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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in the mining industry, governmental agencies, trade associations, and universities were contacted to obtain additional unpublished information.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 generated 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.

Cover Photo: Coal mine refuse pile near Frostburg, Maryland
(Photo courtesy of Mr. Robert Grieser, 40 Madison Place,
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PROLOGUE

The purpose of this document is to summarize and present the highlights of a three volume research report published by the U. S. Department of Transportation, Federal Highway Administration, dealing with the availablility of mining and metallurgical wastes and their potential for use as highway construction materials.

The three volumes, together with their respective FHWA research and development report numbers, are described as follows:

"Volume I - Classification and Technical and Environmental Analysis," FHWA-RD-76-106, reports on the availability of mining and metallurgical wastes in the United States and the potential use of such wastes in highway construction.

"Volume II - Location of Mining and Metallurgical Wastes and Mining Industry Trends," FHWA-RD-76-107, contains maps and tabulations, which depict the location and types of mineral wastes obtainable from the 35 principal mining states. Information relevant to mine and ore-processing plant expansions and the opening of new mines and plants in the near future is also furnished for these mining states.

"Volume III - Annotated Bibliography," FHWA-RD-76-108, contains 80 of the most pertinent references on mineral waste utilization. They were chosen by a critical review of domestic and foreign literature with particular emphasis given to those presenting findings of research concerned with engineering properties and field performance of specific waste materials.

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.

OBJECTIVES

The objectives of this study 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.

RESEARCH APPROACH

The work performed in this research was conducted in four distinct tasks:

TASK A - REVIEW OF PUBLISHED LITERATURE PERTAINING TO MINING AND METALLURGICAL WASTES

A thorough review was made of available domestic and foreign literature dealing with mining, mineral processing, metallurgy, ceramics, aggregate production, highway construction, and highway research. This review focused on obtaining the following information:

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.

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

A considerable amount of very useful information was obtained during the study by contacts with knowledgeable individuals in mining and steel companies, State highway departments, universities, trade associations, and governmental officials in environmental, geological, or mining departments. State liaison officers from the U. S. Bureau of Mines in principal mining states were also particularly helpful. A number of contacts with industry were followed up by site visits to typical mining or mineral processing operations. Representative samples of mining and metallurgical wastes were also obtained from 85 different sources.

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

Based on information obtained in the first two tasks, a complete inventory and classification system was developed and presented. This system includes an estimate of annually produced and accumulated quantities of various categories of solid wastes from different types of mining and mineral processing operations. A more detailed presentation of specific locations of known mining and metallurgical waste deposits in 35 principal mining states was also developed and is presented in Volume II of the main report.

The technical, economic, and environmental considerations related to utilization of these materials in highway construction were also evaluated. Physical inspection of material samples was combined with information available from the literature and the experiences of others familiar with the characteristics and past performance records of specific waste materials.

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

Based on the work performed in the three preceding tasks, a number of general and specific recommendations were developed concerning further use of mining and metallurgical wastes in highway construction. Additional recommendations were also made for possible future research into particular aspects of these materials.

CLASSIFICATION, INVENTORY, AND DESCRIPTION OF MINING AND METALLURGICAL WASTES

CLASSIFICATION OF MINING AND METALLURGICAL WASTES

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 non-metallic 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 contain significant amounts of water.

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.

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.

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 U. S. 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.

DESCRIPTION OF MINING AND METALLURGICAL WASTES

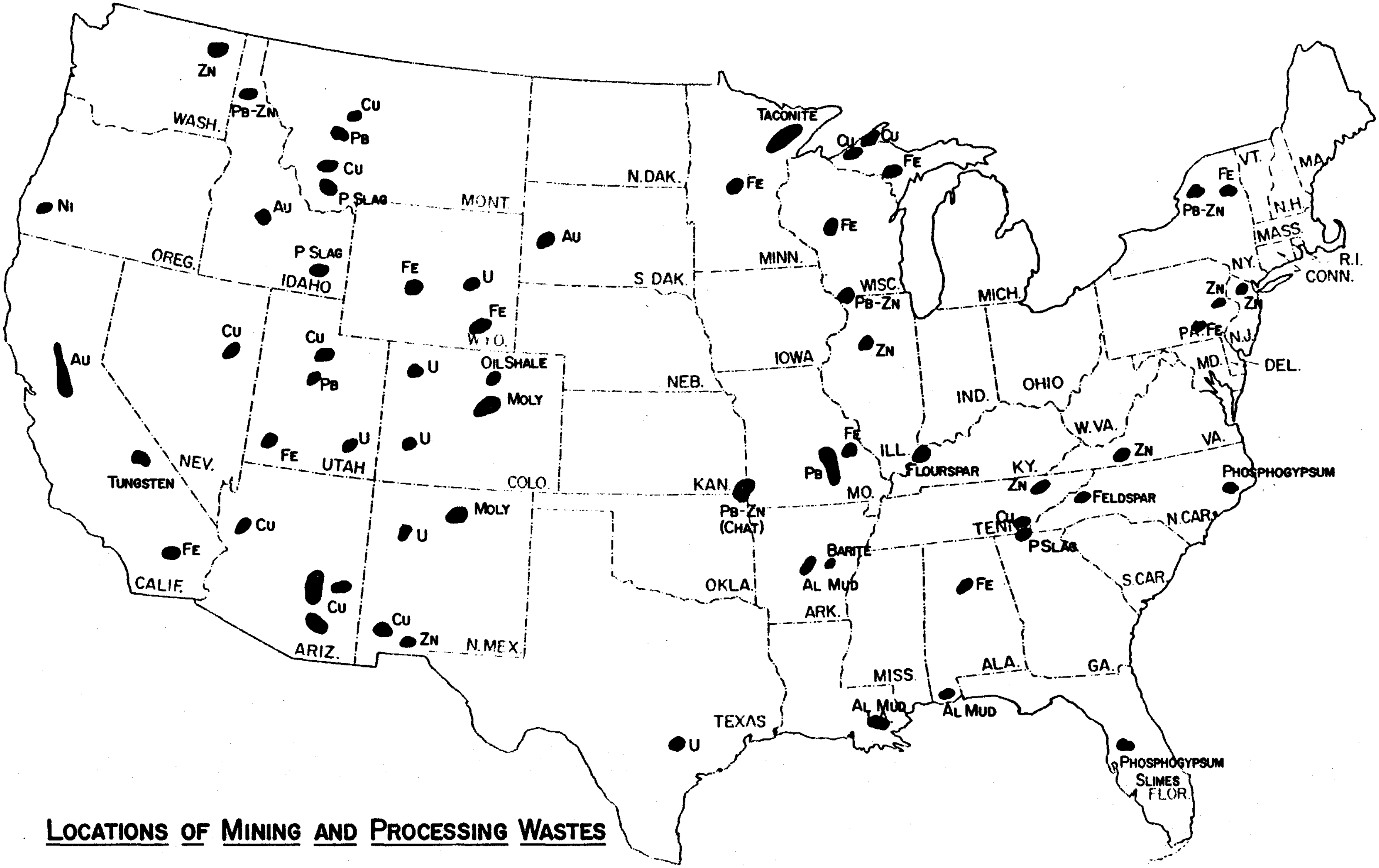
Waste Rock

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.

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. Often, especially in open pit mining, the overburden material, consisting of mixed soil and rock, is excavated and disposed in a mine waste dump, where it is difficult to separate and determine precise amounts of waste rock.

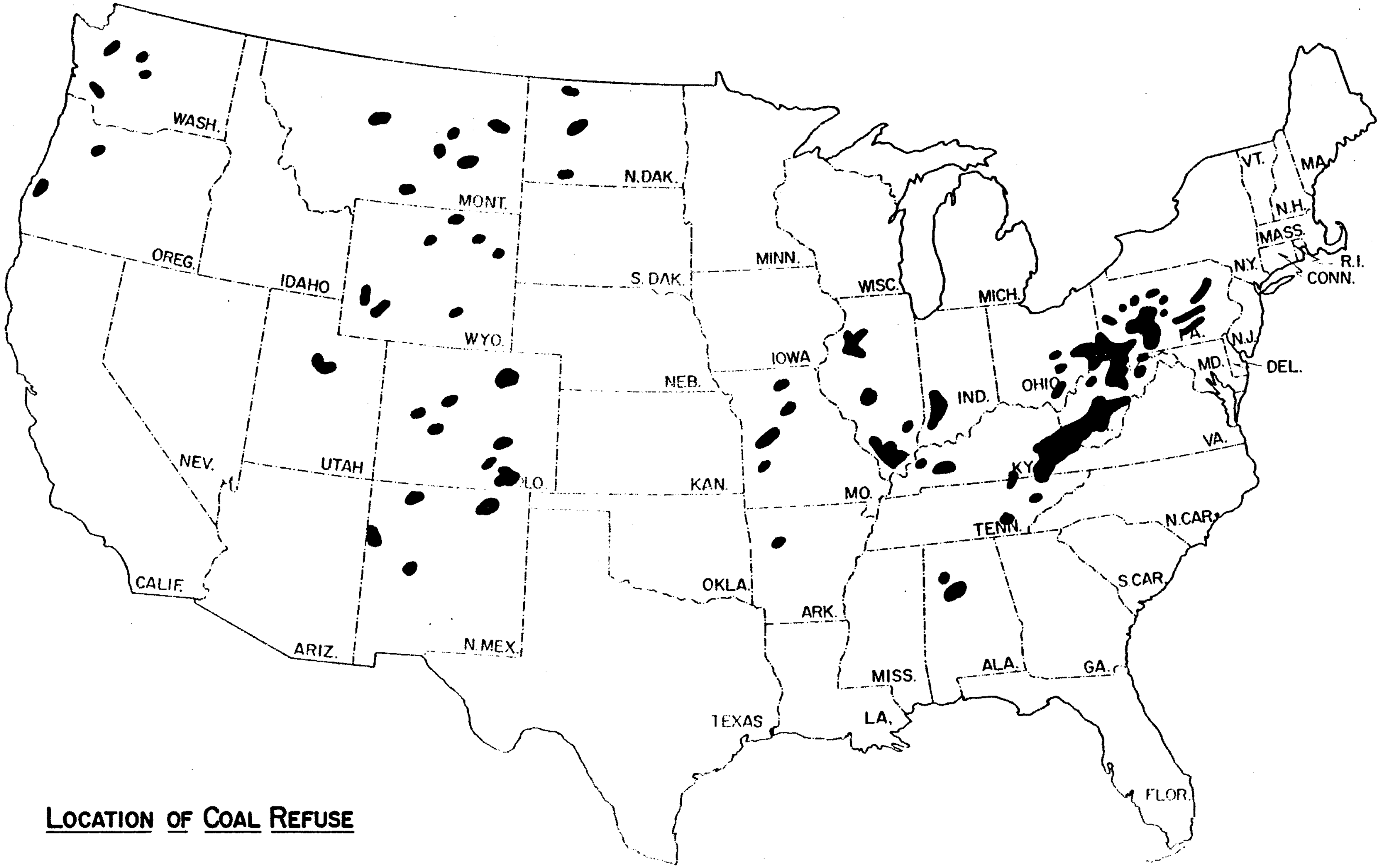
The value of a particular source of waste as a construction material is

FIGURE 1



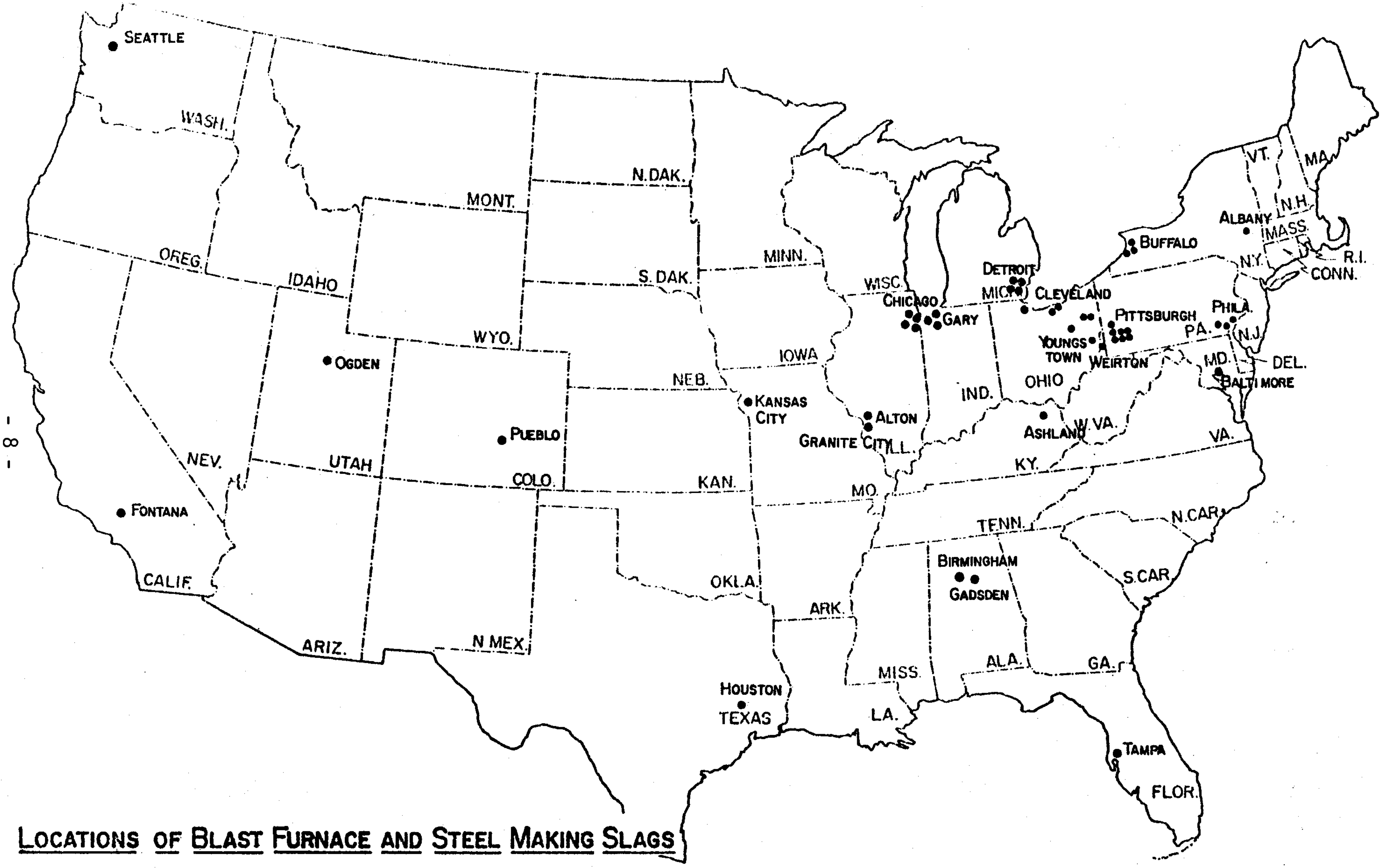
LOCATIONS OF MINING AND PROCESSING WASTES

FIGURE 2



LOCATION OF COAL REFUSE

FIGURE 3



LOCATIONS 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.*

NOTE: 1 short ton = 0.9072 metric tons.

TABLE 2. Mining and matallurgical wastes produced annually, in thousand tons.

Mining Industry	Waste Rock[1]	Mill Tailing	Smelter Slag	Washery Reject	Estimated Total Waste Accumulation
METALS & NON-METALS					
Alumina	9,200	100	--	6,000	50,000
Asbestos	700	2,000	--	--	15,000
Barite	2,100	3,400	--	--	25,000
Copper	688,000	260,000	4,000	--	8,500,000
Feldspar	200	900	--	--	Uncertain
Fluorspar	100	400	--	--	Uncertain
Gold	16,000	6,000	--	--	500,000
Gypsum	15,700	250	--	--	Uncertain
Iron Ore	30,000	30,000	--	--	800,000
Lead	600	9,000	500	--	200,000
Nickel	--	--	750	--	15,000
Phosphate	254,000	--	4,000	60,000[2]	1,000,000[3]
Silver	200	650	--	--	Uncertain
Slate	100	80	--	--	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 & STEEL SLAG					
Blast Furnace	--	--	30,000	--	Uncertain
Steel Furnace	--	--	12,000	--	Uncertain
		Coarse Refuse		Slurry	
COAL					
Anthracite	--	500	--	200	1,000,000
Bituminous	--	75,000	--	25,000	2,500,000

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[1] Includes waste rock and overburden 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.*

NOTE: 1 short ton = 0.9072 metric tons.

related to the type and geological source of the parent rock formation, its hardness, mineralogical composition, and extent of impurities (if any). The manner in which ore deposits have developed in specific rock formations may alter the rock and severely affect its value as an aggregate.

Waste rock from numerous types of metal mining activities may still contain relatively low percentages of ore which can be separated from the waste rock by various techniques. This is particularly true in the copper, iron, and uranium industries, where varying quantities of waste rock are considered as potential resources because of their low-grade metal content.

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 ores(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.

In general, the extensive amount of grinding required to liberate the desired ore from the host rock results in tailings by-products which are extremely fine-grained. Since the number of ore sources, rock types, and mineral processing techniques can vary so greatly, it is difficult to generalize regarding the characteristics of mill tailings. However, the great majority of tailings are composed of hard, angular siliceous particles with a high percentage of fines (40 to 90 percent passing a 200 mesh or .074 mm sieve).

It is possible, through the use of size separation or classification devices, to selectively remove the coarser fraction of certain tailings. This has been successfully accomplished with copper and taconite tailings, in which the resultant coarser fraction is recovered as a well graded fine to medium sand.

Because of the presence of co-products in many ore formations, it is possible that certain tailings may contain a recoverable amount of one or more other metals. Therefore, it is advisable to be fully aware of the chemical composition of any tailing source being considered for construction use.

Coal Refuse

Coal refuse is a variable material produced at the preparation plant as the discard from the processing and cleaning of coal. The amount of refuse produced at a specific preparation plant depends on the yield or quality of the coal being prepared and the separation techniques employed. Normally, the average amount of refuse produced is from twenty-five to thirty percent of the coal being cleaned.

Coal refuse consists of varying amounts of slate, shale, sandstone, siltstone, or clay-type minerals which occur within or adjacent to the coal seam, as well as some coal which was not separated during preparation. It is well known that coal refuse contains a certain amount of sulfur-bearing minerals, notably pyrite and marcasite, which result in acidic discharge when exposed to water.

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 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 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.

Coarse coal refuse, as well as "red dog," is well graded material with nearly all particles less than 4 inches (101.6 mm) maximum size. The material exhibits some particle degradation under compaction, but once it has been well compacted, it can be a useful engineering material. Although fine refuse is more uniformly graded, it is normally found in the field as a slurry and, in its unstable condition, provides little or no strength-carrying capability.

Metallurgical Slags

Although metallurgical slags have different origins, they are all related insofar as they are derived from elevated heat treatment of ores and are formed under similar cooling and processing conditions. Three basic slag types were evaluated: blast furnace slag, steel slag, and heavy metal slags.

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." 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.

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.

Among the desirable physical properties of air-cooled blast furnace slag are its hardness, angular and interlocking particle shape, vesicular pore structure, high durability, wear resistance, and lighter than normal unit weight.

Steel Slag

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 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.

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.

There is considerable variability in the composition of steel slag. This is because of differences in chemistry between the slag products from steel furnaces of different types. Another major variable is the operational philosophy of the furance superintendent.

Steel slags possess a number of the same desirable physical properties of blast furnace slag. The material is resistent to abrasion and wear, also has an angular particle shape, and a vesicular pore structure. Moreover, it is denser and harder than blast furnace slag. Steel slag practically always occurs in the air-cooled state.

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

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.

Heavy Metal Slags

Slags produced from the smelting of copper, lead, nickel, phosphate, and zinc ores can be found as air-cooled or granulated materials. Generally, slag by-products resulting from the smelting of a particular category of metal ore are comparatively similar in their chemical composition. There is, however, a variation between slags from different types of heavy metal ores.

Although the chemical composition of these slags varies, the copper, lead, and zinc slags can be characterized as ferrous silicates, while slag by-products from phosphate and nickel furnaces are calcium or magnesium silicates. In general, these slags are dense, well-graded granular materials, usually black or dark gray in color, which are also high in hardness and wear resistance. Air-cooled heavy metal slags can be crushed and sized to meet desired gradation requirements the same as blast furnace and steel slags.

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 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 particles being less than one micron in diameter. 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.

These slimes have been found to contain a number of minerals, including mainly carbon fluorapatite, montmorillonite, and quartz, with lesser amounts of kaolinite, attapulgite, and feldspar. The slimes are essentially clay-like with some phosphate mineral value. The greatest deterrent to possible utilization of phosphate slimes is the problem of reducing the moisture content of these materials.

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.

There are two basic types of alumina extraction processes and, therefore, two basic types of mud by-products. The Bayer process is used to refine Jamaican or Surinam bauxite ores and results in generation of a red mud product. The combination process consists of the Bayer process, followed by sintering and leaching of red mud from high silica domestic bauxite ore to obtain higher alumina recovery. This process produces a brown mud waste.

The particle size distribution of these muds is in the clay range, with nearly all particles finer than 200 mesh. Although chemical compositions vary, they are essentially clay-like and are complex compounds of soda, silica, alumina, and water. Although alumina muds do settle over time to approximately fifty percent solids, high annual rainfall in the southern regions of the country where the materials are stockpiled retard this settlement. Eventually, the surface or drying pond dries to a moderately hard consistency, with numerous shrinkage cracks and a dust coated surface.

UTILIZATION EXAMPLES AND RESEARCH EFFORTS RELATED TO MINING AND METALLURGICAL WASTES

UTILIZATION EXAMPLES

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 - Related research directed toward developing additional uses.

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.

Although numerous examples of mining and metallurgical waste utilization in highway construction can be cited, this report will note only those applications which are considered to be most outstanding. There are, however, many other instances in which similar waste materials have been successfully used in highway projects, either on a smaller scale or only within close proximity to the source of the material. When considering possible highway use of these materials, it must be kept in mind that mining and metallurgical wastes have also been successfully used in a number of non-highway applications.

Waste Rock

Approximately 100,000 tons (90,000 tonnes) of waste rock and heavy media tailings from fluorspar mining in Illinois are used as coarse aggregate in the southeastern part of the state.[1]

A considerable amount of material from "poor rock" piles located in the copper mining district of Houghton and Keweenaw Counties in the Upper Peninsula of Michigan have been used in various stages of construction. This rock, mainly trap and conglomerate, has performed well as base and subbase material, depending upon particle size.[2]

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.[3]

Waste rock from abandoned lead mining operations in St. Francois County has 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.[4]

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.[5]

Mill Tailings

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 as commercial aggregate by two producers in a ten-square mile (25.8 square kilometer) area east of Marysville and north of Sacramento 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.[6]

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 tailings have also been used as aggregate for concrete structures built during the construction of Interstate Route 10 and as concrete aggregate for industrial construction project.[7]

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.[8]

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.[9]

The primary use of taconite tailings is for thin surface overlays of one inch (25.4 mm) or less in thickness. The serviceability 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 in the state of Minnesota because of their skid resistance qualities.[10]

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.[11]

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.[12]

Coal Refuse

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. A distinction will be made between coal refuse and "red dog," which is the product of burning of a coal refuse bank.

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 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.[13]

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.[14]

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.[16]

In West Virginia, "red dog" is used as a subbase 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 ten percent by weight of portland cement with "red dog" can form an excellent construction material.[17]

Several years ago, the Environmental Protection Agency arranged for a demonstration of coal refuse as a 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: untreated coal refuse, coal refuse treated with twenty-five percent fly ash, and fly ash treated coal refuse mixed with five percent hydrated lime. A drainage collection system was installed to monitor the quality and chemical composition of leachate from each base course mixture. Leachate from fly ash treated mixtures was neutral with much lower concentrations of heavy metals than the untreated coal refuse mixture. It has been concluded that the addition of fly ash (with or without lime) tends to neutralize acidity and reduce heavy metal concentrations from pyritic discharge of coal refuse.[18]

Metallurgical Slags

Air-cooled blast furnace slag has been accepted and is known to be specified as highway construction material in at least twenty states. The utilization of blast furance slag has become so widespread in areas where it is produced that the material actually belongs in the category of an approved construction aggregate.

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

The number of specific applications of steel slag in highway construction are somewhat limited. In California, about 250,000 tons (225,000 tonnes) of open hearth slag in the vicinity of Fontana are processed annually for use in embankments, subbase, aggregate base, and asphaltic concrete.[19] Steel slag from the Pueblo works has been used in Colorado to make concrete that is highly resistant to abrasion.[20]

The use of open hearth and basic oxygen furnace slags for highway construction in Michigan have thus far consisted of base course applications on an experimental basis. In Missouri, experimental work on steel slag use in bituminous wearing surfaces in the St. Louis area has indicated that steel slag is quite resistant to wear and exhibits very good skid resistance compared to pavements using locally available aggregate.[21]

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.[22]

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.[23]

There are also a number of examples of the successful use of slags from the smelting or roasting of heavy metal ores such as copper, lead, zinc, phosphate, and nickel.

Since 1955, Monroc, Inc., Utah Sand and Gravel Division, has, under lease with Kennecott Copper Corporation, reclaimed, processed, 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 select material for use in bituminous wearing surfaces and as aggregate in seal coatings.[24]

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 suitability 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.[25]

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.[26]

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.[27] 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.[28]

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.[29] Slag residues from the zinc smelter located in Monaca, Beaver County, have been used in a variety of applications, including anti-skid materials, aggregate for the paving of parking lots and driveways, base material for asphalt surfacing, and bedding for pipelines.[30] Aside from anti-skid use, there is probably no other application of this material on state highways in western Pennsylvania.

In southeast Idaho, phosphate slags from the Pocatello and Soda Springs areas are used in various phases of highway construction, including borrow material, 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.[31]

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.[32]

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.[33]

RECENT RESEARCH EFFORTS

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.

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.[34]

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.[35]

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.[36]

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 emulsufied 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.[37]

Coal Refuse

Researchers at Penn State University have 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 subbase. This study concluded that anthracite coal refuse should be used in shoulders and embankments.[38]

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.[39]

Metallurgical Slags

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.[40, 41]

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.[42]

Washery Rejects

Battelle Columbus Laboratories recently completed a study for the Environmental Protection Agency entirled "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.[43]

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 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.[44]

TECHNICAL, ENVIRONMENTAL, AND ECONOMIC ANALYSIS

TECHNICAL EVALUATION

This phase of the evaluation involved a study of the physical properties, chemical composition, and previous uses of specific mining and metallurgical wastes in order to determine whether:

1 - Certain of these materials could be used in highway construction with little or no processing.

2 - Further research is needed on particular aspects of some materials to fully assess their potential.

Visual inspection of waste material samples obtained during the study were also of great value in the technical evaluation.

Each material was evaluated for potential use in highway fill, base or subbase, bituminous paving mixtures, and portland cement concrete. Among the indicators most influential in recommending a particular material for highway construction use are current highway acceptance, favorable service record, notable physical properties, principal use in highway construction, other related uses, and minimal processing required prior to use.

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.

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 successfully 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 non-plastic 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."[45]

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 detrimental factors can be divided into two categories:

1 - Problems that can be solved by special processing or construction techniques.

2 - Problems that are practically insolvable for some types of highway applications.

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). The fineness of some tailings has been cited as a reason for these materials being unsatisfactory for use in highway construction. In many cases, the removal of a portion of the fines can result in a fine aggregate material with an acceptable gradation. Methods of separating coarse and fine tailings are available and have been successfully used.

Another common disadvantage of most tailing materials is their lack of cohesion, even in the very fine fractions. The lack of cohesion or cementitious bond between particles indicates a high potential for slope erosion. However, such problems are not new to the highway construction industry and can be solved by strictly observing established erosion control procedures and protecting final slopes with an adequate cover of topsoil.

Because of their fineness, most tailings have a tendency toward dusting. Control of dusting from tailings is not substantially different from that experienced in the handling and use of other fine-grained materials and can be solved by proper moisture control during construction.

Coal Refuse

In the past, the principal objections to the use of coarse coal refuse in highway construction have been its carbonaceous content and tendency toward ignition by spontaneous combustion, and its pyritic composition and 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 subbase material. The "cleaning" or removal of coal from the refuse will further improve the problem. A cover of several feet of natural soil is also recommended over the slopes of coal refuse embankments. The acidic nature of coal refuse can be effectively neutralized by the addition of fly ash.

Steel Slag

Many engineers are hesitant to use steel slag in any highway application because of its expansive properties. Hydration of free calcium and magnesium oxides in the steel slag are responsible for the objectionable volume expansion. It is now well recognized that the problem of expansion can be controlled by properly aging the steel slag for a time period of six months under prescribed moisture conditions.

PROBLEMS THAT ARE PRACTICALLY INSOLVABLE FOR SOME TYPES OF HIGHWAY APPLICATIONS

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 paving mixtures, though in many cases the materials are able to satisfy gradation requirements. As an example, the use of classified copper mill tailings as mineral filler in Utah has resulted in premature age hardening of the asphalt in bitumimous mixtures.[46]

Coal Refuse

Oxidation of the pyrite and marcasite in coal refuse is detrimental to its use in portland cement concrete. These materials are deleterious and produce an acid discharge upon contact with water. Furthermore, strength development of concrete mixtures using coal refuse is comparatively poor.

The inherently low strength of individual refuse particles, the clay content normally found in these materials, and the tendency toward weathering are factors which preclude the practical use of coal refuse in bituminous mixtures.

Steel Slag

The expansive nature of steel slag is a negative factor to consider for use of the material in confined applications where exposure to water is likely, such as base courses. Although well-aged steel slag could be used in a base course, some additional expansion may still 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 possibility 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.

ENVIRONMENTAL EVALUATION

A general evaluation was made of adverse environmental effects from disposal of mining and metallurgical wastes. A more detailed evaluation was also made of the possible environmental effects of using the specific wastes most highly recommended from the technical evaluation.

The general evaluation focused on the following factors:

1 - Health and safety.

2 - Air and/or water pollution.

3 - Aesthetic blight.

4 - Proximity to populated areas.

5 - Public nuisance.

Those wastes having the most adverse effect on the environment are coarse and fine coal refuse, phosphate slimes, uranium mill tailings, alumina muds, and slags from the smelting of lead and zinc ores. Environmental problems of greatest concern are acidic drainage from coal refuse and sulfide-based tailings, leaching of heavy metal content from tailings, discharge of asbestos particles into the air, and radiation hazards from uranium mill tailings.

Of the mining and metallurgical wastes recommended from the technical evaluation, only the waste rock from heavy metal sulfide ores presents much potential for environmental problems in the form of leaching, particularly when used in base course construction.

The following guidelines are offered in order to identify and avoid serious environmental problems that could occur from using mining and metallurgical wastes in highway construction:

1 - The material should give a pH between 6 and 8.

2 - Materials containing sulfides or heavy metals should be approached with caution.

3 - Materials that are predominantly silicates, if not finely divided, can generally be considered acceptable for any use.

4 - Dusting and air pollution from use of most mining and metallurgical wastes should be minimized.

ECONOMIC EVALUATION

Regardless of favorable technical and environmental factors, the ultimate determinant of whether or not a particular waste material will be utilized in a highway construction project will depend on economic factors. The cost factors involved in an analysis of mineral waste usage are the selling price, processing costs, and transportation costs.

The selling price of a particular waste material depends on a number of factors, including the value of the materials, the cost of competitive materials, the market demand, and the cost of disposing or stockpiling of the waste material. A survey of the probable selling prices of numerous mining and metallurgical wastes has indicated that the FOB prices for such materials ranges from $.35 to $6.00 per ton ($.386 to $6.61 per tonne). For the most part, these materials can be made available to a potential user at a cost of $2.00 to $3.00 per ton ($2.20 to $3.31 per tonne).

In addition to the selling price, the cost of retrieving, processing, and transportation must also be considered. In the case of fine grained wastes, dewatering may sometimes be necessary. If a waste material could be recovered prior to disposal, it is possible that it could be obtained at a relatively low cost. For most by-products, processing will probably involve some form of size control, which should not exceed $1.00 per ton ($1.10 per tonne).

Transportation costs are generally the single factor most responsible for limiting the use of mining and metallurgical wastes. The cost of shipping these by-products is often substantially higher than comparable shipping costs for conventional materials, even though most of these wastes can be classified according to normal bulk commodities such as slag or chat. Regardless of the mode used, it will be necessary to negotiate a favorable rate for transporting a by-product. The transportation rate will depend on the type of material, its intended use, the origin and destination of the movement, the quantities involved, and the type of equipment required for transportation.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Regarding the overall production and utilization of mining and metallurgical wastes, the following conclusions are made:

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 - 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.

The following conclusions have been formulated concerning specific categories of mining and metallurgical wastes:

Waste Rock

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. In general, waste rock from igneous formations have been found to be most suitable for highway construction.

2 - 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.

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 - 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.

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 - Because this material has demonstrated its usefulness in construction, it should now be considered as a potential resource instead of an unwanted waste.

Metallurgical Slags

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.

Washery Rejects

1 - To date, no suitable uses have been developed for alumina muds or phosphate slimes. However, lightweight aggregate has been produced from each of these by-products in the laboratory. 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.

RECOMMENDATIONS

The following general recommendations are made as a result of this research:

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 - 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.

With respect to the highway use of specific sources of mining and metallurgical wastes, the following recommendations are made:

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 also recommended to be blended with fly ash (and possibly lime and/or cement) and used in subbase, base course, and shoulder work. 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 - 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.

6 - 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.

7 - 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.

8 - 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.

9 - 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.

10 - Phosphogypsum should be more widely used as a select fill or subbase material. It is available in large quantities and has been used successfully in these applications.

Several recommendations for further research are also offered, including the following:

1 - 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.

2 - 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.

3 - 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.

4 - 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.

SUMMARY

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.

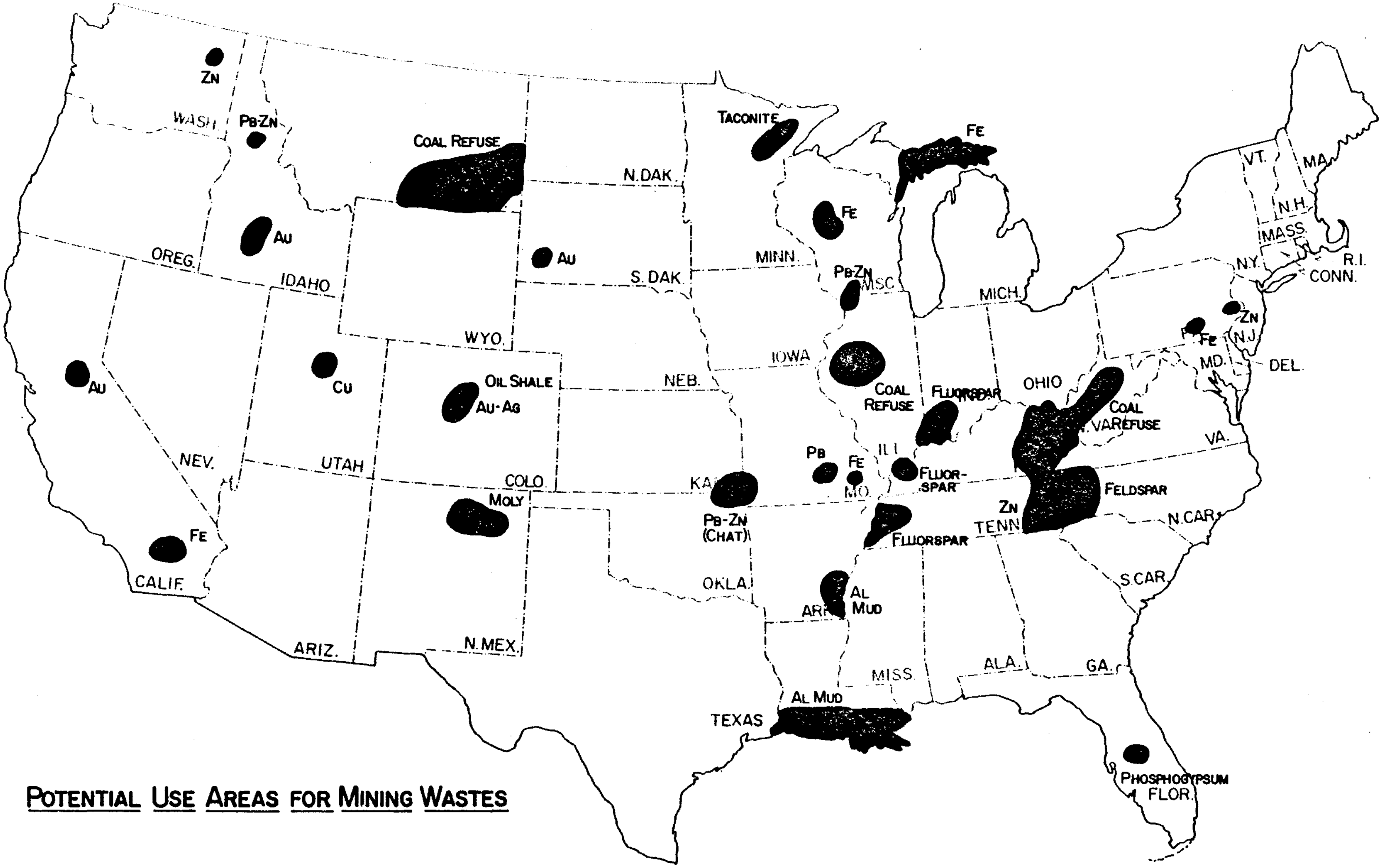
Highway materials engineers should recognize the value of mining and metallurgical wastes as a prime source of construction material. Initially, they must be aware of the locations, amounts, and composition of these materials. Greater efforts should also be made to evaluate them and incorporate suitable 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 mineral processing wastes are shown in Figure 5. Areas most highly recommended for utilization of metallurgical wastes are shown in Figure 6. In most of these areas, plentiful supplies of mining and/or metallurgical wastes can be found, while suitable conventional sources of aggregates or borrow materials are not often available.

The most significant mining waste materials recommended for highway construction use are coal refuse in the Appalachian region; taconite tailings in Minnesota; iron ore waste rock in Pennsylvania and Missouri; gold gravels in California; lead-zinc tailings in Wisconsin; copper tailings in southwestern states; and molybdenum tailings in New Mexico. Metallurgical wastes of greatest significance, aside from air-cooled blast furnace slags, are steel slags which have been sufficiently aged; phosphate slags in Idaho, Montana, and Tennessee; copper smelter slags in Arizona, Michigan, and Montana; lead smelter slags in Idaho, Missouri, and Montana on an experimental basis; and zinc smelter residues in Pennsylvania, also on an experimental basis.

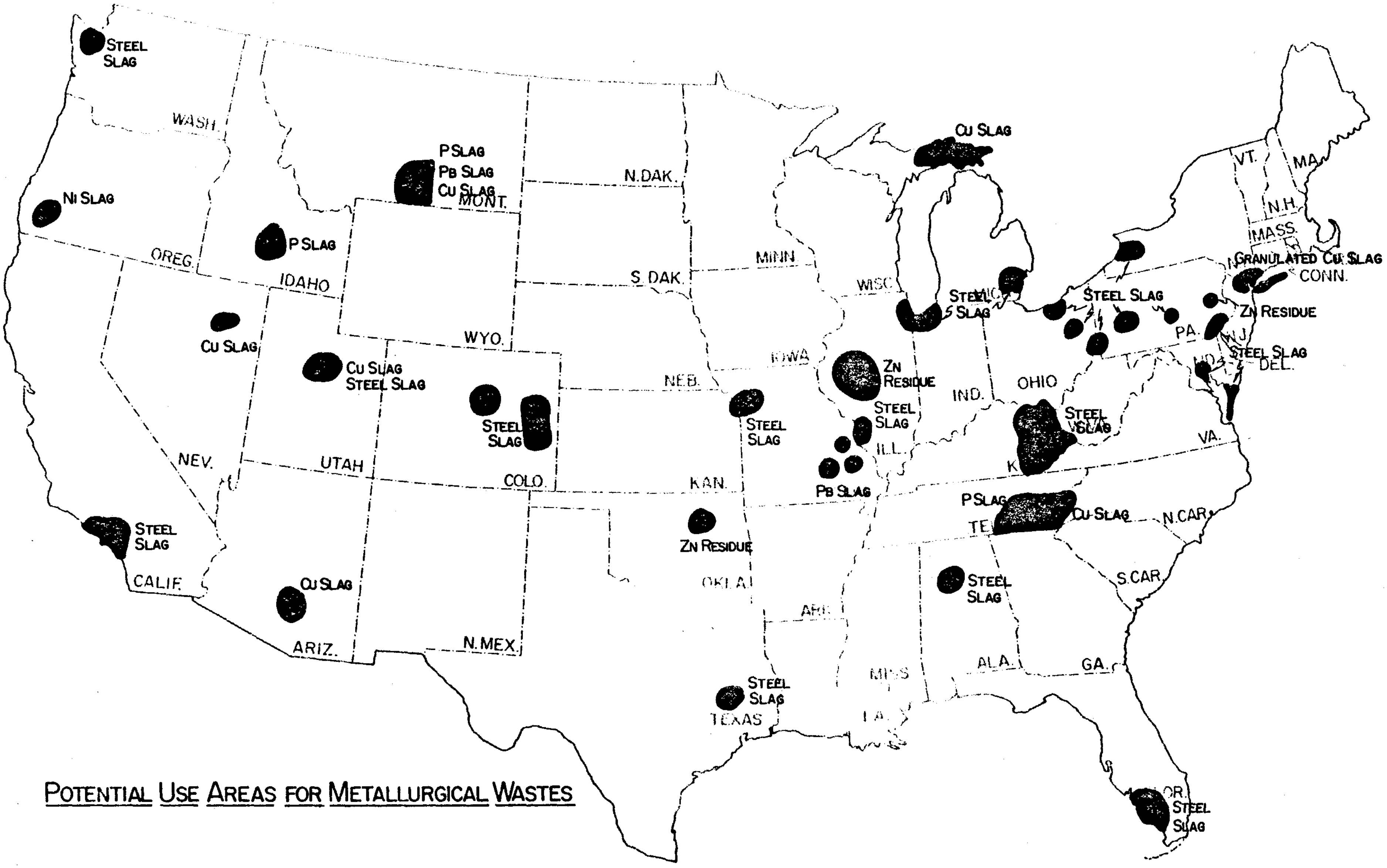
These and other suitable mining and metallurgical wastes should be considered acceptable engineering materials and not unwanted by-products. Because of the large quantities involved, they represent in many cases an ample supply of readily available resources for economical highway construction use. All that is needed is to recognize their value and be willing to devote sufficient efforts to implementing their use.

FIGURE 5



POTENTIAL USE AREAS FOR MINING WASTES

FIGURE 6



<u>POTENTIAL USE AREAS FOR METALLURGICAL WASTES</u>

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