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Tonnage-cutoff model and average grade-cutoff model for a single ore deposit

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ABSTRACT

Ore reserve estimation and resource prediction are important aspects of deposit exploration and mining. The cutoff has great influence on the reserve and resource calculation. Despite this, the study on the mathematical relationships of the tonnage, average grade and cutoff is still scant. According to the fractal distribution of element concentrations, which are obtained from analysis of channel samples of constant length along exploration or mining works, the tonnage-cutoff and average grade-cutoff models are constructed, which are applicable in both exploration and operating mine environments. Via these models, the relationships between ore tonnage, metal tonnage and cutoff are obtained in terms of the fractal model of element concentrations. Moreover, the thickness of the mineralized zone in each exploration or mining work follows a fractal model, and assuming that the thickness is a continuous variable, a model for calculating the mass of the mineralized zone in a single deposit is established. Given the mineralized zone mass, the tonnage-cutoff and average grade-cutoff models can be utilized to calculate ore reserve and average grade, especially when the cutoff changes. A fault-controlled disseminated-and-veinlet gold deposit in Jiaodong gold province, China, is selected as a case study. The estimates of the ore reserves obtained from these models are found to be consistent with the results obtained by the traditional geometric block method.

1. Introduction

The tonnage, average grade, and cutoff are the basic parameters in mineral resource assessments and mining operations. Research on the inherent relationships between the tonnage, average grade above cutoff and the cutoff has been carried out for decades on the scale of an ore camp, district or ore province. During both exploration and mining environments within an individual deposit, it is also an essential task to continually study relationships between the average grade, tonnage, and cutoff (Taylor, 1985; Minnitt, 2004). Such research not only benefits understanding of the essence of metallogenesis in geological terms, but serves as a basis for further exploration or mining. For instance, although the cutoff is often stable during an on-going mining operation, it may also be adjusted due to any major long-term increase or decrease of metal price, or other change in market conditions, which induce modifications of the deposit tonnage and average grade above cutoff. Despite the volume of previous works, studies on the tonnage-cutoff model and average grade-cutoff model for a single ore deposit are still scant. In this paper, it is proposed that models can be established based on the element concentrations obtained from the mineralized zones exposed by exploration or mining works.

1.1. Traditional methods for ore tonnage and average grade estimation

Traditional methods for ore tonnage and average grade estimation in a single ore deposit can be roughly classified as either geometric or geostatistical (Henley, 2000). In exploration, both of these methods utilize the orebody thickness and the grade over a given thickness (e.g., in drillholes or drifts) located in a grid to estimate the reserve. In traditional methods, as a cutoff is given, the orebody thickness and average grade above cutoff of each exploration work are calculated, and the corresponding ore tonnage and average grade of the orebody and ore deposit are estimated. This calculation process is repeated each time the cutoff changes to obtain the relationships between ore tonnage, average grade and cutoff. Theoretical principles and practical applications of the traditional methods have served mining for decades, and have become much easier with the aid of modern programming (David, 1974). The explicit formulae describing the inherent relationships between ore tonnage, average grade and cutoff are, however, rarely studied.

1.2. Models of grade, tonnage and cutoff

The distributions and relationships of the tonnage, grade and cutoff have been studied for decades to predict resources at a regional scale, generally involving a larger number of mineral deposits (Musgrove, 1965; David, 1974; Harris, 1984; Gerst, 2008). USGS researchers studied the grade frequency distribution model and tonnage frequency distribution model for various types of ore deposits, and used the models to

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estimate resource potential at the regional scale (Singer, 1993, 1995; Singer et al., 2000, 2005). Ore tonnage of the deposits in a given region is proven to follow a fractal distribution (Barton and La Pointe, 1995; Turcotte, 2002). Lasky (1950) demonstrated that the grade and the logarithms of cumulative ore tonnage above a given cutoff conform to a linear relationship. In addition, a lognormal relationship between tonnage and cutoff was also introduced by Musgrove (1965). Matheron (1959) further pointed out that Lasky's model is derived from the lognormal distribution of the ore grades. DeYoung (1981) proved, however, that Lasky's equation has mathematical limitations; it was discovered that a plot of cumulative metal tonnage versus log cumulative ore tonnage from Lasky's model has a maximum, which implies that the grade becomes 'negative' beyond the maximum value. This is an undesirable mathematical property for any practical tonnage-grade model. Therefore, Lasky's model is not widely applicable. In contrast, Cargill et al. (1980) obtained a fractal (power–law) relationship for tonnage and average grade by plotting the cumulative tonnage against the grade. Turcotte (1997) further developed a tonnage-grade model, which results in a fractal relationship between tonnage and grade, by modeling the geological ore-forming process.

It is suggested that the fractal model is an effective tool to describe the relationship between tonnage and grade than the lognormal model at a regional scale. The mathematical relationships between tonnage, grade and cutoff have, however, rarely been investigated within a single deposit.

1.3. Fractal distributions of geological objects

Geological objects and variables normally show irregular, heterogeneous, and skewed characteristics. These complex characteristics can be described by fractal models. The number-size model is one of the most widely applied fractal models (Mandelbrot, 1983; Cheng et al., 1994; Agterberg, 1995; Wang et al., 2008, 2010b; Deng et al., 2010). Orebody thickness and grade-thickness in the exploration workings of a single deposit were described by the number-size model (Wang et al., 2010a). Additionally, the element concentrations in precious and base metal deposits also conform to the number-size model. For example, Sanderson et al. (1994) showed that Au grades in the La Codosera quartz vein deposit, Spain, follow the number-size model; Monecke et al. (2001) noted that base metal concentrations in drillholes from the Hellyer massive sulfide deposit, Tasmania, Australia, also obey the model. Monecke et al. (2005) showed that the frequency distributions of Zn, Pb, Cu, and Ag in the Waterloo massive sulfide deposit, Australia, conform to the fractal model. Roberts (2005), Wang et al. (2007) and Deng et al. (2009) discovered that the Au concentrations in some disseminated-and-veinlet deposits in Australia and China can be described by the fractal model.

1.4. Research objective

It is proposed that the fractal model is suitable for describing the relationship between tonnage and grade at a regional scale, and the distribution of element concentrations in a single ore deposit. Based on the number-size fractal model, this paper aims to work out the formulae of the relationships between ore tonnage and cutoff, and between average grade above cutoff and the cutoff. The Shangzhuang disseminated-and-veinlet Au deposit, Jiaodong province, China, (Deng et al., 2008) is selected as a case study.

2. Raw data and geological models

In the exploration or operating mine environments of a deposit, a series of exploration or mining works are performed. The following modeling is based on such workings in an exploration environment; by analogy, the same process is nevertheless also applicable in an operating mine environment.

2.1. Raw data and geometric block method (GBM)

Channel samples with constant length e are taken in the mineralized zone along exploration intersections and their element concentrations are analyzed. In traditional reserve calculation methods, the orebody thickness and the grade of each exploration intersection are then calculated based on a given cutoff (Fig. 1a). In the next step, each exploration working is projected horizontally onto a vertical plane (a vertical longitudinal projection, VLP) in the case of an orebody that dips at more than 45°, or is projected vertically onto a horizontal plane (horizontal longitudinal projection, HLP) if the dip is less than 45°.

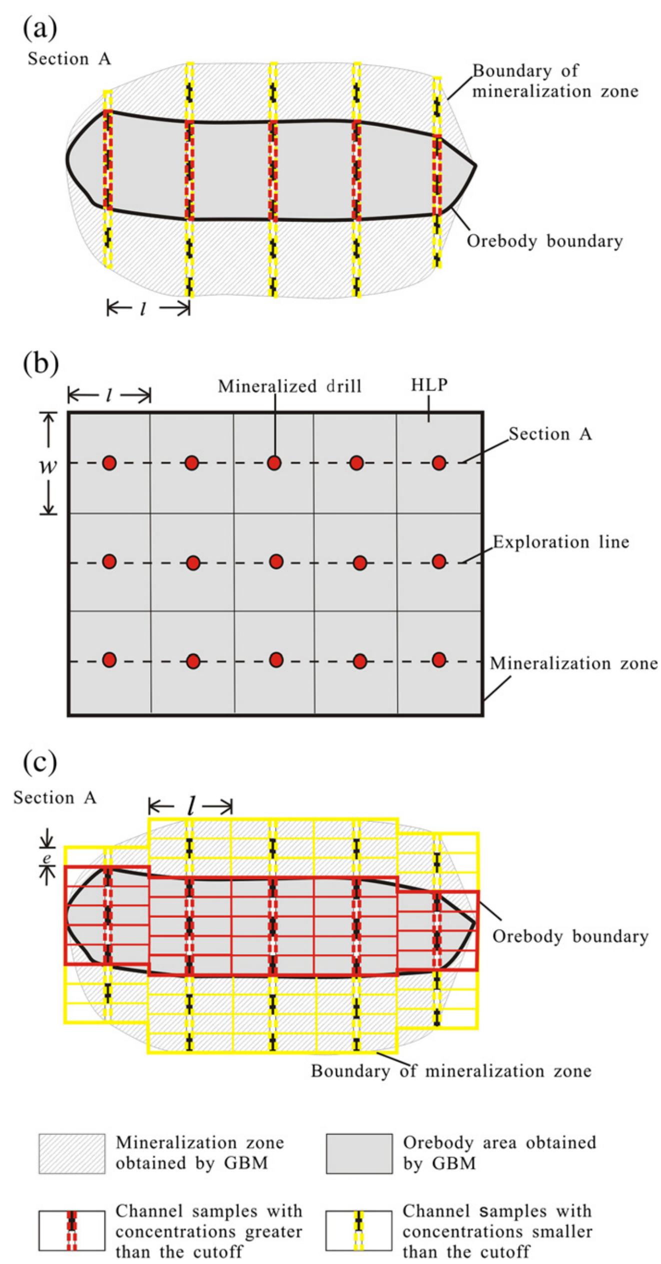

Fig. 1. Geological models of the ore tonnage calculation model and tonnage-cutoff model. (a) Delimitation of the mineralized zone and orebody by geometric block method in a section; (b) delimitation of the mineralized zone in a horizontal longitudinal projection (HLP) for the calculation of mineralized zone mass; and (c) delimitation of the mineralized zone and orebody in the tonnage-cutoff model established in this paper. (l and w represent the intervals parallel and perpendicular to the exploration line, respectively).