition of pyrite) will also be evaluated.

5. Because of potential structural value, uranium tailings may have some use as a construction material. Levels of radioactivity associated with these tailings must be reduced significantly before the material can be considered acceptable. A study is recommended to determine whether radiation levels can be reduced to safe limits by economically feasible methods, including size separation. This study should also address itself to the question of what constitutes acceptable or safe limits of radiation for highway construction use in isolated areas.

   Uranium mill tailings should be monitored to determine the levels of residual radioactivity emanating from different tailings sources. Any source where radioactivity levels may be low enough to consider for construction use should be further evaluated to identify basic engineering properties.

6. Methods of improving the cohesive nature of tailings should be investigated with particular emphasis placed on stabilization techniques to prevent erosion. A considerable amount of research has been conducted by the U.S. Bureau of Mines into chemical and vegetative stabilization techniques for mill tailing deposits. This work needs to be reviewed and evaluated in terms of the erosion and dusting problems usually associated with highway construction.

   A laboratory investigation is needed of physical and/or chemical methods for increasing the cohesive strength of various tailing sources. The most effective techniques should be further evaluated in the field in terms of erosion and dust control in highway construction. Different tailing materials and climatic conditions must be considered.

The findings of this research indicate that many mining and metallurgical wastes are definitely suitable for highway construction. A number of these materials have outstanding properties and boast excellent performance records. Others exhibit high potential for highway construction use with a reasonable amount of processing.

Highway materials engineers should recognize the value of mining and metallurgical wastes as a prime source of construction material. Initially, they must be aware of the locations, amounts, and composition of these materials. Greater efforts should also be made to evaluate them and incorporate suitable materials into highway construction and maintenance programs in areas where they principally occur.

Areas most highly recommended for initial or increased utilization of mining and processing wastes are shown in Figure 45. Many of these coincide with areas where supplies of conventional aggregates are scarce, as shown in Figure 42. Of particular significance are coal refuse in West Virginia, Kentucky, and Illinois; feldspar tailings in North Carolina; fluorspar waste rock in Illinois; gold gravels in California; iron ore waste rock in Missouri and Pennsylvania; lead chat in Missouri; lead-zinc tailings in Wisconsin; molybdenum tailings in New Mexico; and taconite tailings in Minnesota.

Areas most highly recommended for utilization of metallurgical wastes are shown in Figure 46. Many of these also coincide with areas where shortages of conventional aggregates have been noted. Steel slags and phosphate slags because of their outstanding properties, are most highly recommended for use wherever they are available. Others of particular significance include copper smelter slag in Arizona, Michigan, and Montana; lead smelter slag in Idaho, Missouri, and Montana; and zinc smelter residue in Pennsylvania.

These and other suitable mining and metallurgical wastes should be considered acceptable engineering materials and not unwanted by-products. Because of the large quantities involved, they represent in many cases an ample supply of readily available resources for economical highway construction use. All that is needed is to recognize their value and be willing to devote sufficient efforts to implementing their use.

Figure 45. Potential use areas for mining wastes.

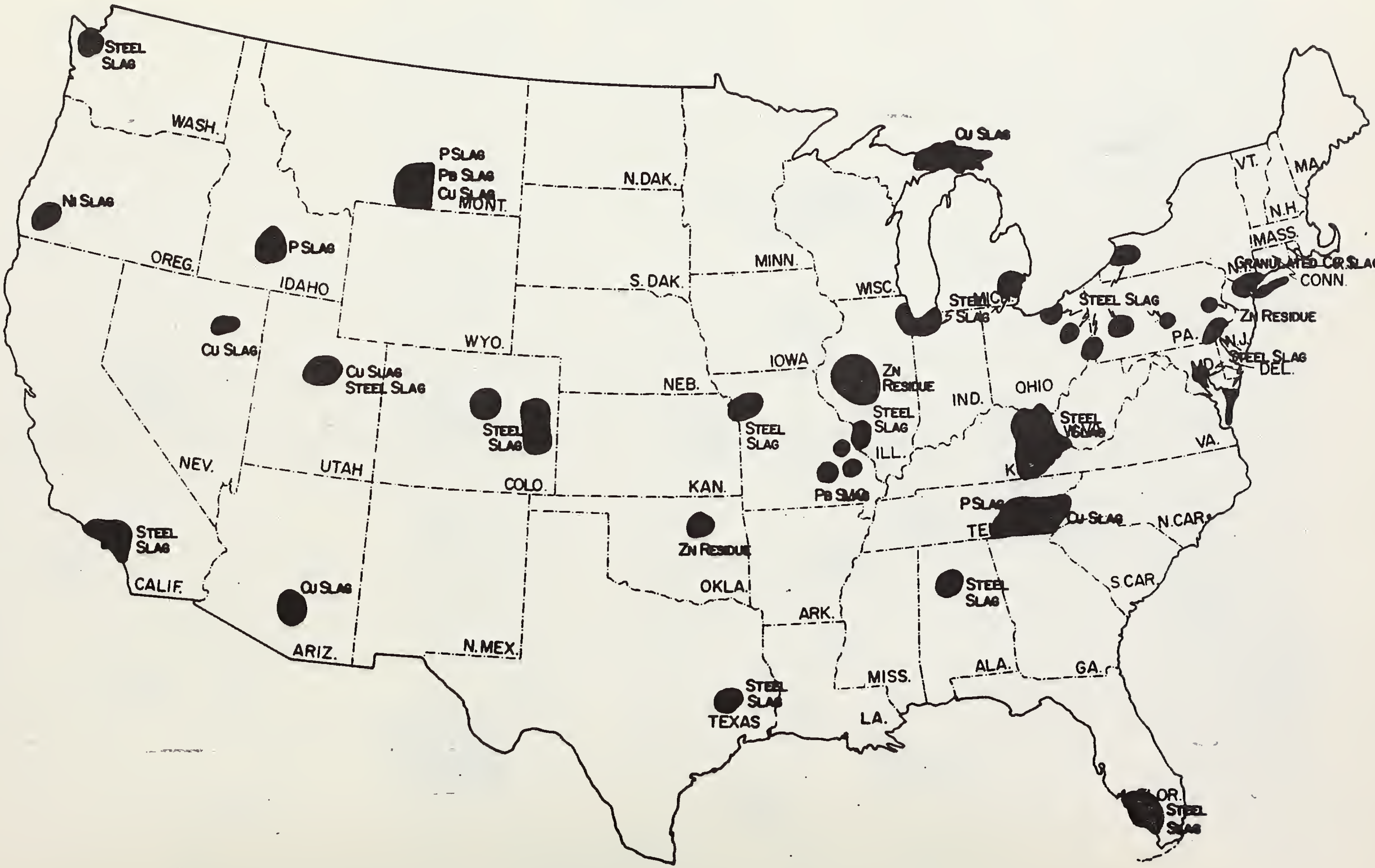

Figure 46. Potential use areas for metallurgical wastes.

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