Huge quantities of solid wastes are generated as a result of mining and mineral processing activities in the United States. Over the years, the majority of these by-products have been disposed of in unsightly dumping areas which are aesthetically unattractive and often degrading to the environment. However, many of these wastes, because of their similarity to conventional soils and aggregates, represent potentially useful sources of material for a variety of applications.

This paper describes the principal classifications of solid wastes from mining and mineral processing. The outstanding physical and chemical properties of each type of waste material are included in these descriptions. The paper also discusses the principal locations and approximate quantities of each category of mining and mineral processing waste. Examples are given of ways in which each type of waste has been utilized in different areas of the United States. Pertinent technical, economic, and environmental considerations involved in specific uses are included in these discussions. Significant research needs and efforts involving particular waste materials are also documented.

INTRODUCTION

The annual generation of solid wastes in the United States is now approximately 4 billion tonnes and is increasing at a rate of between 3 to 5 per cent per year. Of this total, nearly 2 billion tonnes is generated by mining and related mineral processing activities.

In addition to the large quantities of mineral waste currently being produced, the production of earlier years has resulted in huge accumulations located in many areas throughout the United States.

At present, only very small percentages of mineral wastes are being utilized in the United States. However, local scarcities of conventional materials, together with a growing awareness of the need to protect the environment and conserve resources, has created an awareness of the need to consider alternative material and energy sources. Consequently, attention has been focused in recent years on making use of available supplies of mineral wastes in ways that are or may become economically feasible.

This paper describes the principal types of mineral waste being produced in the United States, their location and amount, and current and potential applications for utilization of these materials. Factors to be considered in a decision to make use of a particular type of mineral waste are also discussed.

CLASSIFICATION OF MINERAL WASTES

Although a wide variety of waste products results from the many mining and mineral processing activities, the most significant types of mineral wastes are:

1. Waste rock is the coarse graded material that is broken and removed during metal and non-metal mining operations in order to expose the ore. Often, waste rock is removed together with overburden and disposed of in waste dumps. Waste rock is usually fairly homogeneous at each mining operation, but can be quite different from one mine to the other, even when the same type of ore is mined. Although the size of the waste rock is also variable, most individual pieces of rock are probably 305 mm or less in size.

2. Mill tailings are finely sized particles that are discarded following the concentration and recovery of mineral values from metallic and non-metallic ores. Most tailings are characterized by a predominance of very fine sized particles, although the sizing is directly related to the degree of crushing and beneficiation required for effective, economical separation or concentration of the ore. The finer fraction of most tailings is normally disposed of in a slurry form into settling basins or impoundments.

3. Coal refuse is the reject material that results from the preparation and washing of coal. This is composed principally of shale, slate, some clay, and variable amounts of coal, depending on the efficiency of the preparation plant operation. Coal refuse is usually produced and disposed of in both a coarse and fine form. Coarse refuse (essentially from 100 mm to 2 mm particle size) is found as a solid, while fine refuse (less than 2 mm particle size) is discarded in slurry form.

4. Quarry waste is the unwanted material from stone quarries and sand and gravel pits, consisting of a variety of waste from excavation, blasting, crushing, and sizing operations.

5. Metallurgical slags are the molten by-products from smelting or sintering of metallic ores, particularly iron and steel, copper, lead, nickel, phosphate, and zinc.

6. Washery rejects are the large quantities of muds, sludges, and/or slimes that are produced during the refining of crude bauxite and pebble phosphate ores. These wastes are generated from processes in which large amounts of water are used, resulting in slurries having low solids content. Following their disposal in holding ponds, these wastes contain significant levels of water, even after prolonged periods of drying.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF MINERAL WASTES

Waste Rock

Waste rock is variable in size, due to variations in ore formations and different mining techniques. Size ranges are from boulders down to gravel. In general, all sources of waste rock can be reduced to a desired gradation by normal crushing and sizing methods. Often, especially in open pit mining, the overburden material, consisting of mixed soil and rock, is excavated and tipped onto a mine waste dump, where it is difficult to separate and determine precise amounts of waste rock.

Waste rock from numerous types of metal mining activity may still contain relatively low percentages of ore which can be separated 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

Because 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. Since ore sources, rock types, and mineral processing techniques do vary, it is difficult to generalize regarding the characteristics of mill tailings. However, the great majority of tailings are composed of hard, angular silicious particles with a high percentage of fines (40 to 90 per cent passing a 200 mesh or 0.074 mm sieve).

It is possible, through the use of size separation or classification devices, to 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.

Coal Refuse

Coal refuse is a variable material produced at the preparation plant as the discard from the processing and cleaning of coal. It 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. Coal refuse also contains a certain amount of sulfur-bearing minerals, notably pyrite and marcasite, which result in acidic discharge when exposed to water.

The coarse refuse from the preparation of anthracite and bituminous coals is similar in physical appearance. Most older refuse banks contain some incinerated coal refuse, termed 'red dog.' Coarse coal refuse, as well as 'red dog,' is well graded material with nearly all particles less than 100 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.

Quarry Waste

The term quarry waste encompasses a wide variety of reject materials from stone quarries and gravel pits. Included in these materials are topsoil, overburden, poor quality stone, reject material from crushing and screening operations, and the dust collected from baghouses or cyclones.

Metallurgical Slags

There are three basic slag types: blast furnace slag, steel slag, and heavy metal slags.

Blast Furnace Slag

Blast furnace slag is the non-metallic by-product, consisting essentially of silicates and alumino-silicates 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 presently comprises approximately ninety per cent of all blast furnace slag that is 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 (1.1 to 1.6 grams per cubic centimeter).

Steel Slag

The basic types of steel slag 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.

Steel slags possess a number of the same desirable physical properties of blast furnace slag. The material is resistant 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 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 hydrates fairly rapidly (within a period of weeks) and its hydration results 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.

Heavy Metal Slags

Slags produced from the smelting of copper, lead, nickel, phosphorus, and zinc ores are found either as air-cooled or granulated materials. Although the chemical composition of these slags varies, the copper, lead, and zinc slags can be characterized as ferrous silicates, while slags from phosphorus and nickel furnaces are calcium or magnesium silicates. The granulated slags are dense, well-graded 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: phosphate and aluminum. 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.

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 less than 0.1 millimeter in particle diameter with over seventy per cent of the particles being less than one micron in diameter. The slimes are usually deposited at two to six per cent solids. Due to colloidal particle size, settling rates are extremely slow. Even after years of settlement, solids contents seldom exceed twenty per cent, which is a main deterrent to their use.

The extraction of alumina from bauxite ores produces clay-like solid waste by-products which are disposed of in slurry form at about twenty per cent solids content. These