**STATE OF NEW MEXICO**
**BEFORE THE WATER QUALITY CONTROL COMMISSION**

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# EXHIBIT SCOTT – D-40

EPA 0107

# THE DESIGN AND OPERATION OF WASTE ROCK PILES AT NONCOAL MINES

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U.S. Environmental Protection Agency
Office of Solid Waste
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# 2.0 BASIC DESIGN AND OPERATION OF WASTE ROCK PILES

To design and operate stable waste rock piles, the operator must ensure proper foundation materials, allow for slope angles and construction processes that will ensure stability throughout the life of the mine, and provide for proper water drainage to minimize infiltration/seepage. The shear strength and durability characteristics of both the foundation and waste materials must be considered, as well as drainage patterns and predicted pore water pressures. This section addresses the major factors that affect the stability of waste rock piles and how they should be considered during the design and operation of the pile.

## 2.1 Preliminary Design Considerations

Generally, the first step in initiating the design of a waste rock pile is the assembly of all available information and data necessary to characterize the waste rock and proposed site. Much of the data is available from public or government organizations (e.g., topographic maps, climate information). This information is typically supplemented with field investigations that may include land surveying, sampling from test pits, trenches, or boreholes, groundwater monitoring, and piezometric and percolation testing. Further details on field testing requirements and techniques are provided in CANMET (1977), McCarter (1985), Piteau (1991), and Brodie et.al., (1992).

### 2.1.1 Waste Rock Characterization

Since mining sites vary in the types of materials encountered in the excavation of ore, a full characterization of the anticipated waste materials should be completed concurrent with mine design planning. However, Piteau Associates points out that the diversity of particle size and physical properties associated with waste rock leads to a difficult and complex sampling and analysis process relative to that required to characterize foundation soils and overburden materials. In addition, material properties may change over time due to stresses within the waste pile, weathering, chemical changes, and other types of degradation. Although abrasion and durability tests attempt to measure potential degradation, the effect of combined factors over time is difficult to predict.

The waste rock material to be disposed in the pile should be analyzed for both physical and chemical characteristics. The strength of the proposed pile may be assessed by such parameters as rock type (igneous, metamorphic or sedimentary), density, particle size distribution, and pore water pressures within the waste pile. The density and pore water pressures also are influenced by the pile construction method and subsequent amounts of consolidation and settlement. Pore water pressures decrease the stability of both the waste and foundation materials. With respect to shear strength, the most favorable pile materials are hard, durable rock with little or no fines present. Failure can occur when a pile containing material with excessive fines is constructed on a steep slope. In addition, waste fines may become saturated from water runon and snow melt and trigger a failure. Ideal waste rock would be of sufficient durability, hardness and coarseness to provide high shear strength and low pore water pressure. A description of the mineralogy of the pile material is necessary to identify, for example, the presence of sulfide materials such as pyrite, which indicate the potential for acid rock drainage. Likewise, the presence and amount of basic minerals (e.g., calcite) must be determined in order to evaluate the acid neutralization potential of the rock pile.

Once waste material characteristics are known, proper design and construction methods can be implemented. For example, as poor-quality waste materials are encountered during construction of a waste pile, specific sections of the pile can be prepared to receive the materials or additional protection can be installed. Overburden materials (e.g., soils), due to their fine nature, would contribute to instability in the waste rock pile and should, therefore, be placed in a separate location. Likewise, acid-generating rock may be segregated so that immediate measures may be taken to control acid generation. Lastly, since the physical and, particularly, the chemical properties of mined rock can change over time, there also should be a program of periodic or continuous characterization to ensure that changes can be made to design and operation as conditions warrant.

### 2.1.2 Site Characterization

A complete site characterization involves the collection and consideration of a diverse set of information that encompasses site activities, layout, terrain, hydrology, and climate. For example, physiographic data address the proximity of the location to the source of the waste, nearby mining activities such as blasting that could affect pile stability, the site capacity, and topographic features such as slopes and valleys that may determine placement of the waste rock pile and surface water flows. Hydrologic considerations address natural drainage and climate concerns include storm events, temperature, precipitation, and wind patterns. The MWRPRC data indicate that more failures have occurred during winter and spring seasons, which typically bring greater amounts of precipitation, than in summer and fall (Broughton, 1992). The hydrogeology of the site, including the position of the water table, groundwater flow systems, distribution of discharge and recharge areas, and groundwater usage, assists in identifying pathways for potential environmental and human health risks. In addition, ground and surface water quality, air quality, fish and wildlife habitat and productivity, vegetation, and existing and future land use must all be determined in order to assess potential environmental impact (Piteau, 1991).

## 2.2 Stability Factors

A close look at the factors that affect waste dump failures provides important information relative to the stability parameters that should be considered during the design and operation of waste rock piles. The Canadian Mine Waste Rock Pile Research Committee conducted an in-depth study of over 40 failures of waste rock dumps from coal mines aimed at improving the design and operation of future dumps (Broughton, 1992). The research committee identified numerous factors that potentially contribute to waste dump failures. For example, the data indicated that most waste dump failures occur on foundation slopes exceeding 20 degrees. Piteau and Associates (1991) identify seven major factors that affect pile stability: dump configuration, foundation conditions, waste material properties, method of construction, dumping rate, piezometric and climatic conditions, and seismic and blasting activities.

### 2.2.1 Foundation Stability

An important aspect of site characterization includes an accurate characterization of foundation stability. Soil tests for shear strength, permeability/hydraulic conductivity and consolidation, and depth determinations for any loose or incompetent soils, are important in assessing the strength and preparatory requirements of the foundation. Competent foundations refer to foundation material with higher shear strength than the waste materials; weak foundations have lower shear strength than the waste materials (CANMET, 1977). Level foundations are also more stable than sloping foundations. The strength and durability of the underlying bedrock should also be evaluated.

Foundation soil conditions, including the type of soil and the amount of pore pressure, have a large effect on overall waste pile stability. In addition, excess pore pressures may result from high loading rates and steep foundation slopes. Where sloped foundations are present (*i.e.*, greater than 10 degrees), a stability analysis is necessary to determine the maximum potential displacement due to base shearing.

Where a level foundation (i.e., less than 10 degrees) is provided, the pile will generally not be susceptible to mass sliding along the base unless it is constructed on very weak foundation materials (e.g., organic soils). In general, sloped foundations present greater risks associated with sliding than level foundations (foundations are less stable and material may move farther and more quickly). Therefore, CANMET recommends higher safety factors for waste rock piles on sloped foundations (CANMET, 1977). In addition, foundation stability also may be affected by temporal conditions that are not considered during a site characterization. For example, the Mine Waste Rock Pile Research Committee found that winter freezing of foundations, before loading, may also contribute to some failures (Broughton, 1992).

### 2.2.2 Waste Rock Pile Stability

The size and configuration of a waste pile directly affect its stability. The variables that need to be considered in the configuration of a waste pile are height, volume, and slope angles. The height of a pile is defined as the vertical distance from the ground at the toe of the pile to the pile crest. Piles may range from 20 m up to 400 m (Piteau, 1991). In the U.S., the size of waste rock in a pile is usually defined as tonnage or acres covered; however, the Canadian protocol describes the size of a waste rock pile as a volume unit. The slope angle of a pile is determined by the type of construction method used. End-piled materials result in slopes at the angle of repose, approximately 37 degrees, the average angle of repose for free-piled cohesionless rockfill. Steeper slopes may result if the piled materials have some cohesive properties (such as significant fines) or consist of largely angular boulders.

At sites where waste rock consists of frictional, coarse materials, the maximum slope at the pile perimeter is the angle of repose (as indicated previously, typically about 37 degrees). Where competent foundation materials are found and adequate drainage is provided, the height of the pile is generally unlimited. Where foundation materials are weak, stability analyses must be performed to determine the maximum height and slope to ensure the desired level of stability. (CANMET, 1977, provides guidance on such analyses, depending on the specific characteristics of the foundation materials.) Compacting foundation materials along the perimeter slopes (where maximum stresses are found) can increase stability and allow for greater slope angles and/or pile heights. However, compaction reduces permeability, thereby increasing the need for drainage controls.

In addition to pile overall height, volume, and slope angle, the presence of lifts or benches is an important pile configuration factor for aiding the stability of the pile. Lifts and benches reduce the overall angle of the pile slope and control runoff from the pile. Benches are slightly sloped horizontal surfaces constructed into the slope of a waste rock pile. They are typically constructed in piles as part of reclamation, be it concurrent with construction or during final reclamation. Lifts are the working levels of a waste rock pile. A specific area of a waste rock pile may be worked at a particular lift level until the lift is completed. Another lift may then be constructed on top of the previous lift. Constructing a pile in lifts, or utilizing benches, during the active operation of the pile typically results in lower slope angles and, therefore, increased stability. Other pile operation methods can affect pile stability as well. Most importantly, a rapid rate of waste dumping can contribute to the instability of a pile and has been attributed to several pile failures. High dumping rates can lead to increased pressure in the dump and not allow for adequate time for consolidation and settling of the pile to ensure stability (Piteau, 1991). The direction of crest development is another operational factor that should be closely monitored; deviations from the design plan may direct the waste pile to foundations of greater slope and lead to reduced stability.

### 2.2.3 Assessing Waste Pile Stability

The common method of assessing the overall stability of a proposed waste rock pile is to calculate a factor of safety (FS). The FS represents the ratio of the shear strength to the shear stress. As noted above, the stability is directly related to the foundation and waste rock materials and drainage, along with general dump features, including size, volume, slope angle, degree of confinement, method of construction, and dumping rate. The acceptable FS for an individual pile will depend upon site-specific conditions related to the potential impacts/risks of a slope failure. CANMET (1977) recommends an FS (greater than unity) to account for differences between predicted design parameters and actual conditions within the pile. Methods used to calculate safety factors generally focus on shear stress and pore water pressure along "critical surfaces" within the pile (including the variability in these parameters along such surfaces). Selection of the methodology to be used at a specific site depends on the operator's determination of the most likely failure mode. Piteau (1991) includes a description of the types of failure modes associated with waste rock piles (edge slumping rotational failure, liquefaction, etc.). Mine dumps located in areas of high seismic risk require specialized safety analyses.

For piles constructed on sloped foundations, the following equation can be used to determine the maximum possible foundation slope angle (assuming no hydrostatic pressures, i.e., proper drainage exists) (CANMET, 1977):

$$\tan i = \tan \delta / FS$$

$i$ = foundation slope angle
$\delta$ = friction angle between waste and foundation materials
$FS$ = factor of safety (stability factor)

Where uneven foundation slopes are encountered, the Wedge method described in CANMET (1977) can be used to determine whether the calculated factor of safety is acceptable to the operator.

Piteau (1991) includes a dump stability rating system to provide a "semi-quantitative" method for assessing waste rock pile failure potential. Based on the results of the rating analysis, dumps can then be placed in one of four dump stability classes. The classes are correlated to "negligible," "low," "moderate," and "high" failure potential. The purpose of this system is to guide operators in waste rock pile design (in conjunction with information on the site-specific risks associated with a failure).

## 2.3 Types of Waste Rock Pile Configurations

Taylor and Greenwood (1985) presented a classification system for non-impounding waste rock pile types based on the topographic setting and the configuration (geometric shape) of a pile. This classification system was developed ostensibly to provide waste rock pile vocabulary common to industry and government representatives. The pile types identified in Taylor and Greenwood (1985) are illustrated in Figure 2-1 and discussed further below.

### Valley-Fill

A valley-fill waste rock pile partially or completely fills a valley. It is typically constructed by dumping waste rock at the head of the valley and extending the pile by continuous dumping of waste rock on the downstream slope. A valley-fill also can be constructed by building horizontal lifts at the farthest downstream location of the pile toe and then proceeding upstream toward the head of