Why can't we interpret near-mine drilling data effectively?

E. J. COWAN[1]

Introduction

Like many industries, mining is in the midst of a data revolution. The ability to obtain previously unobtainable data from drill cores and down-hole sensors has increased exponentially since the year 2000, and this trend is likely to continue. Implied in the collection of such multiple datasets, and the ability to computationally process this information, is an assumption that we are heralding a new data-driven age, which will translate into better understanding of ore deposits. The benefits we expect to see, among others, are increased identification of near-mine exploration targets, and increased confidence in resource estimations.

This paper argues that this assumption of reaching 'mining nirvana' is illusory, based on the lack of progress of the industry since 2000. Despite the ever-increasing datasets and processing power that we have access to now, the benefits have largely remained static. I discuss the reason for this mismatch and the causes for this anomaly. I propose a way forward so that we can reap the benefits of the data revolution for exploration and resource definition in the near-mine environment.

Rationale and scope

The rationale for focusing on the near-mine environment is both technical and economic:

1) **3D data availability:** Unlike regional datasets, which are largely 2D and have little 3D sampling, near-mine environments provide the highest sampling densities from drilling, and a variety of data types are available to elucidate a 3D understanding of mineral deposits.
2) **Economic importance:** From a commercial perspective, near-mine exploration opportunities represent minimal financial investment that results in the most profitable activity for little risk. Thus, there is a clear economic interest.

The scope of the discussion is limited to near-mine exploration and resource definition – subjects that I am most familiar with.

Has big data helped identify exploration targets?

The predicted big data-driven enlightenment has not yet occurred. We still do not understand how to efficiently identify exploration targets within the near environment of a particular mineral deposit any better than we did prior to 2000. Although data availability has dramatically increased in mining, no commensurate economic benefits have been realised. This mismatch between the input and output can be seen at any high-level technical conference that directly addresses topics related to near-mine exploration and resource definition, such as the recently held *Target 2017* conference in Perth.

At *Target 2017*, sixty-four papers and posters were presented by industry and academic exploration experts (Wyche and Witt 2017). The vast majority were conceptual and largely addressed regional greenfield targeting methodologies. Most will go untested. Only one paper demonstrated a measurable economic benefit from applying a geophysical method to directly improve resource estimations at the grade control resolution (Wijns 2017).

Four other papers that were relevant to near-mine exploration addressed specific data processing methods for drilling data. All described novel data processing or visualisation techniques. These intermediary solutions, which are beneficial in their own right, did not address how to apply these methods to obtain an economic exploration benefit.

Any useful ideas to improve and identify near-mine exploration targets would be of great interest to most mining companies. Therefore, it is surprising how few papers directly addressed near-mine targeting at this conference, at which were gathered exploration targeting specialists from around the world. Instead, academic and mining industry geologists are gravitating towards regional targeting problems, which have poor 3D information, the highest risk profile, and the least expected economic benefit. This pattern of research, which concentrates on the conceptual, is no different to the

1. Orefind Pty Ltd, PO Box 230, Fremantle WA 6959, Australia. *Corresponding author:* E. J. Cowan *Email:* jun.cowan@orefind.com

state of research 20 years ago before 'big data' became part of the mining lexicon.

Do service companies that sell technical solutions fare better than academic and working geologists in terms of showing the industry a way forward with exploration?

Virtually all technical solutions offered by commercial service companies behave no differently to the academics who work on near-mine data – they only offer solutions for closed-ended problems that exist in the mining industry. Their products typically address a segment of the solution and do not directly address the ultimate benefit, such as how their products allows companies to identify exploration targets or increase their confidence in resource estimates. They allude to the usefulness of their products in their marketing material, often by using buzzwords to get the attention of the consumer, but stop short of actually demonstrating the end benefit beyond their identified closed-ended problem.

Has big data helped resource estimation?

One would expect the advances in geological modelling methods during this century would have increased the confidence of resource estimates, but this does not appear to be the case.

The dramatic 90% resource downgrade at the Canadian Phoenix gold mine in January 2016 shows that the mining industry is still waiting for a positive impact from new technologies. This downgrade occurred even though the resource modelling was conducted by a well-respected industry consulting firm, using the latest implicit geological modelling software. The resource downgrade was described in the media as 'one of the worst Canadian mining meltdowns in years' (Financial Post 2016). A 90% reduction is a massive miscalculation that deserves a better explanation than 'unforeseen geological complexity', particularly when the *indicated* and inferred resource were both downgraded. The failure of Phoenix gold mine clearly contradicts the software company's claim that using the software would 'reduce geological risk'.

Why aren't we seeing the benefits from the data explosion?

The above examples show that the benefits from the analysis of 'big data' and new software products is but a trickle compared to the deluge of data being produced in the mining industry. There is clearly an input-output mismatch. Several reasons help explain the existing input-output mismatch.

1. **Deposit models that lack geometrical understanding:** Modern ore deposit models have been formulated by largely ignoring first-order mineralisation geometries – this can be simply demonstrated by searching for various ore deposit model types in Google Images (Cowan 2012). Most economic geology exploration concepts and ore body models are still based on 2D line drawings, a practice that has been going on since the 1970s. Cartoon-like ore deposit models continue to be used by mining companies as templates for regional exploration; despite them being poor predictors of mineralisation continuities (the formulation of these models lacks geometrical consideration). Vearncombe and Zelic (2015) recently noted that various gold ore deposit models have not contributed to the discovery of gold deposits, so even these more geometric models have little beneficial value to exploration. Therefore, it isn't a surprise that academics will not talk about the specifics of near-mine exploration at a conference on exploration targeting, because they are largely ignorant about expected 3D geometries of mineral deposits.
2. **Structural anatomical ignorance:** The lack of geometrical knowledge of mineral deposits highlights the general ignorance of structural architecture and anatomy at the deposit scale, even though mineral deposits of various commodities are demonstrably structurally controlled (Fig 1). Medical specialists can interpret anatomical scans efficiently and accurately

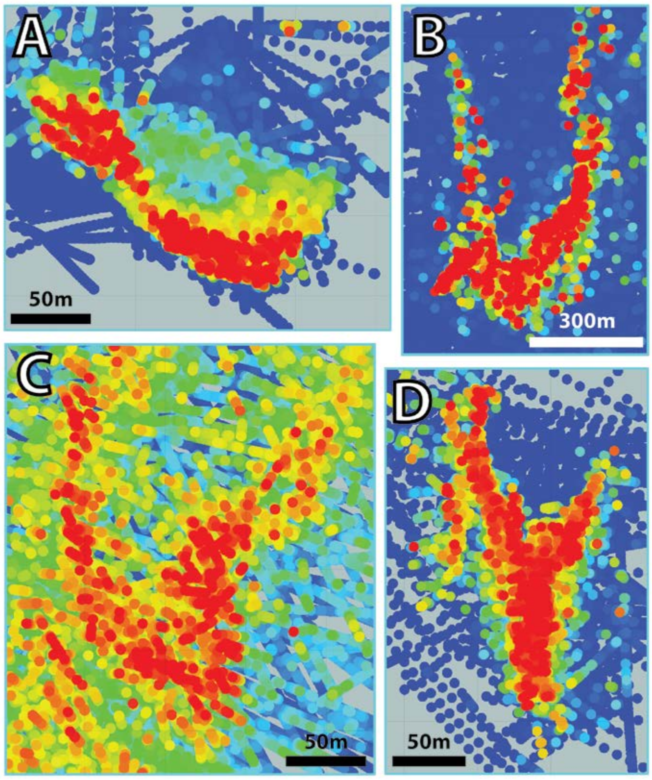

Figure 1. Down-plunge views of fold-controlled mineral deposits, rendered with maximum intensity projection, as discussed by Cowan (2014). The deposits represented by these four images are: orogenic gold; komatiite-associated nickel; zinc mineralisation in a volcanic massive sulfide, and iron-oxide copper deposit (but not necessarily in this order). These images are of well-known deposits. Published theoretical ore-body models are very distinct for each commodity, yet in reality these deposits are very difficult to differentiate based on the structural architecture seen in these images. Try this test yourself. Can the reader match the commodities (Au, Cu, Ni, Zn) with the images (A, B, C, D) with any confidence?

because they base their interpretation on their detailed knowledge of human anatomy. Conversely, geologists interpret approximate shapes without knowing their likely structural architecture; this process is so ingrained in modern methods of resource estimation that it is considered normal practice. 'Geological modelling' of wireframe shapes in 3D is nothing more than 'shape drawing', and with the incorrect use of implicit modelling software (such as Leapfrog), this 'shape modelling' continues at a blindingly fast pace. This industry-accepted practice is the foundation of our understanding of mineral deposit resource estimation – but it is a practice that completely ignores structural geometry, and is antithetical to the best practices seen in fields such as medicine.

3. **The lack of in situ documentation:** Certain ore models, such as the mineralisation in volcanic massive sulfide (VMS) and sedimentary exhalative ore models (SEDEX), are thought to have formed before tectonic deformation; therefore, any ductile structural overprints are not considered important, with the result that researchers ignore the structural features during the data gathering and analytical process. This has been common practice with these particular ore deposit models since the 1970s. Interpretations are always of the geometries that existed *prior to deformation*, and are invariably presented in cartoon form, which is not useful for exploration. There is a lack of basic documentation of in situ structural features, so the data required for reasonable scientific enquiry are never collected. This now routine practice, which confidently assumes the currently accepted syngenetic ore models will not shift in interpretation in the future, has now impacted two generation of geologists and is currently impacting the third generation. The confidence shown in such theoretical models is of concern, should there be a paradigm shift (Kuhn 1962) – a practice that does not document the basic structural information from deposits that could be useful for future generations of geologists, is flawed. Such basic documentation is required if the scientific method is to be used and allow opportunities for falsification of hypothesis (Popper 1958, Vann and Stewart 2012). This lack of basic documentation seriously affects how geologists behave and their ability to interpret mineral deposits effectively – only a small fraction of geologists have a clear view of what these deposits look like in situ.
4. **The long-term degradation of structural geological education:** Structural documentation of mineral deposits is not possible without good university education and related experience in structural field work; unfortunately, such education has been slowly degrading over the last 50 years, and has affected the academic community for two generations. This is a serious problem that faces the mining industry. This lack of structural geological competence can be demonstrated from a selection of academic economic geology articles published in reputable journals – not only are the authors lacking in competence, but the reviewers are also lacking in structural geological education; therefore, they cannot identify the obvious logical errors that invalidate many research papers. Unfortunately, there are very few competent academic structural geologists who are interested in researching applied structural problems in the mining industry, and this has resulted in a chronic ignorance problem the industry.
5. **Unjustifiable overemphasis on field-scale observations:** There is a saying in the mineral exploration industry that 'the best geologists are those who have seen the most rocks'. Field work is a critical training ground for all geologists, but this does not mean that field observations alone should be the basis for geological interpretation at all scales, especially at the scale of the entire deposit. Geological observations are made at various scales and regional understanding of geological architecture is routinely interpreted from remotely-sensed data – deposit-scale interpretation should be equally valid using 3D drilling data that can be ground-checked with field observations. However, structural patterns observed at the deposit-scale are often unobservable directly on the ground or in core, so there is a justifiable logic to integrating all scales of observation. Assuming that structural inferences made from outcrop observations can be scaled up to the deposit scale is fraught with risk, but this is a practice common in the mining industry, whether it can be justified or not. The practice of viewing drill-sampled grade data and interpreting structural controls at the deposit scale using 3D rendering software should be a routine analytical process undertaken by all those who work with drill hole data (Cowan 2014), but it is not routinely practiced by structural geologists who have the skills to interpret such data. Unfortunately, the examining of grade data for the purposes of analysis is not generally viewed as a structural analytical methodology. Because of this bias, the examination of drilling data is a task commonly left to a 'geological modeller', who may not have any structural field experience to identify significant structural patterns.
6. **Biased collection of structural data:** Unfortunately, the lack of structural knowledge results in not knowing what features to observe, measure, and interpret from outcrop and core. This affects the design of data-gathering devices and equipment by commercial service providers.
7. **Non-disclosure of data:** The general unavailability of drill hole data due to company confidentiality reasons has not helped academic research. This limits the number of geologists who have seen enough drill hole data, which in turn restricts the understanding of how data can be interpreted. Theoretical ore deposit models are often formulated by academics who have the least amount of exposure to viewing drill hole data, and this forces them to concentrate mainly on samples or field information that does not involve direct observation of drilling data.

8. **Uncritical use of implicit modelling software devoid of structural geological considerations:** Originally conceived as a geological modelling tool to be used in conjunction with sound structural geological practice (Cowan *et al.* 2002, 2003), the latest implicit modelling software – which can create mistakes much faster – is no longer designed with structural geology concepts in mind. This makes it no different to previous generalised mining software, which did not incorporate structural concepts as part of their design. As mentioned above, the Phoenix gold mine resource downgrade, helped by the rapid modelling that only implicit modelling can provide, is a pattern that will be become the norm for many years to come. No amount of good quality data acquisition will benefit the mining industry if geologists continue to believe that geological modelling software will automatically solve all of their modelling issues without them becoming a dedicated student of structural geology. To assume that the correct geological model will magically appear from the data by using the default settings in implicit geological modelling software is completely delusional. A piano student consults a piano teacher and not the piano maker if they want to become an expert player, yet mining industry geologists routinely do so – they consult the software maker (who has no geological experience) and believe they have acquired expertise just by being able to operate a software product, instead of consulting an industry expert who has experience in 3D modelling that is based on sound structural geological interpretation. It is no mystery that the mining industry is not seeing the benefits of big data and that mines keep on failing – they will continue to fail if this mindless practice continues.

The above reasons are why I believe there is a complete disconnect between the expected benefits flowing from the vast volumes of data being collected from drill core and the benefits resulting from the interpretation of that data. Addressing each of these concerns will eventually allow geologists to increase the benefits to exploration and increase the confidence of resource estimation.

Conclusions

Kuhn (1962) pointed out that scientific data collection and experimental design are not independent of influence, but are framed within the context of an existing 'paradigm' (a reigning or dominant approach to solving problems in a given area of science). The existing paradigm is assumed by scientists to be correct, so subconsciously the scientific community does not question the paradigm and only measures and sees patterns that can be explained by, or that are relevant to, the existing paradigm. Therefore, scientists can be blind to patterns that do not fit within the paradigm, but also to patterns not directly relevant to the paradigm that, even if viewed, are not seen as important. As a result, data that could potentially reveal important patterns may not be collected.

The existing paradigm for the mining industry – for most ore deposits – is to ignore structural geological anatomy. This is in contrast to the petroleum industry, which benefitted from the realisation that petroleum accumulations were underpinned by stratigraphic and structural controls; the mining industry is yet to take a similar systematic approach.

Mining industry geologists have not examined data from a framework of structural understanding at all scales from the core, to the outcrop, to the entire deposit. Despite the data deluge, without this critical shift in approach the industry will continue to collect information that will not unlock real value for the mining industry. When unsophisticated data, even as simple as 20-year old single assay value data, is viewed in a structural context, unexpected patterns start to appear, some of which are quite anomalous in terms of our current understanding of how ore deposits should look. Such a shift in approach is far more beneficial to the mining industry than collecting even more data and using sophisticated analytical techniques within the current paradigm, which is demonstrably ineffective.

References

Cowan, E.J., Beatson, R.K., Fright, W.R., McLennan, T.J. and Mitchell, T.J. 2002. Rapid Geological Modelling. In: S. Vearncombe, S. (ed.) Applied Structural Geology for Mineral Exploration and Mining International Symposium Abstract Volume. Australian Institute of Geoscientists Bulletin, 36, 39–41.

Cowan, E.J., Beatson, R.K., Ross, H.J., Fright, W.R., McLennan, T.J., Evans, T.R., Carr, J.C., Lane, R.G., Bright, D.V., Gillman, A.J., Oshust, P.A. and Titley, M. 2003. Practical Implicit Geological Modelling. In: Dominy, S. (ed.) Fifth International Mining Geology Conference Proceedings. Australian Institute of Mining and Metallurgy Publication Series No 8/2003, p. 89–99.

Cowan, E.J. 2012. The Deposit Model Paradox. In: J. Vearncombe, S. (ed.) Structural Geology and Resources 2012 – Extended Abstracts Volume. Australian Institute of Geoscientists Bulletin, 56, 48–49.

Cowan, E.J., 2014, 'X-ray Plunge Projection'— Understanding Structural Geology from Grade Data. Australian Institute of Mining and Metallurgy Monograph 30: Mineral Resource and Ore Reserve Estimation — The AusIMM Guide to Good Practice, second edition, 207–220.

Financial Post, 2016. Rubicon Minerals Corp shares plunge as miner slashes its gold resources by 88%. (http://business.financialpost.com/news/mining/rubicon-minerals-corp-shares-plunge-as-miner-slashes-its-gold-resources-by-88) [accessed 16 June, 2017]

Kuhn, T. 1962. The Structure of Scientific Revolutions (1st ed.). Chicago, IL: The University of Chicago Press. p. 210. (http://projektintegracija.pravo.hr/_download/repository/Kuhn_Structure_of_Scientific_Revolutions.pdf) [accessed 16 June, 2017]

Popper, K. 1957. The logic of scientific discovery, New York, Harper and Row, pp. 480.

Vann, J. and Stewart, M. 2012. Philosophy of science: a practical tool for applied geologists in the minerals industry. Applied Earth Science (Trans. Inst. Min. Metall. B) 120, 21–30.

Vearncombe, J. and Zelic, M. 2015. Structural paradigms for gold: do they help us find and mine? Applied Earth Science (Trans. Inst. Min. Metall. B) 124, 2–19.

Wijns, C. 2017. Geophysics at the small end of the scale: understanding the resource. In: Wyche, S. & Witt, W.K. (eds.) TARGET 2017, Perth, Australia: abstracts: Geological Survey of Western Australia, Record 2017/6, 163–165.

Wyche, S. and Witt, W.K. (eds.) 2017. TARGET 2017, Perth, Australia: abstracts: Geological Survey of Western Australia, Record 2017/6, 166p.

Biography

JUN COWAN, on the first day he became a structural geology consultant in 1999, learned that resource estimation and 'geological modelling' were often conducted by those who had no training in geology, using software more suited for designing buildings. This anomaly didn't seem to bother anyone else. Intrigued by this disconnection and frustrated by ineffective mining software, in 2001 Jun conceived Leapfrog—the first implicit modelling software released for the mining industry in 2003. He predicted that, through using Leapfrog, within five years the mining industry would see that structural geology is essential to obtain a deep understanding of all mineral deposits. Some 14 years after the release of Leapfrog (which he left in 2007), he is still waiting. Jun's mission is to lead the mining industry into an age of structural geological enlightenment, based on the experience he has gained from examining data from more than 600 deposits worldwide. He is an independent consultant with Orefind, with MSc and PhD degrees in sedimentology and structural geology from the University of Toronto, and is an Adjunct Senior Research Fellow at Monash University.