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RESEARCH PAPER

Minimum critical thickness of dike for ore-bearing fluid injection: A new approach applied to the Shihu gold deposit, Hebei Province, North China

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Abstract According to the metallogenic theory by transmagmatic fluid (TMF), one magmatic intrusion is a channel of ore-bearing fluids, but not their source. Therefore, it is possible to use TMF's ability for injection into and for escaping from the magmatic intrusion to evaluate its ore-forming potential. As the ore-bearing fluids cannot effectively inject into the magmatic intrusion when the magma fully crystallized, the cooling time and rates viscosity varied can be used to estimate the minimum critical thickness of the intrusion. One dimensional heat transfer model is used to determine the cooling time for three representative dikes of different composition (granite porphyry, quartz diorite and diabase) in the Shihu gold deposit. It also estimated the rates viscosity varied in these time interval. We took the thickness of dike at the intersection of the cooling time – thickness curve and the rates viscosity varied versus thickness curve as the minimum critical thickness. For the ore-bearing fluids effectively injecting into the magma, the minimum critical thicknesses for the three representative dikes are 33.45 m for granite porphyry, 8.22 m for quartz diorite and 1.02 m for diabase, indicating that ore-bearing dikes must be thicker than each value. These results are consistent with the occurrence of ore bodies, and thus they

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could be applied in practice. Based on the statistical relationship between the length and the width of dikes, these critical thicknesses are used to compute critical areas: 0.0003–0.0016 km^2 for diabase, 0.014–0.068 km^2 for quartz diorite and 0.011–0.034 km^2 for granite porphyry. This implies that ore-bearing minor intrusions have varied areas corresponding to their composition. The numerical simulation has provided the theoretical threshold of exposed thickness and area of the ore-bearing intrusion. These values can be used to determine the ore-forming potentials of dikes.

1. Introduction

The large and super-large ore deposits are commonly relevant to minor intrusions (Tanng and Li, 2006). The mineralization mechanism is, however, not well understood. These minor intrusions are generally considered to be protrusions of deep batholiths or their branches (Lowenstern, 1994; Heinrich, 2005). Therefore, they have not been studied thoroughly, and do not have strict definition. Tang (2002) and Tang et al. (2007) examined the relationship between scales of intrusions and their ore-forming potentials, suggesting that the minor intrusion might bear large deposits. In comparison with large intrusions, minor ones have obviously different mechanism in generation, ascent and emplacement. Thus some traditional petrologic understandings cannot be directly applied to minor intrusions. However, the ore-forming mechanism and the identifiable criteria of minor intrusions are not clear, and it is not known how to find the ore deposits in minor intrusions. Therefore, it is crucial to understand the nature of minor intrusions, which will give good understanding of the ore-forming mechanism and geologic prospecting.

Due to the various extent of exposure, it is difficult to strictly define an intrusion as a minor intrusion. Luo et al. (2009) suggested that a minor intrusion can be considered as an analogue of a dike with the same volume. Thus, minor intrusions can be studied as dikes. However, most of the dikes or veins are not ore-bearing, the ore-forming potential of an intrusion is related to the amount of ore-bearing fluids injected into the intrusion based on the transmagmatic fluid hypothesis (Luo et al., 2008, 2009). As the dikes and veins cool rapidly, ore-bearing fluids would not mix with them. The role of these dikes is primarily to prevent the dissipation of ore-bearing fluids, and the ore-forming metals are generally concentrated in these porphyry intrusions in the region where dike swarms occur (Luo et al., 2008, 2009). This can be seen in the Antuoling molybdenum ore district, Hebei province, where the porphyry molybdenum deposit is located in the region where is distributed the post-orogenic dike complex (Luo et al., 2009).

There is currently no quantitative evaluation involving the relationship between the dike thickness and its ore-forming potential. This paper aims to simulate the cooling time and its viscosity effect of the representative dikes in the Shihu gold deposit, and to shed light on the relationship between the dike thickness and its ore-forming potential.

2. Geological model for the dike metallogenesis

According to the metallogenic theory by transmagmatic fluid (Luo et al., 2007, 2008, 2009), the ore-forming potential of an intrusion depends on the magnitude of the injected ore-bearing fluids, the solubility of metals in the fluids, and the ability of magmas entrapped ore-bearing fluids. Therefore, the preconditions for ore-forming potentials of dikes are: (1) that large volume of ore-bearing fluids can inject into them, and (2) that ore-bearing fluids can be entrapped within these intrusions before ore minerals deposit.

Generally, the magma mixing occurs in a chamber when magmas have the similar viscosities (Sparks and Marshall, 1986). The viscosity of ore-bearing fluids is much lower than that of silicate melts. Therefore, their mixing cannot theoretically occur in a short time, and ore-bearing fluids can only partially dissolve into melts. The ore-forming potential of the magma is then limited. Nonetheless, if the ore-bearing fluids pass through the intrusion from the bottom, it is then possible for ore-bearing fluids to mix with melts due to their higher activities and lower densities. This would lead to produce abundant ore-bearing magmatic fluids, and enhance mineralization potentials of magmas. Especially in case of the exsolution of gas phase from fluids, the gas expansion can make more fluids into melts, which was proved by the volcanic eruption experiment (Trigila et al., 2007).

The viscosity of magma decreases as the temperature increases (Giordano et al., 2008). Rapid increase in magma viscosity in dikes occurs when the heat transfers from the dike to the host rock. Ore-bearing fluids cannot effectively enter into the dike when the magma viscosity reaches a critical value. The declining rate of the temperature depends on the thermal properties, emplacement depth, volumes of the magma and the ratio between the surface area and the volume. Within the required cooling time for magma viscosity to reach the critical value, the capability of ore-bearing fluids entering into magmas can be evaluated. The minimum critical thickness of the ore-bearing dike (MITOD) can also be estimated. Similarly, if the dike is thick enough, the time required to reach the critical viscosity will be much longer, resulting in ore-bearing fluid escaping from the magma, and entering into the host rock. By estimating the rate of fluids escape, the maximum thickness of the ore-bearing dike (MATOD) can be evaluated. Areas of dikes can be calculated based on a statistical relationship between the thicknesses and the length of dikes (Rubin, 1995a; Gudmundsson, 2000). By using numerical simulation of ore-bearing dikes, it is possible to constrain the minimum and maximum thickness of them, thereby giving a more precise definition of the exposed area for small intrusions.

With the above understanding, we try to present a geological model of dike mineralization. The dikes, characterized by the small volume, various composition and synchronous injection in a region, are treated as a specialized dike swarm (Luo et al., 2006), and might provide channels for ore-bearing fluids (Luo et al., 2008). To test this hypothesis, we assume that dikes are similar to the connecting pipe model (Fig. 1). If all dikes at the time of emplacement are roughly at the same level, the temperature of the host rock might be similar. If (1) the thermal conductivity of the