U.S. DEPARTMENT OF INTERIOR
U.S. GEOLOGICAL SURVEY

A simplified economic filter for open-pit gold-silver mining in the United States

By

Singer[1], Donald A., Menzie[2], W. David, and Long[3], Keith R.

Open-File Report 98-207

[1]United States Geological Survey, MS 901, 345 Middlefield Road, Menlo Park, CA 94025
[2]United Sates Geological Survey, MS 945, 12201 Sunrise Valley Dr., Reston, VA 20192
[3]United States Geological Survey, GD, 520 N.Park Ave., Menloo Park, AZ 85719

1998

Table Of Contents

Introduction	pg3
Nature of Data	pg4
Capacity of Mine Life	pg4
Capital Expenditures	pg5
Operating Costs	pg8
Economic Filter	pg9
Summary	pg11
References	pg13

INTRODUCTION

In resource assessments of undiscovered mineral deposits and in the early stages of exploration, including planning, a need for prefeasibility cost models exists. In exploration, these models to filter economic from uneconomic deposits help to focus on targets that can really benefit the exploration enterprise. In resource assessment, these models can be used to eliminate deposits that would probably be uneconomic even if discovered. The U. S. Bureau of Mines (USBM) previously developed simplified cost models for such problems (Camm, 1991). These cost models estimate operating and capital expenditures for a mineral deposit given its tonnage, grade, and depth. These cost models were also incorporated in USBM prefeasibility software (Smith, 1991).

Because the cost data used to estimate operating and capital costs in these models are now over ten years old, we decided that it was necessary to test these equations with more current data. We limited this study to open-pit gold-silver mines located in the United States.

Open-pit gold-silver mines use one of several processing methods depending on deposit characteristics, so our examination of costs considers open-pit mining and five different processing methods. Heap-leach processing is designed for low-grade gold or gold-silver deposits where gold is in predominantly oxide minerals or non-mineral materials. The autoclave process is designed for deposits where most gold is in sulfide minerals. In an autoclave process, ore is treated at elevated pressures and temperatures in an oxygen-rich environment to oxidize it for processing by another method. Following the autoclave process and in oxide gold deposits that contain fine clays or natural carbon, a carbon in leach (CIL) agitation vat-leach process is commonly used. Oxide gold deposits with little byproduct are sometimes processed using a vat-leach process followed by a carbon-in-pulp (CIP) method. Gold deposits with high silver contents relative to gold are frequently processed by vat leach followed by Merrill-Crowe recovery. Explanations of these various processing methods are available in Camm (1991).

For open-pit mining and each of the five different processing methods, we compare capacity and cost estimates using the USBM models with observed mines. If significant differences exist between the observed costs and those predicted by the USBM model, we modify the equations appropriately.

NATURE OF DATA

Economic deposits used in this study include open-pit gold-silver mines of which 28 used heap-leach, three autoclave, eight CIL, five CIP, and two Merrill-Crowe. Data sources were files purchased from D. Briggs (Briggs, 1994).

A total of 46 economic deposits were used to estimate the parameters of the model equations. Because the information available varied by mine, various subsets of the 46 deposits were used. To test the revised equations, the economic deposits were combined with uneconomic deposits from each of the following processing methods; 27 heap-leach, four CIL, two CIP, and one Merrill-Crowe.

Determination of whether a known deposit was economic was based on having reported a profit in more than 70 percent of the years operated. In cases where only the first 2-3 years of an operation were reported, this rule was relaxed to allow for commonly reported first year losses. Even so, this scheme is not perfect in that a mine could have small losses in a third of its production years and yet have a large profit over the life of the mine.

Operating costs are most commonly reported as total operating costs in dollars per once. In order to be compatible with estimates by the USBM method, the mine and mill operating costs made by the USBM method were added to represent total operating costs. Operating cost estimates from the observed mine data were adjusted to dollars per ton.

Capital expenditures used here represent the total reported over the life of a mine. Frequently open-pit gold-silver mining operations are observed to spread out their capital expenditures by means of mine or mill expansions over a period of years. The simplified nature of the economic analysis used assumes that capital expenditures are made at the beginning of the first year and that mining/mill capacities remain constant until the deposit is depleted.

CAPACITY AND MINE LIFE

All cost estimates in the USBM method are derived from the estimated daily mining capacity or its estimated mine life. Because of this, unbiased estimates of daily mining capacities are critical.

Observed daily mining capacities appear to be larger than the capacities estimated by the USBM method. In Camm's (1991) report, daily mining capacities are calculated using Taylor's rule (Taylor, 1978) from the total amount of ore in the deposit as:

$$C = [T^{0.75}] / 70 \qquad (1)$$

where C is capacity in short tons per day, T is ore tonnage in short tons, and 350 operating days per year are assumed.

Analysis of daily capacity and ore tonnages in known economic deposits shows a significantly different relationship from equation 1 (fig. 1). This was true for each of the processing methods and, because the regression slope was not significantly different between processing methods, they were combined. The revised relationship determined from 41 deposits is:

$$C = [T^{0.5874}] / 2.404 \qquad (2)$$

The USBM estimated mine life in years (L) based on Taylor's rule is:

$$L = 0.2 \cdot T^{0.25} \qquad (3)$$

The direct relationship between mine life and ore tonnage could not be determined from the present data because too few mines were depleted. However, life can be estimated from daily capacity and ore tonnage as:

$$L = T / (C \cdot 350) \qquad (4)$$

again assuming 350 operating days per year.

CAPITAL EXPENDITURES

Observed total capital expenditures of open-pit, heap-leach operations are significantly larger than the total capital expenditures estimated in the original U.S. Bureau of Mines cost models (Camm, 1991). The USBM equation for the capital cost of an open-pit mine is:

$$\text{Capital expenditure per mine} = 160{,}000 \cdot C^{0.515} \qquad (5)$$

and for a heap-leach processing facility:

$$\text{Capital expenditure per heap-leach facility} = 296{,}500 \cdot C^{0.515} \qquad (6)$$

where C is capacity in short tons per day as above.
Whereas the revised equation based on regression using 21 economic deposits (fig. 2) is:

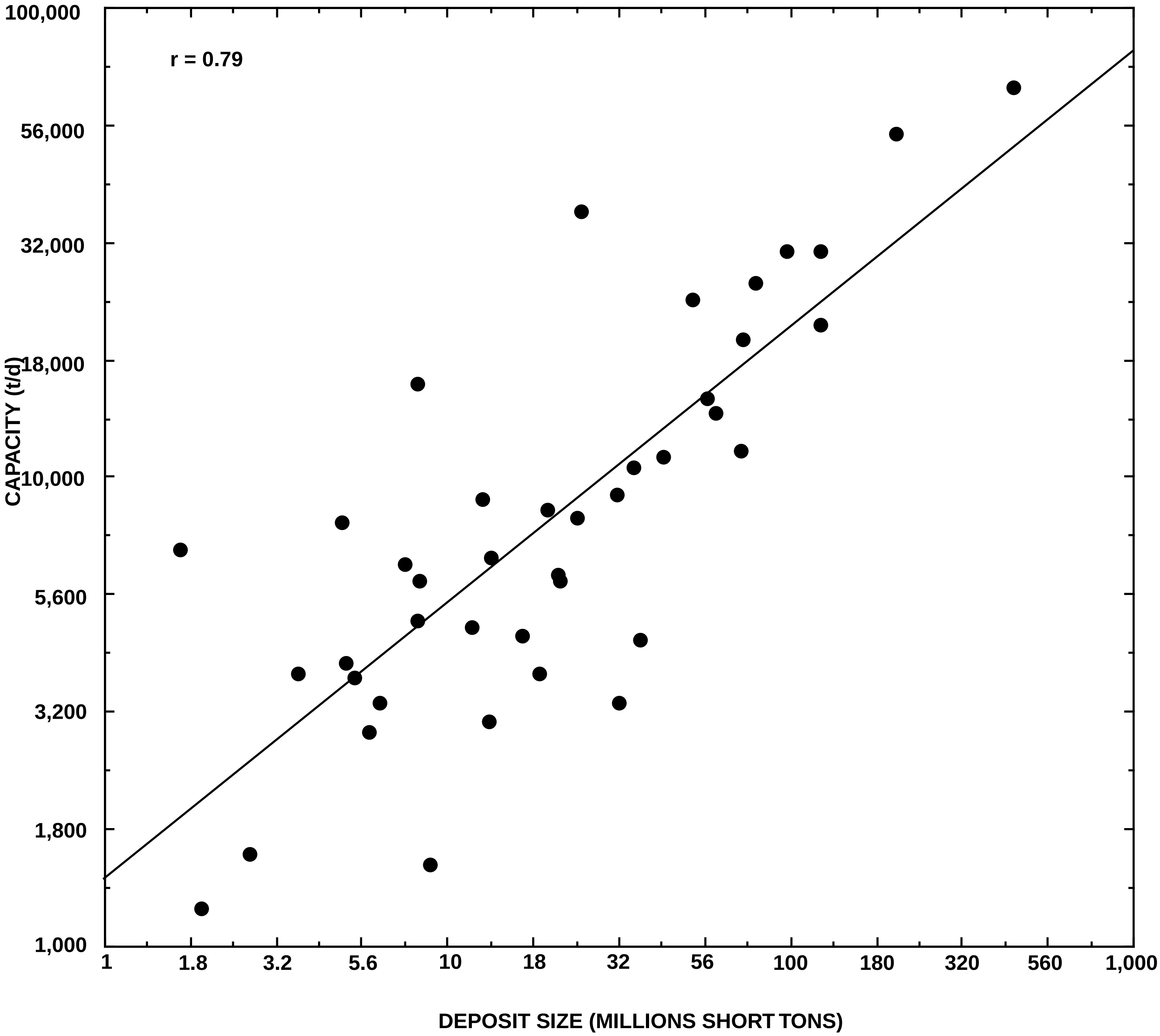

Figure 1--Relationship between mine capacity and size (tons of ore) of economic U. S. open-pit gold-silver mines.

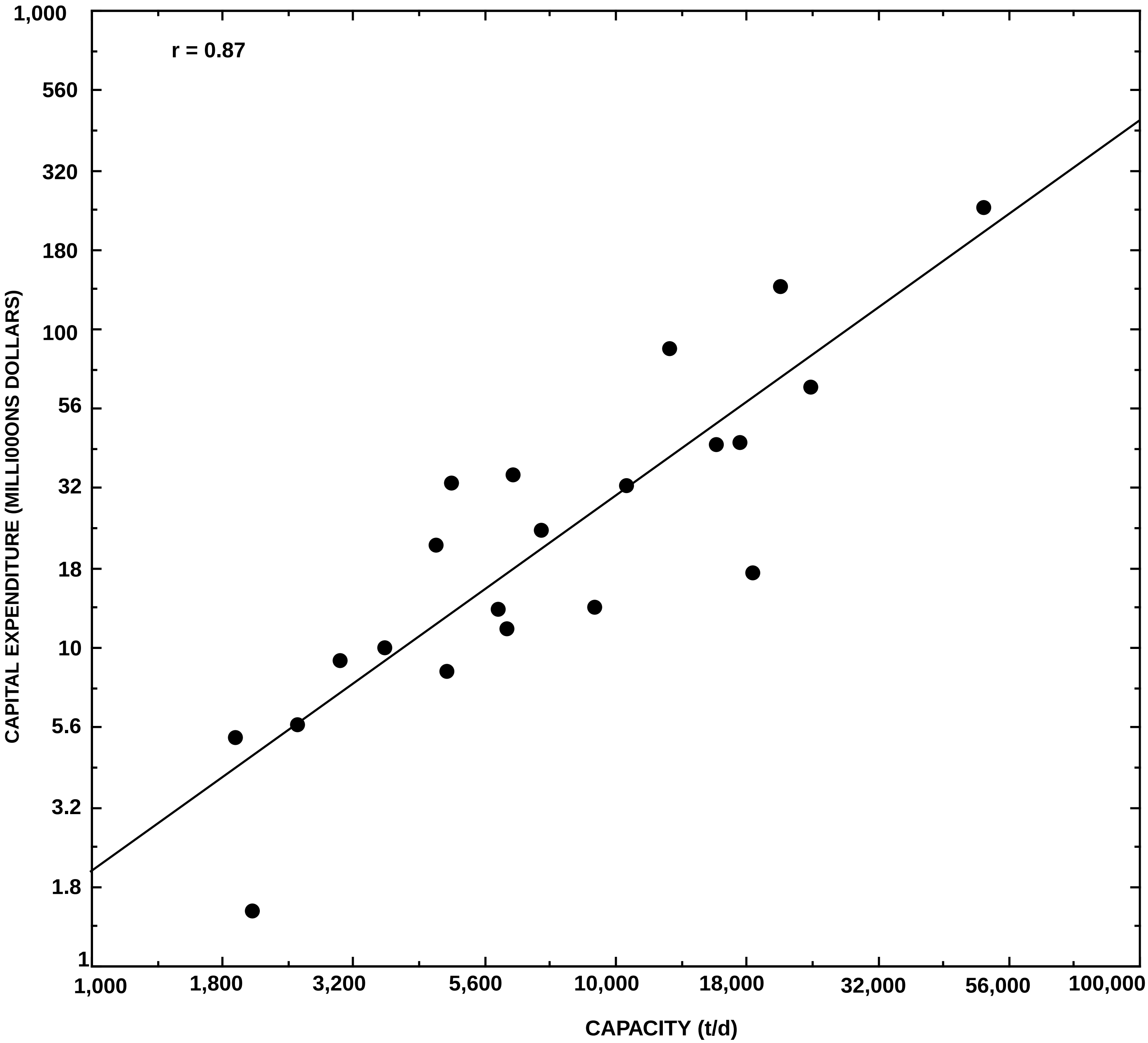

Figure 2--Relationship between capital expenditure and mine capacity of economic U. S. open-pit, heap-leach gold-silver deposits.

Capital expenditure = $586 \cdot C^{1.1766}$ (7)

Data available did not allow consistent separation of mine and mill capital expenditures, so the revised model combines them. Observed capital expenditures are in current dollars so the higher new estimates could be due to inflation. In the observed data, the capital expenditure per ton does not change over the years of initial capital expenditure from 1975 to 1990, suggesting that any inflation must have been balanced by productivity gains.

Although total capital expenditures also tended to be higher for open-pits with autoclave, CIL, CIP, and Merrill-Crowe processes than predicted by the original models (Camm, 1991), the results were not significantly different, so no modification was made to the original equations. From Camm (1991) the capital expenditure for an open-pit mine with a mill designed for one or more autoclaves:

Capital expenditure = $96{,}500 \cdot C^{0.778}$ (8)

the capital expenditure for an open-pit mines with a CIL mill is:

Capital expenditure = $50{,}000 \cdot C^{0.745}$ (9)

the capital expenditure for an open-pit mine with a CIP mill is:

Capital expenditure = $372{,}000 \cdot C^{0.540}$ (10)

and, the capital expenditure for an open-pit mines with a Merrill Crowe mill is:

Capital expenditure = $414{,}000 \cdot C^{0.584}$ (11)

OPERATING COSTS

Total operating costs of open-pit, heap-leach operations are significantly larger than the total operating costs estimated in the original U.S. Bureau of Mines cost models (Camm, 1991).

The original equation for the operating cost of the open-pit mine is:
Mine operating cost / ton = $71 \cdot C^{-0.414}$ (12)
and for the heap-leach operating cost:

$$\text{Operating cost heap-leach} = 31.5 \cdot C^{-0.223} \quad (13)$$

Whereas the revised equation based on regression using 24 economic deposits (fig. 3) for open-pit mines using heap-leach processing is:

$$\text{Operating cost} = 614.2 \cdot C^{-0.472} \quad (14)$$

Although total operating costs also tended to be higher for open-pits with autoclave, CIL, CIP, and Merrill Crowe mills, than predicted by the original models (Camm, 1991), the results were not significantly different, so no modification was made to the original equations. From Camm (1991) the operating costs for an open-pit mine with an autoclave mill is:

$$\text{Operating cost} = 78.1 \cdot C^{-0.196} \quad (15)$$

The operating costs for an open-pit mine with a CIL mill is:

$$\text{Operating cost} = 84.2 \cdot C^{-0.281} \quad (16)$$

The operating costs for an open-pit mine with a CIP mill is:

$$\text{Operating cost} = 105 \cdot C^{-0.303} \quad (17)$$

and, the operating costs for an open-pit mine with a Merrill-Crowe mill is:

$$\text{Operating cost} = 128 \cdot C^{-0.300} \quad (18)$$

ECONOMIC FILTER

For the appropriate mining and processing method combination for a particular deposit, the deposit's tonnage is all that is needed to estimate various mining costs using the equations above. The deposit's grade(s) can, when combined with assumed gold and silver prices, be used to estimate the deposit's ore value per ton. Value of production per year can be calculated by multiplying the difference between value per ton and total cost per ton by capacity per day times number of operating day per year (350 days used here).

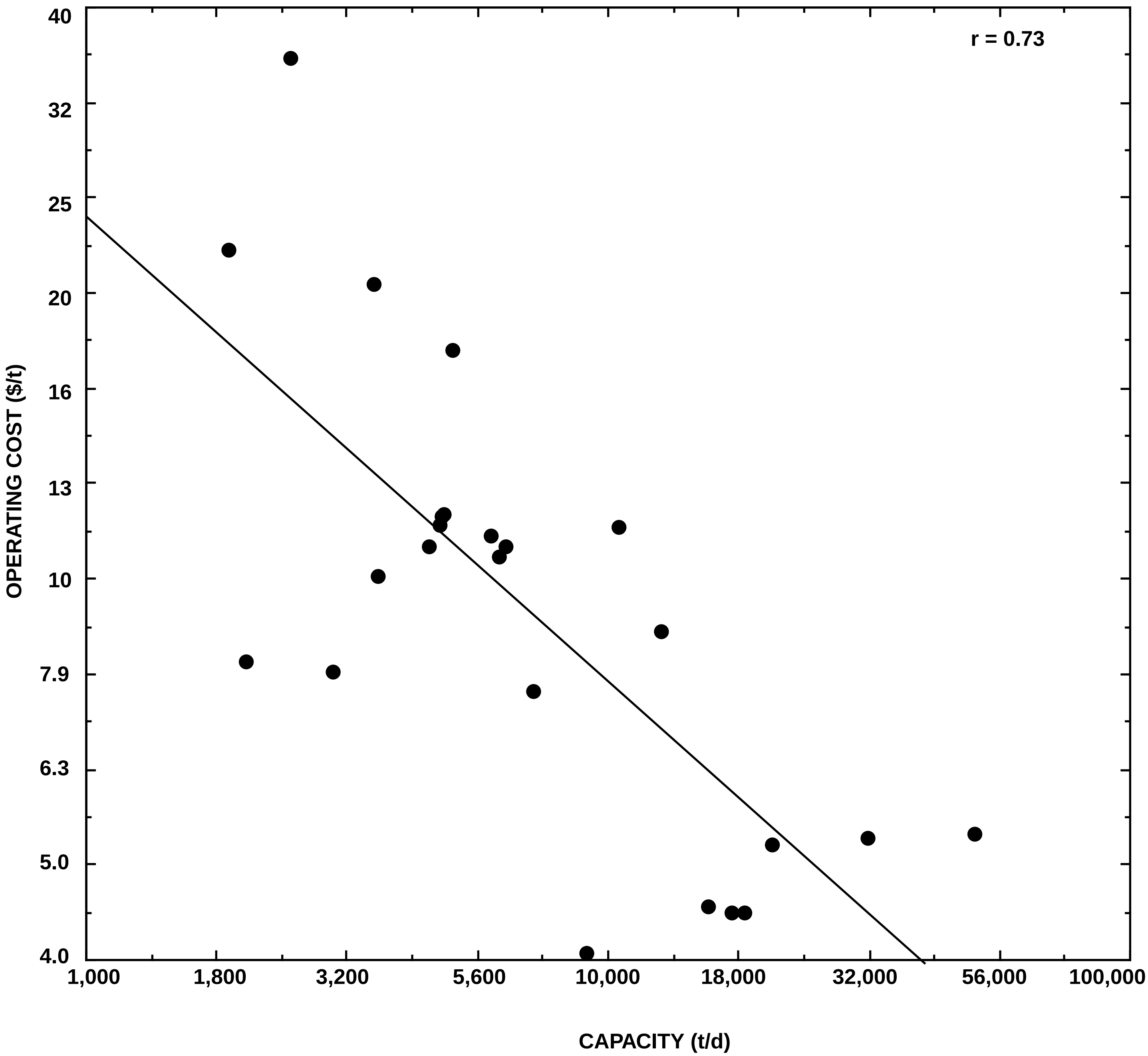

Figure 3--Relationship between operating costs and mine capacity of economic U. S. open-pit, heap-leach gold-silver deposits.

The life of the mine estimate is then used with the value of production per year and an acceptable rate of return (15 percent used here) in a standard present-value equation in a spreadsheet to estimate a deposit's present-value of production. The present-value of production minus the estimated capital expenditure for the deposit is the present-value of the deposit. If the deposit's present-value is positive, the filter is predicting that it is profitable. Negative present-values predict economic failure at the assumed metal prices and rate of return.

For a particular tonnage, the dividing (or break even) line between economic and uneconomic can be estimated by adding the estimated operating cost to the capital expenditure divided by capacity times operating days per year times the present-value of a dollar for the life of the mine. To account for variabilities and uncertainties in most of the inputs to these estimates, we have taken 0.7 and 1.3 of this break-even value to estimate boundaries for uneconomic, marginal, and economic deposits (fig. 4).

In order to see how well these revised cost equations estimate economic viability, we have plotted on figure 4 economic and noneconomic open-pit heap-leach deposits. The plot demonstrates that the revised equations are performing well. All of the deposits that plot in the non-economic region are not economic. Only one of the deposits in the economic region is not economic. Gold recovery or other problems can render an apparent economic deposit uneconomic. At gold prices that have existed in the recent past, such as $425/oz, or lower required rates of return, some of the marginal deposits will plot in the economic domain.

SUMMARY

Based on analysis of the relationships in U.S. gold-silver deposits, we modified the simplified cost models for open-pit operations to reflect higher capacities observed in heap-leach, autoclave, CIL, CIP, and Merrill Crowe mills. For heap-leach operations, we also modified equations for estimating operating cost and capital expenditure. The resultant equations appear to provide reasonable estimates of costs, but all such estimates can be wrong because of factors such as poor gold recovery.

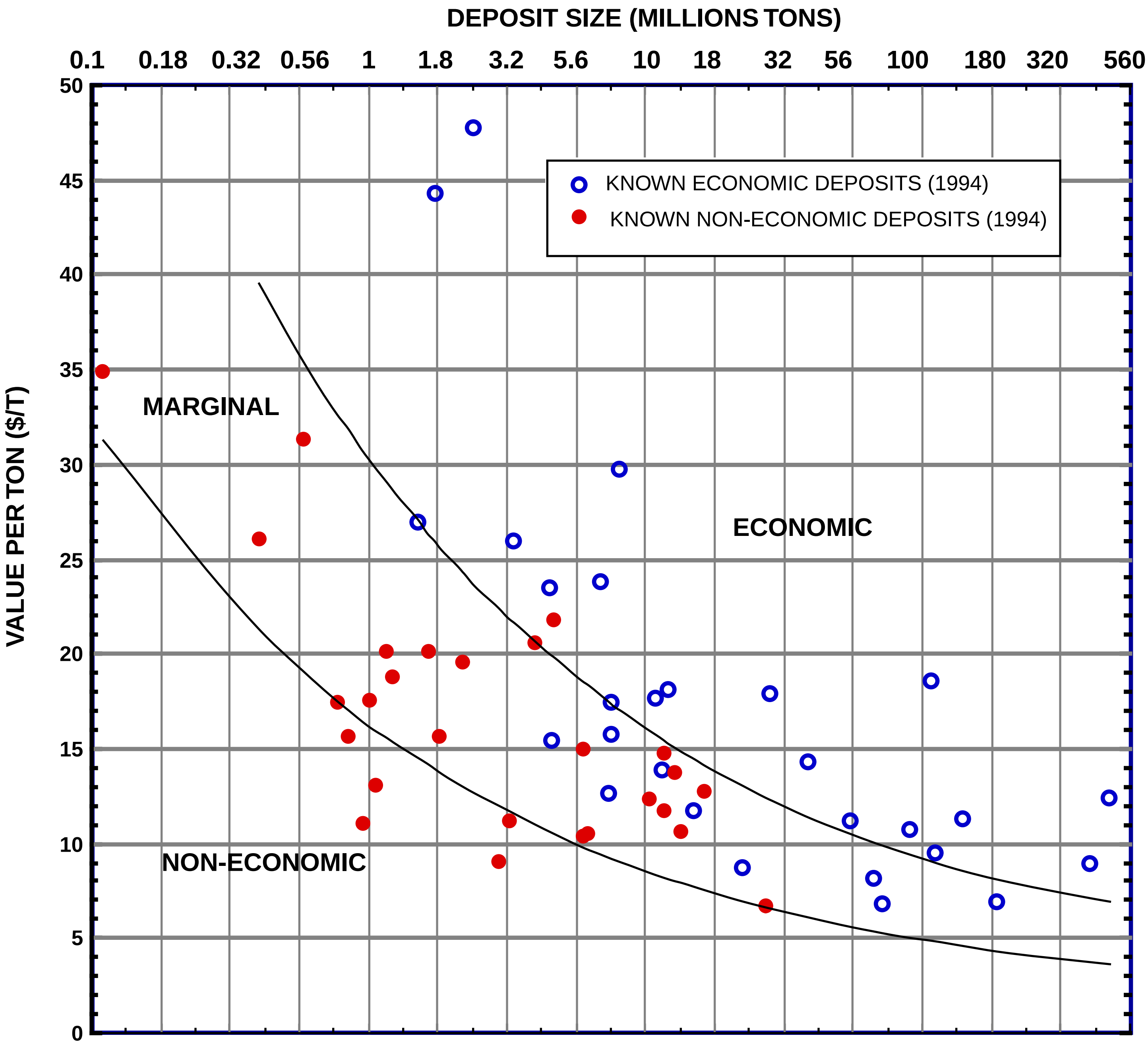

Figure 4--Relationship between value per short ton and deposit size (tons of ore) for U. S. open pit, heap-leach gold-silver deposits. Economic filters of 0.7 and 1.3 of break-even values based on a gold price of $380/oz., silver price of $5/oz., and a 15 pecent rate of return.

REFERENCES

Briggs, D.F., 1994, 1994 United States mining operations report: Tucson, Arizona, D. Briggs, 2233p.

Camm, T.W., 1991, Simplified cost models for prefeasibility mineral evaluations: US Bureau of Mines Information Circular 9298, 35 p.

Smith, R.C., 1992, PREVAL–Prefeasibility software program for evaluating mineral deposits: U. S. Bureau of Mines Information Circular 9307, 35p.

Taylor, H.K., 1978, Mine valuation and feasibility studies: *in* Hoskins, J.R. and Green, W.R., eds., Mineral industry costs: Spokane, Washington, Northwest Mining Association, 2nd. ed., p. 1-17.