Rare and Precious Part 2

By John Benson

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1. Introduction

About a week before the original "Rare and Precious" was scheduled to post, I received my hardcopy of my monthly IEEE Spectrum. Actually I may have received it a few days earlier, but I believe my wife grabbed the mail that day, and it disappeared onto the stuff on her desk. When this happens, I catch my mail when I periodically dig through this stuff looking for my stuff or anything that needs immediate attention.

Once I found the Spectrum Issue, it took me a few days thereafter to read through this issue until I saw the paper version of the article referenced here.[1]

I knew right away that this covered similar ground to the original "Rare and Precious." This was a bit strange, as the original came from a Science article. The Spectrum article covered a similar narrative from the viewpoint of a private firm (as Spectrum articles frequently do). The subject was the same: the search for critical (rare and precious) elements.

However the first part of this story is better told by the original Rare and Precious. This is the major federal funding source that drove both of these projects (USGS' Earth MRI initiative). Thus If you have not read the original post, you might start with that, which is referenced here:

Rare and Precious: *I have recently spent much time delving into new materials: "Many of my papers start with a chemists identifying a material that performs a particular function much more effectively than the incumbent material."*

However there is one type of material that chemists cannot create, elements. There are currently 118 elements. Other than using nuclear physics to create them (one atom at a time) there are only two ways to obtain elements: (1) recycle used materials to obtain their component elements, or (2) mine the ore containing the element, and refine it.

https://energycentral.com/c/rm/rare-and-precious

These posts actually complement each other and cover different parts of, and different methods for this search (and this one doesn't have a periodic table of elements).

2. KoBold Metals

In June 2022, six Boeing 737s—fully loaded with tents, food, satellite Internet equipment, drones, geophysical survey gear, drilling equipment, and a team of experienced geologists—flew to a remote airstrip in northern Quebec. The geologists were hunting for major deposits of the minerals needed to power a clean-energy future. Given the mix of cutting-edge scientific computing and old-school bravado, it was as though they were channeling Alan Turing and Indiana Jones simultaneously.

[1] Josh Goldman and Kurt House, IEEE Spectrum, "This AI Hunts for Hidden Hoards of Battery Metals," April 29, 2023, https://spectrum.ieee.org/ai-mining

Our startup, KoBold Metals, acquired an 800-square-kilometer (309 square-mile) mineral claim in the region based in part on predictions from our artificial intelligence systems. According to the AI, there was good reason to believe we'd find valuable deposits of nickel and cobalt buried below the surface. Summer snowmelts in this near-arctic region created a brief window to bring in a small village's worth of equipment and personnel to test our predictions.

We cofounded KoBold in 2018 with backing from Bill Gates's Breakthrough Energy Ventures and Silicon Valley venture capital firm Andreessen Horowitz. Our goal is to develop ways to discover major new deposits of vital metals needed for electric vehicle (EV) batteries—for which there is an enormous and growing need.

We're trying to transform mineral exploration from a manual, judgment-guided, trial-and-error process into a data-driven and scalable science. It's the mother of all needle-in-a-haystack problems: Find the significant minable deposits of cobalt, copper, lithium, and nickel resting anywhere from 100 to 2,000 meters deep in the Earth's surface.

Preventing the most catastrophic impacts of climate change requires achieving net-zero greenhouse gas emissions by 2050, which includes, among many other things, replacing all fossil-fuel-powered cars and trucks (etc.) with electric vehicles. That, in turn, will require manufacturing billions of EV batteries. Even today's demand for the metals outstrips supply—as evidenced by nickel prices doubling and lithium prices quintupling over the last year. To realize a global transition to electric vehicles, we'll need to discover and mine an additional US $15 trillion worth of cobalt, copper, lithium, and nickel by midcentury. (We're currently on target to mine about $3.6 trillion worth of these metals by 2050)…

Investors are aware of the supply challenge as well. In February 2022, KoBold raised $192.5 million in Series B financing, which has gone toward securing more than 50 exploration sites in Australia, Canada, Greenland, sub-Saharan Africa, and the United States. We plan to use AI to streamline the largely scattershot process of discovering new ore deposits. Once they're discovered, we plan to partner with mining companies for the actual mining operations and advise them on efficient extraction, again using our AI tools…

The mining industry's rate of successful exploration—meaning the number of big deposit discoveries found per dollar invested—has been declining for decades. At KoBold, we sometimes talk about "Eroom's law of mining." As its reversed name suggests, it's like the opposite of Moore's law. In accordance with Eroom's law of mining, the number of ore deposits discovered per dollar of capital invested has decreased by a factor of 8 over the last 30 years. (The original Eroom's law refers to a similar trend in the cost of new pharmaceutical discoveries.)

Geologically speaking, the decline in new discoveries is largely because most of the easy-to-spot deposits, such as those on the surface, have been found. New discoveries will be deeper underground, concealed by layers of rock.

Author's comment: KoBold Metals' Metals headquarters is in Berkeley, CA, about a block from the University of California. Link to their website is below.

https://www.koboldmetals.com/

In fact, the vast majority of Earth's ore deposits are still waiting to be found. The chemical and physical processes that form these ores occur at temperatures and pressures that exist kilometers below the surface…

At KoBold, we're treating exploration as an information problem—finding and analyzing multiple types of data in order to uncover what we're looking for. In particular, it's an information problem in which acquiring more of those data types comes at a high cost. Our solution is to combine AI systems with geoscience expertise to figure out what piece of information reduces our uncertainty the most.

There is a vast body of geoscience information already in the public domain, but it's dispersed and fragmented. Some of it comes from government-funded geological surveys, and some comes from surveys conducted by private companies that were required to make their findings public. This information is spread across millions of data sets, including geological maps showing types of rocks observed in different locations; geochemical measurements of the concentrations of dozens of elements in samples of rock, soil, drill cores, plants, and groundwater; geophysical measurements of the gravitational field, magnetic field, natural and induced electric currents, seismic waves, and radiation from the decay of heavy-element nuclei in Earth's crust; satellite imagery—in both visual and infrared bands—measuring the spectral reflectance of minerals at the Earth's surface; and text reports describing field observations. The volume of data is, in a word, overwhelming.

Our data system, called TerraShed, parses this information and brings it into a standard form to make it accessible and searchable by both humans and algorithms. Curating the data and putting it through quality control are just the first steps. We then use various algorithms to guide our decisions about what data to collect at each stage in the exploration process, from getting a sense of whether a particular deposit is worth mining all the way to construction of the mine itself…

Our exploration program in northern Quebec provides a good case study. We began by using machine learning to predict where we were most likely to find nickel in concentrations significant enough to be worth mining. We train our models using any available data on a region's underlying physics and geology, and supplement the results with expert insights from our geologists…

After we acquired the relevant land rights, our geologists worked out of a field camp on-site, making observations and taking measurements of rock outcrops. Across the more than 800 km^2 of our claims, the choice of which rocks to sample is practically limitless. Time and money, however, are not—and in the region we were working, there's less than a three-month window when the ground is free of snow.

So, the information challenge becomes: How do we decide which rocks to sample?

We built Machine Prospector, which comprises the machine-learning models, with historic data, such as information from previous discoveries elsewhere in the province. It helped us predict which rocks we should sample, given the limited time we had. Specifically, we were looking for spots where eons-long geologic processes would have formed nickel- and cobalt-rich magmatic sulfide deposits.

Our models generated predictions with 80 percent lower false positive and false negative rates compared to conventional predictions from geological maps. Such maps are constructed by making observations of the rocks at a relatively small number of locations and then using a set of rules and principles to extend those observations to larger regions. That means the conventional predictions are largely inference—and worse, they result in unquantified uncertainty. In other words, we don't know what we don't know about how accurate those maps are. By comparison, KoBold's predictive models do quantify uncertainty, which in turn guides our data collection, as the most uncertain rocks often represent the most valuable ones to sample.

Guided by the results from our AI systems, our field team found a large boulder field that geologist Lucie Mathieu identified as very anomalous, and not typical of the kind of igneous rock making up most of the region's boulders.

The boulder field originally piqued our interest after electromagnetic measurements we had taken indicated unusually high conductivity—consistent with the kinds of minerals we were seeking. The electromagnetic data was gathered by a helicopter towing a 30.5-meter-diameter transmitter coil loop for a daily time-domain electromagnetic survey.(see image below) For these surveys, the transmitter pulses current through the loop at 7.5 hertz, which induces currents in conductive materials underground. When the transmitter pulse ends, the receiver coil detects the decay of those induced subsurface currents, enabling us to build a three-dimensional model of the subsurface rocks' conductivity. The high electrical conductivity of the ore minerals we're seeking is just one of several things that we can use to distinguish ore from other rock.

In order to survey large areas quickly, KoBold uses a helicopter carrying a transmitter coil loop 35 meters in diameter that can detect conductive bodies, such as ore deposits, below the surface.KOBOLD METALS

To do better, we quantify the uncertainty in our predictions about the subsurface. Our machine-learning models are trained on many fewer parameters than traditional best-estimate models, and the parameters are directly related to the key exploration questions: How many conductive bodies are present? How deep are they? What is their orientation? Is their conductivity in the range that's consistent with high concentrations of ore minerals? The output of our models is the joint probability distribution of these parameters.

Ultimately, the most useful data to collect is that which reduces the uncertainty of finding an ore deposit that can be mined. Together with our collaborators at Stanford University's Mineral-X initiative, we have developed a novel way of quantifying how useful an incremental piece of data is. We published the framework, which we call "efficacy of information," in Natural Resources Research in March 2022, and we used it to design our drilling program for our northern Quebec exploration and for our other expeditions.

Over the course of the summer in Quebec, we drilled 10 exploration holes, each more than a kilometer away from the last. Each drilling location was determined by combining the results from our predictive models with the expert judgment of our geologists. In each instance, the collected data indicated we'd find conductive bodies in the right geologic setting—possible minable ore deposits, in other words—below the surface. Ultimately, we hit nickel-sulfide mineralization in 8 of the 10 drill holes, which equates to easily 10 times better than the industry average for similarly isolated drill holes.

That particular discovery was made just days before the end of the field season. The data helped define the subsurface geology so that our team will start the next season—which begins soon—by making the most effective drill holes to establish the shape and size of that ore deposit.

Assuming that ore deposit and others we've begun to identify in the area turn out to be as promising as we hope, we'll be well on our way toward another mine for one of the crucial metals needed to electrify the planet. Collectively, the world needs at least 1,000 new mines to be developed by midcentury to provide enough critical metals to produce enough EVs and avoid the worst consequences of climate change. That's a tall order. But by applying new AI systems like KoBold's, we may just be able to dig up new opportunities fast enough.

Author's comment: I deleted details in the above article that were not necessary to provide a reasonable summary. If you are interested in the above, I would strongly suggest that you click through the link in reference 1 and read the entire article.

Although the primary goal of this paper is a review of intelligent prospecting for high-value minerals, it also has another purpose.

Many professionals have advocated a "pause" in using AI. This seems to be driven by a fear that using AI could have unintended consequences. I have a different opinion. AI's only function is to search for and describe knowledge, and this <u>cannot</u> be dangerous.

I use a Microsoft Edge Web Browser, which uses a Bing Search Engine, which uses AI. I find the latter very useful, but also very limited. The above article describes how AI, when combined with human-professionals' knowledge and technology, can help us solve one of our most important problems – finding rare and precious materials we need for many of our machines. The most important of these machines are those we need to mitigate climate change, like electrified vehicles and grid battery energy storage systems. The most dangerous thing in this paragraph is "climate change", not "AI."