VIEWS

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Cognitive Biases and Fallacies in Decision-Making During Mineral Exploration

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There are numerous cognitive biases and fallacies that are relevant to mineral exploration. Explorationists must be aware of these so that more rational decisions can be made, resulting in exploration programs with a higher probability of success. Illustration of their impact on exploration decision-making can lead to simple strategies to avoid these issues.

Cognitive biases have been recognized in various forms for millennia; however, their study was formalized and integrated into models of human behavior by Israeli researchers Daniel Kahneman and Amos Tversky, among others, in the early 1970s (Lewis, 2017). Cognition refers to our thought processes, and cognitive biases are people's systematic but often flawed thought processes relating to judgment and decision problems. Many cognitive biases are believed to have an evolutionary basis, giving humans some selective advantage through rapid decision-making using mental "shortcuts" (heuristics) under conditions of uncertainty (Haselton et al., 2005). For example, pulling back from a rustling in the bush, even if it was due to the wind or a covey of quail rather than a real threat, may have led to enough people surviving to reproduce more often than those who investigated the source of the sound before reacting that it became ingrained behavior. The cognitive biases and fallacies that I believe are relevant to mineral exploration are reviewed below, followed by some examples and suggested remedies.

Cognitive Biases and Fallacies: Examples from Mineral Exploration

We are faced daily with masses of information, which must be processed and remembered. To reduce the confusion and uncertainty inherent in this, humans tend to organize this information into a simple, linear narrative. Often this story is deterministic, with the outcome made to seem inevitable based on the prior sequence of events when, in reality, most of life is stochastic, with a huge element of randomness and a wide range of outcomes possible, depending on the probability distributions of the individual input variables. So, instead of increasing our understanding of the information, our story can actually result in a highly confident but false explanation—thus, the narrative fallacy (Taleb, 2007).

Patternicity (Shermer, 2008) is related to the narrative fallacy. It is the tendency to find meaningful patterns in random noise. Both conspiracy theories and spurious exploration targets may result from this bias. Once a narrative is constructed, or a pattern elucidated, we humans have an unfortunate tendency to selectively filter through the data available to us for those that support it. This is known as confirmation bias (Nickerson, 1998; Taleb, 2007).

A good example of the dangers of the narrative fallacy, patternicity, and confirmation bias in mineral exploration, as well as in other fields of endeavor (e.g., business education), is the use of case studies. In mineral exploration, case studies take the form of discovery histories, and are used as the basis for, or in support of, designing exploration programs. Sillitoe's excellent series of publications on the discovery history of circum-Pacific deposits (e.g., Sillitoe, 2010) is a popular source of discovery narratives. However, the critical unanswered question rarely addressed when using case studies is, How many exploration programs followed similar strategies and tactics and used similar mixes of techniques as the successful ones, but failed? This negative evidence, lying fallow in the files of mining companies, is critical for evaluating the relative merits of different exploration strategies and techniques on an objective basis. While they are proprietary and not available to the general public, these data could certainly be compiled in house, particularly at a major mining company with a long history, together with the success stories, to give a much more objective picture. Often, a review of completely unbiased data begs the really uncomfortable question, Was success or failure (discovery or no discovery) simply due to luck (e.g., survivorship bias; Taleb, 2007), not the design or execution of the program or the brilliance of management or geologists in the field?

Without taking into account negative evidence (failures), irrational decisions can be made based on a flawed sample or on a current fad or trend in the business and result in failure. The best remedy for this is to build an exploration program from the ground up, based on the most effective and efficient methods for detecting the type of deposit sought in the pertinent geologic, topographical, and weathering environment. Prior to execution, a desk exercise to evaluate a proposed program using case studies could be useful, but only if based on a statistically significant *unbiased* sample of similar programs, not a handful of case studies.

The Sunk Cost Fallacy (Kahneman, 2011) causes us to rationalize the continued pursuit of an endeavor that has failed to produce positive results, simply because so much time, effort, and money have already been invested in it. The Sunk Cost Fallacy can manifest itself in a number of ways in mineral exploration, all potentially fatal. It is exemplified by statements like "We've been exploring here (in country X or region Y) for 20 years and haven't had a discovery, but we've got a good program and good people and know it better than anybody else, so we're just going to stick with it; surely we'll find something." In general, the chances of an economic discovery diminish rapidly as a play ages and the density and depth of drilling increase. Meanwhile, opportunities in less mature and/or more prospective areas are missed. Results that pass predefined hurdles as part of an overall stage-gate process should drive go/no-go decisions for an exploration project or program, not "sunk costs."

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Wishful thinking (Mayraz, 2011) describes beliefs and decisions based on the intense desire for an outcome regardless of reality, objectivity, or probability. I've found that, while explorationists are particularly susceptible to wishful thinking with respect to geopolitical risk, they are not immune to it regarding the mineral endowment of their favorite region. Statements that should be clear warning signs of wishful thinking include the following: "This time is different"; "Country X has a new government run by honest, brilliant, Western-educated technocrats, who've learned the lessons of neoliberal economics, so disregard X's history of nationalization, debt default, bad mining laws, and corruption; the geology is great, so let's open an office and begin a multimillion dollar exploration program!"; "Even though none of the deposits discovered in this geological terrane have the size, grade, or economic returns to be of interest to us, we're going to filter those out early on and get to the hidden monster." In the first case, a discovery may result, but a long-term viable business is a dubious and risky proposition. In the second, ignoring basic statistics and probability results in either no discovery or a subeconomic discovery, with explorers facing gambler's ruin.

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Evaluation of geopolitical risk of countries, provinces, etc., for entry *and* exit, is best done as a coordinated effort between geologists, locals, and international experts. Geologists and locals tend to be overly optimistic and international experts more pessimistic.

Evaluation of geological terranes for favorability for discovery of deposits that pass minimum grade-tonnage-economic return thresholds should be based on rational statistical criteria. If a significant number of deposits of the type sought are known in the terrane, then the chances of success can be quickly assessed using the relevant empirical probability distributions. If not, then global statistical parameters for the deposit type can be substituted, assuming the terrane or tract is analogous to productive ones elsewhere.

Key factors today in many tracts are (1) exploration maturity and, closely related, (2) estimated depth to the top of undiscovered deposits. These have a huge impact on both the probability of discovery and economic viability. When all of these are combined with a discounted cash flow economic model, then a powerful stochastic tool is available that can provide a solid basis for area-selection decisions.

Automation bias (Alberdi et al., 2009) is the propensity for humans to favor input from automated data-interpretation and decision-making systems and to ignore contradictory information made without automation, even if the latter is correct. If unchecked, it can be a path to wasting money by drilling spurious anomalies (false positives). Statements such as the following are clues to this cognitive failure: "This computer-generated inverse-modeled geophysical anomaly looks compelling, so even though there is little or no supporting evidence from other data (or direct observation), let's drill a hole anyway"; "We haven't come up with a decent play in this area despite decades of concerted effort by good geologists, so why don't we just feed all of the historical data into a black box and see if it generates a target?"

Automation bias and patternicity often go hand in hand. Geophysical, geochemical, or geological data are often subject to (or tortured with) multiple levels of computer processing and modeling until a "pattern" is visible. Whether it is real or simply an artifact of the processing is best evaluated by comparing the pattern with the original data and seeing if it is still resolvable. If not, it should be treated with the appropriate skepticism. Machine-generated anomalies and patterns should be just one form of input to a multiparameter targeting exercise and should be weighted accordingly. Their relative importance should be carefully evaluated by geologists with "boots-on-the-ground" experience on the program or project.

Closing Thoughts

Cognitive biases and fallacies contribute to poor decision-making in mineral exploration, as in many other fields of human endeavor. The narrative fallacy, patternicity, confirmation, and sunk cost biases are particularly prevalent and pernicious in our field. In addition, wishful thinking plays a part in many decisions, particularly with respect to geopolitical risk. We are not going to eliminate cognitive biases from our thought processes since, as noted above, they seem to be hardwired into the human psyche. So, the real question becomes, How do we recognize them and then minimize their impact on the decision-making process in mineral exploration? A simple series of questions can help test for biases and fallacies in the planning and execution stages of an exploration program.

Planning

Is the exploration program designed from the ground up, based on the methods most likely to detect the type of deposit sought in the relevant geologic, topographic, and climatic environments? If case studies or discovery histories were used in the design or desktop evaluation of a program, were conclusions drawn from them based on a representative sample, including failures as well as successes (avoiding narrative fallacy and confirmation bias)?

Were statistically valid probabilistic criteria used for target and area selection, both in terms of geological prospectivity and economic potential?

Before entry into or exit from a jurisdiction due to changing geopolitical risk, was an assessment of the latter evaluated by local and international experts (avoiding wishful thinking)?

Execution

Are go/no-go decisions on a project based on whether results passed hurdles, as part of a predefined stage-gate process (avoiding the sunk cost fallacy and wishful thinking)?

Is there an overreliance on machine-generated targets at the expense (or to the exclusion) of other inputs? Have patterns or anomalies generated by computer modeling been backtested against the original data to see if they are still apparent (avoiding patternicity and automation bias)?

Major mineral deposit discoveries often conform to Taleb's (2007) definition of a "Black Swan"—i.e., they have a massive impact and they are unpredictable, but, in retrospect, we tend to concoct a narrative that makes them

Cognitive Biases and Fallacies in Decision-Making *(continued)*

seem less random and more predictable. Using these post hoc narratives and the cognitive biases and fallacies they are based on to design a program to find the next Black Swan deposit can make it more difficult, not easier, to find!

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