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Dear Ms. Fleming,

I am writing to respond to the following questions from you:

1. What are the typical environmental risks associated with silver mining?
2. Which of the typical environmental risks might be particularly relevant to the region near Cobscook Bay and Passamaquoddy Bay in Maine?

In this memo, I am not evaluating the merits of any particular existing or proposed silver mine.

There are many types of environmental risks associated with mining, ranging from air pollution to greenhouse gas emissions to soil contamination to excessive traffic. However, in the case of silver mining, the problem of acid mine drainage is so pervasive and destructive that I would like to devote this entire memo to this subject. Acid mine drainage can occur with all sulfide ore mining, that is, from ore bodies that include sulfide minerals. It is occasionally still possible to find native silver in the form of nuggets or flakes. However, these are only artisanal or hobby mines and all modern industrial mining of silver involves the extraction of silver from sulfide ore bodies.

Sulfide minerals are typically stable when they are beneath the surface. Mining involves the excavation of these minerals so that either tailings (the crushed ore that remains after the commodity of value has been removed) or waste rock (the rock that must be removed to reach the ore body) are left on the surface. Acid mine drainage occurs when these sulfide minerals are exposed to oxygen and water on the surface, so that the oxidation reaction converts the sulfides into sulfuric acid. The generic reaction can be written as a balanced chemical reaction as

2FeS2 + 7O2 + 2H2O → 2Fe+2 + 4SO4-2 + 4H+

or in words as

pyrite + oxygen + water → dissolved iron + sulfuric acid

Pyrite (iron sulfide) is the most common sulfide mineral, but many other metallic elements form sulfides, such as arsenopyrite (iron arsenic sulfide or FeAsS), chalcopyrite (copper sulfide or CuFeS2), galena (lead sulfide or PbS), or sphalerite (zinc sulfide or ZnS). Silver can occur as the sulfide mineral argentite (Ag2S), but it is more common for silver to be contained within the crystal structure of another sulfide mineral. All of the sulfide minerals typically include other heavy metals as part of the crystal structure. Therefore, the oxidation of sulfide minerals also releases all of the heavy metals that were part of the crystal structure.

The consequences of acid mine drainage are acidity, dissolved heavy metals and dissolved sulfate in surface water and groundwater downstream of the mining operation. These consequences can have detrimental impact upon municipal or private water supplies, as well upon aquatic health and the health of plants. It is important to note that acid mine drainage can induce a positive feedback in that the downstream load of dissolved metals can greatly exceed the dissolved metals that result from the oxidation of the exposed sulfide minerals. Stream sediments typically include clay minerals, whose surfaces have negatively-charged sites that bind cations (positively-charged ions). Most dissolved metals are cations, although there are some exceptions, such as arsenic, molybdenum and uranium, which occur in dissolved form as oxyanions (polyatomic negatively-charged ions that include oxygen). When acidic water interacts with these stream sediments, the hydrogen cations displace other cations (such as metallic cations) from the negatively-charged sites, so that metals are no longer fixed onto sediment, but are mobilized in the stream column as dissolved metals. For this reason, mine tailings or mining-affected sediments in stream beds are often referred as a “chemical time bomb.” These mine tailings or mining-affected sediments can be sequestering a substantial load of metals that can be mobilized into the stream following an increase in stream acidity, which could occur after sulfide exposure due to a new episode of mining.

There are a wide variety of means for mitigating acid mine drainage. For example, the tailings or waste rock can be mixed with crushed limestone, which could neutralize the acidity, although it would not remove the excessive sulfate or dissolved metals. Tailings or waste rock piles could be underlain by liners, although all liners will eventually leak and degrade. The acid mine drainage could be collected and treated, although perpetual collection and treatment is not realistic, even though the tailings and waste rock will exist on the surface in perpetuity. The tailings can be permanently covered with water, although this is no longer a recommended practice because it can lead to instability of the tailings pile. Some acid mine drainage can be prevented by converting the waste rock and tailings into a paste and returning it to the exhausted underground mine workings. This does not guarantee that none of the tailings or waste rock will ever be exposed to oxygen and water and, because of expansion of the waste rock and ore after excavation and processing, only a fraction of the waste materials can be returned to the exhausted underground mine. In summary, no single mechanism suffices for the mitigation of acid mine drainage and a mining project must consider a variety of mechanisms.

Although it is theoretically possible for a silver mine to operate without water pollution, such a silver mine has never existed. As an illustration of this, in 1997, Wisconsin passed a “Prove It First” law for sulfide ore mining. According to this law, a sulfide ore mining operation could be approved only if the proponent presented evidence that sulfide ore mining could in fact be carried out without adverse environmental impacts. Specifically, the proponent had to find at least one sulfide ore mine in the US or Canada that had been operating for at least 10 years and at least one mine that had been closed for at least 10 years without contaminating ground or surface water from acid mine drainage at the tailings site or mine site or from the release of heavy metals.

On various occasions, the sulfide mining industry presented seven model mine candidates with claims of no history of water contamination. These seven mines were the Flambeau copper-silver-gold mine in Wisconsin, the Eagle copper-nickel mine in Michigan, the Baghdad copper mine in Arizona, the Raglan nickel mine in Quebec, the Cullaton Lake gold mine in Nunavut, the Sacaton copper mine in Arizona, and the McLaughlin gold mine in California. All of these applications were unsuccessful because, in fact, all of these mines had a history of water contamination. New sulfide ore mines were able to open in Wisconsin only after the repeal of the “Prove It First” law in 2017.

Right now, the state of Minnesota is debating its own version of a “Prove It First” law. One surprising aspect of the debate is that the sulfide ore mining industry and its supporters are presenting the same list of seven model mines, even though those mines have already been discredited. In other words, no new model mine candidates have emerged in the last 24 years.

At this point, it should be clear as to why silver mining would be particularly problematic in the region near Cobscook Bay and Passamaquoddy Bay in Maine. The worst-case scenario for the consequences of acid mine drainage would be the following:

1. private and municipal water supplies downstream from the mining operation
2. fishing and shellfish industry downstream from the mining operation
3. prior history of mining (so that stream sediments could already carry a high metal load)

I believe that the Cobscook Bay and Passamaquoddy Bay areas include all elements of the worst-case scenario.

Please let me know if I can help with anything else or if you would like a detailed analysis of a particular existing or proposed silver mine.

