題號： 177　　　　國立臺灣大學 115 學年度碩士班招生考試試題

科目： 環境科學概論(B)

節次： 8

※ 注意：請於試卷內之「非選擇題作答區」標明題號依序作答。

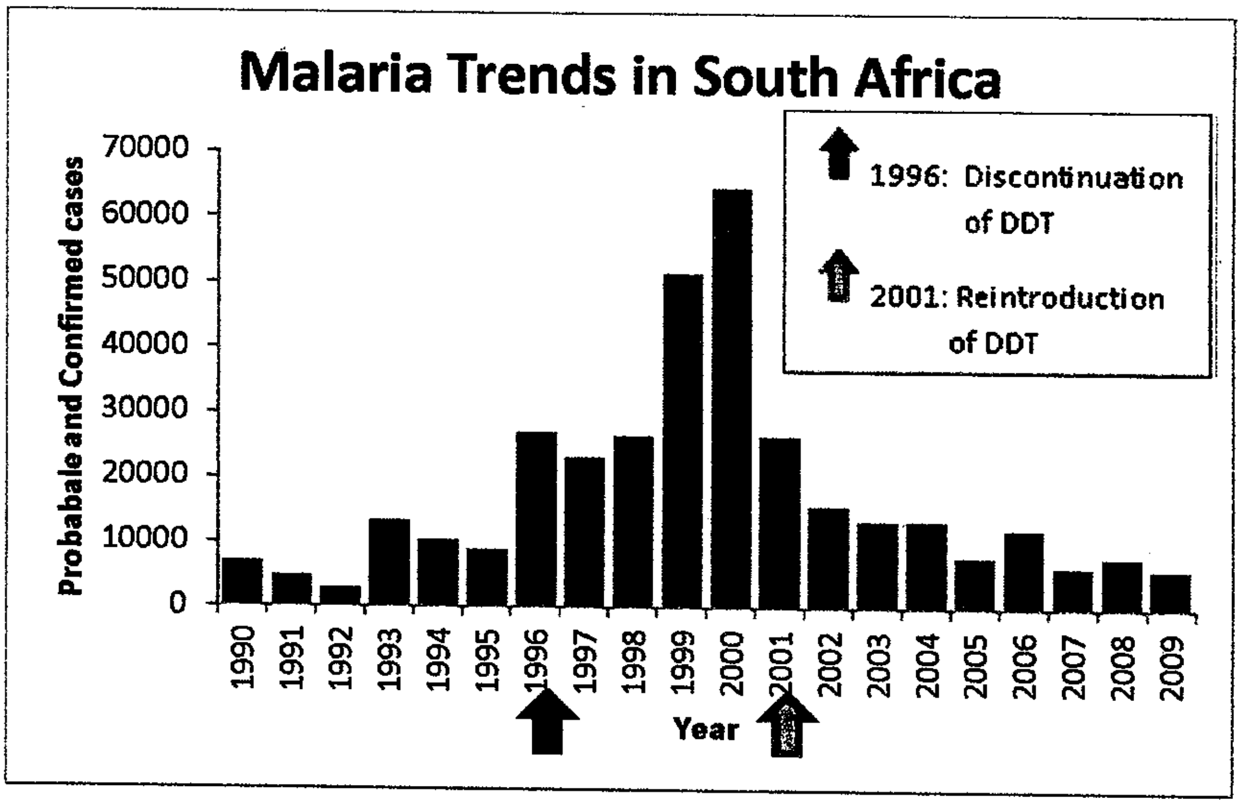
1. (25%) Elaborate the potential environmental concerns when (re)-extracting metals from abandoned mines based on the article by Bao *et al.* (文章請參閱試卷第 2、3 頁，Extracting resources from abandoned mines)

2. (25%) Heap leaching is described on page 732 of Bao *et al.* (本試卷第 3 頁). Suppose that heap-leaching (described on page 2 and visualized in the figure) is used to extract residual Cu from mine wastes. Develop a differential mass balance equation of dissolved/leached Cu in the leaching pond. (i) Set up your system with a diagram with relevant streams and variables. (ii) Define your variables and provide their units. (iii) State assumptions and limitations inherent in your equation.

3. (15%) 請闡述貧窮、糧食不均、以及人口過度增長對於環境可能造成的衝擊。

4. (20%) 請繪出自然界的氮(Nitrogen)循環圖。請將以下元素考慮繪入你的圖中(如有需要可自行添加其他合理元素入圖):
   - 環境介質: 海洋、河川、湖泊、土壤、地層、大氣。
   - 自然/人為的氮源/匯: 火山、大氣、水生與陸生植物、土壤微生物、火力電廠、汽機車、肥料工廠。
   - 反應機制: 固氮作用 (Nitrogen Fixation)、脫硝作用 (Nitrification)、反硝化作用 (Denitrification)、同化作用 (Assimilation)、氨化作用 (Ammonification)。
   - 考慮的氮物種: N_2、N_2O、NO_x、NH_3、NO_2^-、NO_3^-。

5. (15%) 下圖為南非在 1996 年停用 DDT (Dichlorodiphenyltrichloroethane)後與 2001 年再次使用 DDT 後，瘧疾(Malaria)發生的案例變化情形。請(1)提出停用與再次使用 DDT 之可能原因，(2)說明使用 DDT 對環境生態造成的負面衝擊，以及(3)如不使用 DDT，請提出至少三種可以控制瘧疾傳染的方法。



資料來源: Channa et al. Prenatal exposure to DDT in malaria endemic region following indoor residual spraying and in non-malaria coastal regions of South Africa, *Science of the Total Environment*, 2012, 183-190.

見背面

GEOLOGY

Extracting resources from abandoned mines

Recovering minerals and metals from abandoned mines could aid decarbonization

By **Zhongwen Bao, Carol J. Ptacek,**
and **David W. Blowes**

The development of environmentally friendly technologies (e.g., electric vehicles, wind turbines, solar panels, and lithium-ion batteries) to achieve a low-carbon future will require large quantities of critical minerals and metals (*1*). Mining and extraction of these materials are anticipated to generate substantially larger volumes of mine wastes, including waste rock and tailings (*2*). The release of contaminated water from mine wastes can cause long-term environmental damage and land degradation, posing challenges for pollution control and environmental remediation. Resource extraction from contaminated water, mine wastes, and mine workings (e.g., unexploited open pits and underground tunnels) at abandoned mines could potentially address the increased demands of critical minerals and metals for decarbonization. However, careful planning is required to ensure that negative environmental effects are not exacerbated during resource recovery at abandoned mines.

Mining activities can have long-term positive impacts by supplying valuable minerals and metals to advance economic development, energy transition, infrastructure construction, and technological innovation. However, mining has also caused environmental and societal harm. Vast quantities of potentially chemically reactive wastes are accumulated over large land footprints at mine sites. Globally, land that has been affected by mining amounts to 66,000 km², including waste-rock piles, tailings impoundments, and open pits as well as mining and processing infrastructure (*3*). Much of this mining-affected land includes abandoned mines, which are neither in operation nor managed. Mines are abandoned for a variety of reasons, including depletion of ores, commodity price fluctuations, and technical challenges associated with mining deeper ores. The global area of land use and contamination level at abandoned mines are unknown. Yet, there is a distinct contrast between the number of active mines and the much larger number of abandoned mines. For example, in Canada, there are ~200 active mines compared with more than 10,000 abandoned mines.

Each abandoned mine has distinct attributes, including the physicochemical and geotechnical characteristics of mine-waste deposits and mine voids. These characteristics strongly influence the impacts to land, water, and ecosystems, including releases of water contaminated with high concentrations of toxic metals and metalloids [e.g., acid mine drainage (AMD)] and releases of carbon dioxide (CO_2). Chronic releases of AMD and catastrophic failures of tailings dams lead to "dead zones" at mine sites, which exhibit biodiversity loss, land deterioration, and degraded surface water and groundwater and can be detrimental to human health (*4*). For instance, in 1999, an extremely low pH of −3.6 was reported in AMD from the Richmond Mine of the Iron Mountain copper deposit, USA, which was mined in the early 1900s (*5*). This AMD resulted in fish death and vegetation denudation. Additionally, release of dissolved contaminants and alteration of groundwater and surface water flow systems can harm aquatic ecosystems, such as effects on salmonids (ray-finned fish) and their habitat in northwestern North America as a result of tailings dam failures, such as that at Mount Polley Mine, Canada, in 2014 (*6*).

Although the stored mass of mine wastes is uncertain, an estimated global mass of tailings totals 223 billion metric tons generated from 1771 to 2019, whereas the total mass of waste rock is estimated to be about 10 times that of the mass of tailings (*7*). Exposure of sulfide-bearing mine wastes to water and oxygen triggers complex microbial-catalyzed biogeochemical reactions that generate acidic, neutral, and saline mine drainage. Mine wastes prone to AMD frequently cause the most severe water quality problems that persist for thousands of years (*5*), and thus AMD has been the focus of intense research and environmental remediation. However, neutral and saline mine drainage also have the potential to cause environmental degradation. Selective mining, segregation and encapsulation, subaqueous disposal, lime or limestone addition, cover construction to limit water infiltration or oxygen ingress, and passive techniques (including constructed wetlands, bioreactors, and permeable reactive barriers) have been widely applied to facilitate AMD mitigation either at the source or along the migration pathway (*8*). Typically, a combination of these techniques is implemented.

These AMD mitigation strategies may demonstrate short-term success; however, their long-term performance remains uncertain under changing climate scenarios. For example, subaqueous disposal of tailings into inland water bodies and oceans limits AMD generation by reducing the oxygen supply. It was found that ocean acidification and the present temperature increase caused by climate change can enhance metal leaching from tailings disposed below a deep-water cover, potentially decreasing water quality and causing negative environmental effects (*9*). Without permanent remediation, the long-term impacts of mine wastes on terrestrial and marine ecosystems will persist.

Supplies from active mines cannot currently meet the increased demands for critical minerals and metals for decarbonization measures. Individual mines are operated to recover targeted commodities, which are determined by the economics of mining, processing, and global availability. Mine wastes at abandoned mines may contain recoverable concentrations of rare earth elements (REEs), platinum group elements, and metals—e.g., cobalt, copper, lithium, and nickel—that are more accessible than the low-grade ores that are currently mined (*10*). Many of these elements are indispensable in technology development to achieve carbon-zero goals. Therefore, AMD, mine wastes, and mine workings at abandoned mines are being evaluated as potential sources for these critical minerals and metals. Integration of resource exploration and recovery with environmental remediation provides a promising opportunity to gain value from mine wastes while tackling the environmental challenges associated with abandoned mines.

Assessing the resource potential of critical minerals and metals in AMD, mine wastes, and mine workings at abandoned mines is the first step. Abandoned mines are often located in remote locations with sensitive environments. Appropriate remediation designs, characterization studies, and monitoring programs are needed to as-

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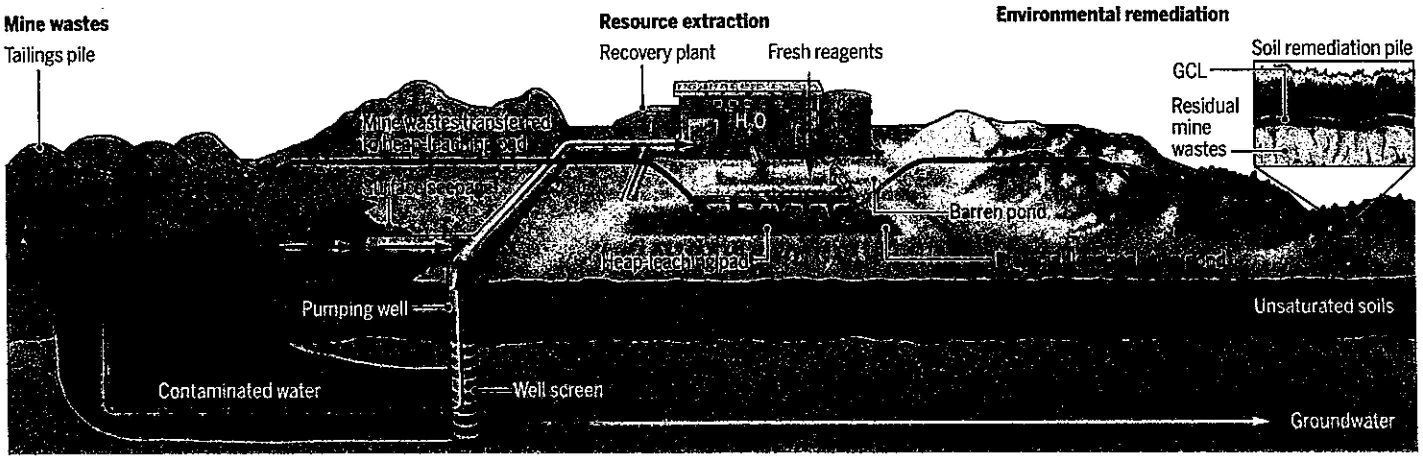

Resource recovery and environmental remediation at abandoned mines

Minerals and metals that are in high demand could be recovered from abandoned mine wastes (tailings and waste rock) through heap leaching, which could also mitigate environmental contamination. Combining this approach with environmental remediation of any residual mine waste, such as with multilayer vegetated soil covers [including a geosynthetic clay liner (GCL)], could achieve long-term mitigation of the impacts of abandoned mines. However, potential pollution from heap leaching should also be addressed.

sess the spatial distribution, bioavailability, and migration pathways of contaminants. Many national inventories of abandoned mines with different risk categories and national registries have been established. For example, national mine-waste registries in France, Hungary, Italy, Portugal, Slovenia, Spain, and the UK were created with basic information that can be used for evaluating potential resource recovery (*11*). Resource potentials of other critical minerals and metals (particularly REEs) in mine wastes should be jointly assessed in conjunction with site-specific characterization and monitoring programs to enhance knowledge of the behavior of critical minerals and metals as well as their geochemical interactions. These efforts will complement the knowledge gap in national mine-waste registries and facilitate decision-making to shift abandoned mines from a source of pollution to a resource for mineral recovery.

Advances in exploration and recovery techniques of critical minerals and metals from different waste streams are promising. In Europe, underwater robots, although still at the prototype stage, were successfully demonstrated for exploration of critical minerals and metals at flooded abandoned mines without dewatering costs and groundwater impacts (*12*). Traditional AMD treatment through neutralization using lime or limestone generates large quantities of sludges that are rich in iron oxyhydroxides, REEs, and other valuable minerals. High-grade aluminum, REEs, cobalt, and manganese were recovered from sludges during AMD treatment using neutralization reagents through a three-staged, pH-dependent precipitation and crystallization process (*13*).

Heap leaching is a method for economical recovery from low-grade ores for the extraction of, for example, copper, gold, and uranium (*14*). This method requires the application of leaching solutions (such as sodium cyanide for gold) through ore-bearing heap pads. Leaching solutions dissolve targeted minerals and metals into pregnant leach solution ponds and are subsequently recovered; the barren solutions can then be mixed with fresh reagents and recirculated into the heap-leaching pads. Given that mine wastes might have higher amounts of critical minerals and metals compared with the low-grade ores that are currently mined, heap leaching could function as a feasible technique for resource recovery at abandoned mines (*10*, *15*). A combination of resource recovery through heap leaching with implementation of environmental remediation (e.g., a multilayer vegetated soil cover) may serve as a potentially sustainable solution for mine-waste management and pollution control (see the figure).

Caution is needed to prevent the introduction of new environmental pollution and harm during resource recovery from mine wastes. For instance, a drainage protection layer should be implemented to prevent the infiltration of leach solutions into underlying soils and groundwater to avoid the long-term retention of hazardous materials in the subsurface. Residual solid wastes after heap leaching need further characterization for proper disposal through environmental remediation. Notably, industrial applications of heap leaching are mostly used for the recovery of copper, gold, and uranium from low-grade ores, whereas heap leaching for resource recovery from mine wastes is still under development. Further research is needed to evaluate the potential impacts of the commercialization of these exploration and recovery techniques through thorough monitoring and evaluation programs in laboratory-, pilot-, and industrial-scale applications and to make the extraction of critical minerals and metals from these waste streams environmentally friendly, socially acceptable, and economically feasible. ■

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