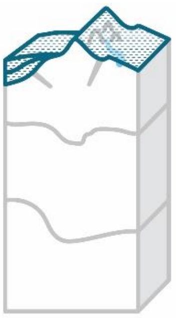
Australian Government
Geoscience Australia

Exploring for the Future
minerals | energy | groundwater

Economic fairways assessments across northern Australia

M. W. Haynes[1], S. D. C. Walsh[2], K. Czarnota[1], S. A. Northey[2] and M. Yellishetty[2]

[1]Geoscience Australia, [2]Monash University



Mineral exploration ideally involves researching geological potential within the constraints of economic feasibility. Nevertheless, explicit consideration of economic factors is often delayed until late in the exploration cycle. This is not ideal. Like mineral prospectivity, projected economic feasibility can be used to refine the search space and thereby reduce the risks associated with mineral exploration undercover. Here, we outline an exploration strategy based on the notion of identifying economic fairways—that is, regions permissive to resource development from an economic perspective. The approach appraises the economics of Au, Cu, Ni, Pb, Zn, potash and phosphate deposits by modelling revenue against capital expenditure (such as the costs of employment, mining overburden and access to infrastructure). We demonstrate the economic fairways approach through regional assessment of a Tennant Creek–style iron oxide–copper–gold deposit across northern Australia. Our results indicate that such a mineral deposit is expected to be economically viable across much of northern Australia, including in areas with several hundreds of metres of overburden. Our analysis sheds light on the need for accurate cover thickness models, without which undercover economic fairways cannot be defined. Our online tool benefits mineral explorers, and also helps to inform investors about the relative strengths of potential mineral projects; policy makers could use it to plan regional infrastructure development in frontier mineral provinces.

One frontier of future Australian mineral exploration lies beneath post-mineralisation cover. For this reason, the characterisation of Australia's cover has been identified as a key research priority (McFadden et al., 2012) and adopted as part of the National Mineral Exploration Strategy of the Council of Australian Governments. In response, Geoscience Australia has been developing comprehensive cover thickness datasets (Ley-Cooper and Brodie, 2020; Mathews et al., 2020) and predictive models (Czarnota et al., 2019; Bonnardot et al., 2020; Wilford et al., 2020) to help define the basic search space for buried mineral deposits.

The technical risks and costs associated with mineral exploration undercover can be reduced by refining the search space. For example, the mineral systems framework (e.g. Wyborn et al., 1994) can be used to predictively map mineral prospectivity (e.g. Dulfer et al., 2016; Skirrow et al., 2019; Murr et al., 2020). In some cases, individual features of lithospheric architecture can also significantly refine the available search space (Hoggard et al., in press). However, assessing mineral prospectivity is only one aspect of the exploration challenge.

The economic feasibility of a potential project is an equally important consideration. If we are looking for a specific play, how does this influence the range of ore body grades and volumes that we should consider valid targets? In practice, simple heuristics (i.e. do not explore beyond 50 m of cover) have tended to guide these exploration decisions, despite never being economically tested. An alternative approach is to combine economic and technical considerations to define economically favourable fairways of under-explored mineral potential in Australia.

Here, we outline the steps involved in this type of economic fairways analysis, and illustrate its use by presenting regional economic assessments for northern Australia. As an example, we focus on the development of iron oxide–copper–gold (IOCG) deposits whose technical prospectivity has recently been assessed in the region (Murr et al., 2020).

Methods

We calculate a series of economic models for IOCG deposits across northern Australia. The economic modelling is undertaken using the Bluecap software platform (Walsh et al., 2020), which we use to estimate (for a hypothetical deposit):

- net present value—the sum of discounted future cash flows over the life of the mine
- break-even grade factor—the change in ore grade required to make a project break even
- annual employment over the life of the project.

Bluecap combines large-scale infrastructure datasets to evaluate mining, processing, administrative and infrastructure expenses of mining operations across Australia. A distinguishing feature of the software is its ability to provide rapid geospatial estimates of economic potential across the Australian continent, suitable for early exploration planning. Components of the Bluecap analysis can be accessed through the Economic Fairways Mapper, an assessment tool incorporated in Geoscience Australia's Exploring for the Future portal. The open-source Bluecap code also provides additional functionality for calculations better suited to offline platforms (e.g. extended analysis, or calculations involving external software or data).

Estimating mining operation costs

Accurate assessment of regional economic fairways requires a cost model capable of estimating the potential expenditure associated with mineral development from minimal input information. For this, we employ a version of the mine cost model developed by Camm (1991) that has been updated and adapted for Australian operating conditions. The model uses Taylor's rule (Taylor, 1977) to estimate the mine life and associated production capacity, from which associated mining and processing costs are determined. The original model was based on operating conditions in the United States; we have updated the cost estimates using a combination of the AusIMM *Cost estimation handbook* (Burt et al., 2012) and data gathered from public financial reports and technical studies provided to the Australian Stock Exchange.

Camm's original mine cost model relies on the user to select the method to develop the deposit. However, this level of input is not practical in a geospatial analysis, which may require evaluation of several million points. Thus, Bluecap automates the process of selecting the development type. For example, the choice between open-cut versus underground developments is made through a determination of the least-cost development type, whereas the development method for underground operations is determined using guidelines provided by Camm (1991) and Carter (2011).

To date, cost models have been calibrated for Au, Cu, Ni, Pb, Zn, potash and phosphate. The cost models do not include the costs associated with exploration or resource definition. A key consideration in the model is the effect of the overburden on mining costs. This cover thickness information needs to be provided by the user or selected from a series of available cover models. Regional variations also arise as a result of the availability of infrastructure (i.e. transportation, energy and water supplies). The distance to infrastructure is calculated using publicly available datasets (openstreetmap.org; © OpenStreetMap contributors) from which the costs of establishing new power, water and road/rail lines are determined.

Once annual gross revenue and costs are known, taxation and state-based royalty rates can be determined for each location. Finally, the after-tax revenue generated by the mine is discounted to give a pre-scoping estimate of the net present value of a deposit at a given location. Mapping this across the area of interest yields a regional assessment of the areas most suited to mineral development from an economic perspective—that is, the regional economic fairways.

IOCG economic assessment and assumptions

Our northern Australia focus area is dominated by the North Australian Craton. To identify economic fairways for exploration, we need to define the aspects of our target deposit. Widespread mineralisation occurred throughout the craton around 1850 Ma (Compston, 1995). We focus on Tennant Creek–style IOCG deposits found within the Warramunga Province (Skirrow, 2000). Only small deposits are known to be associated with the 1850 Ma event in Tennant Creek, so we initially test the viability of finding a similar deposit undercover. Specifically, we adopt 'Peko' as an example of a modest deposit—3.2 Mt at 4% Cu and 3.5 g/t Au (Skirrow, 2000). In contrast, we also test the viability of an 'Earnest Henry'–sized deposit (representative of a globally median-sized IOCG deposit)—89.8 Mt at 1.17% Cu and 0.6 g/t Au.

Table 1 Assumptions adopted in our economic modelling

	Value	Units
Cu price	5500	US$/tonne
Au price	1500	US$/troy oz
Ore body dip	0	degrees
Discount rate	5	%
Currency conversion	0.66	A$/US$
Depth of cover	User supplied	metres

We consider two different cover thickness models to estimate the depth to potential mineral deposits. The national Phanerozoic OZ SEEBASE model (Frogtech, 2005) was used for our primary economic modelling of northern Australia. However, we also juxtapose this against a more recent, localised model of the depth to pre-Neoproterozoic rocks around Tennant Creek (Czarnota et al., 2019).

Results

Our analysis of net present values suggests that the economic fairway for a typical Tennant Creek–style deposit includes the vast majority of northern Australia, including the North Australian Craton (Figure 1a). Even undercover, mining ventures may break even from mineral deposits that have 50–80% of the Cu-equivalent grade for the typical Tennant Creek–style deposit (Figure 1c). As exploration costs are not included, the estimated net present value could be used to guide exploration budgets. In contrast to these results, an Earnest Henry–sized deposit is economic throughout our study domain, with net present values in the deeply covered areas east of Tennant Creek reaching a minimum of approximately $730 million.

The various features controlling the economic modelling can be seen in Figure 2a. The primary effect comes from the depth of burial of the modelled deposit. The prominent discontinuity around areas of outcrop represents the transition from open-cut to underground mining, and cost rises rapidly with the thickness of overburden. A second-order effect is evident from the broad buffers visible around transmission lines. Within these buffers, it is viable to connect to the existing infrastructure, whereas, beyond these, new sources of generation need to be developed. There is also a step change across the state border, representing different royalty schemes. Third-order effects include the distance to transportation infrastructure (i.e. roads, rail and ports) and water, as indicated by the subtle changes in net present value around these features. Bluecap allows all these features to be easily synthesised into an economic appraisal of resource prospectivity.

Our model suggests that, where economic, the development of Tennant Creek–style IOCG deposits would generate around 125–143 jobs per year of operation (Figure 1d). The number of jobs peaks along basin margins, where open-cut mining is still preferable. The number of jobs dips slightly as the cover thickness passes the threshold where underground mining techniques become economically favourable.

To date, four IOCG mineral potential assessments have been conducted across our northern Australia study area (Skirrow et al., 2019): northern Queensland, southern Northern Territory, southern Aileron Province, and the Tennant Creek to Mount Isa region. Our model will be most applicable to the areas of high mineral potential around Tennant Creek—including the East Tennant Ridge (Czarnota et al., 2019) and the Rover field (Skirrow et al., 2019)—as these are expected to contain Tennant Creek–style deposits. Despite several hundred metres of overburden, and to the extent that our assumptions hold, the development of mineral deposits in these regions is viable.

To test the rigour of our current results, we reanalyse net present values using a recently published cover model of the Tennant Creek to Mount Isa region (Czarnota et al., 2019). Our ability to quickly assess and compare these different assumptions highlights the important role cover thickness models play in evaluating economic fairways. The comparison reveals stark changes in the estimated net present value, with differences over short distances of approximately $80 million (Figure 2). Nevertheless, within the

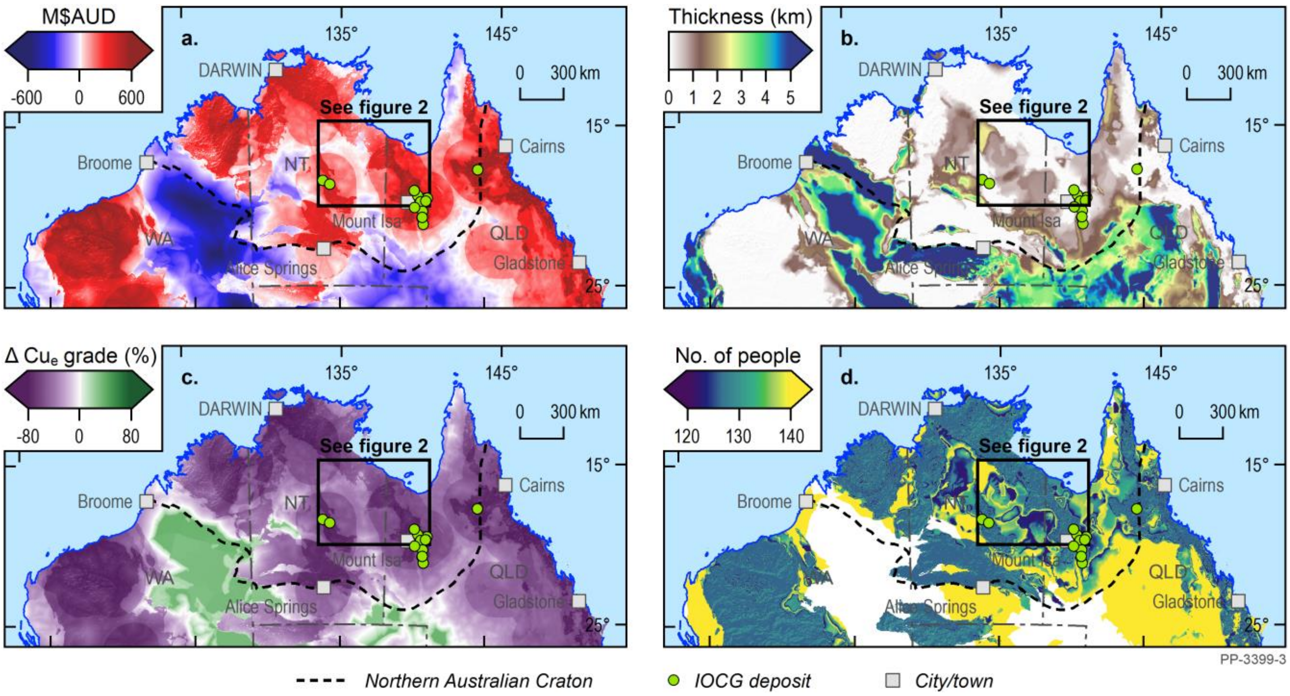


Figure 1 Results of economic modelling for a Tennant Creek–style IOCG deposit (3.2 Mt at 4% Cu and 3.5 g/t Au) across northern Australia, following the assumptions in Table 1. (a) Net present value. (b) Deposit overburden thickness, defined using the Phanerozoic OZ SEEBASE model (Frogtech, 2005). (c) Break-even grade factor, a multiplier for ore grade (calculated as Cu-equivalent [Cu_e]) which would result in a net present value of zero. (d) Estimated annual employment over the life of the hypothetical mining operation.

assumptions we have adopted (Table 1), the results do not alter the conclusion of our case study: that the region represents an economic fairway for covered, modest-sized IOCG deposits. Although our results for northern Australia (Figure 1) provide a first-pass indication of the regional economics, absolute accuracy depends on our ability to estimate deposit cover thickness. This underscores the importance of Geoscience Australia's cover thickness mapping programs (Bonnardot et al., 2020) for understanding both mineral systems and their economics.

Because of the broad-ranging nature of the calculations involved in the Economic Fairways Mapper, the model may be extended to other types of analysis. For example, the model can probe the sensitivity of the simulation results to variations in the input data. This is particularly important given the wide range of uncertainties surrounding the early stages of resource development, and can help to answer questions about value of information. In so doing, the model provides a tool to aid investors in the Australian Stock Exchange on the merits of competing mineral exploration programs. The model can also assess potential government revenue generated through mineral development (ACIL Allen Consulting, 2020), as well as estimating employment opportunities (Figure 1d). We can also assess the impact of developing hypothetical infrastructure projects, and how these alter the economics of mineral provinces. Hence, we have a tool to aid policy makers.

Our modelling is underpinned by cost models calibrated to conditions in 2018 and benchmarked against historical mine developments. However, we acknowledge that the economics change with time (e.g. depending on technology, commodity prices, policy settings, labour pressures), and this will alter our results. To maximise the accuracy of economic fairways analysis, there is an ongoing need to maintain and update cost models, infrastructure datasets, and cover thickness models as conditions change and new information is gained.

Conclusions

Economic fairways analysis complements more traditional considerations of mineral prospectivity by bringing forward financial considerations of resource development to maximise economic outcomes from mineral exploration projects. Our free online tool provides mineral explorers, policy makers and investors with the ability to assess the distribution of economic fairways for Au, Cu, Ni, Pb, Zn, potash and phosphate resources based on their economic outlooks, with unprecedented ease.

Here, we have illustrated the economic fairways approach by considering the approach for a modest Tennant Creek–style IOCG system in northern Australia. Our results indicate that Tennant Creek–style IOCG mineral deposits are expected to be economically viable across the North Australian Craton. This includes several regions that have been previously assessed as highly prospective for IOCG mineralisation, including the Rover field and East Tennant Ridge. The modelling demonstrates the strong control that depth of cover has on the economics of potential projects. It also suggests that the economic favourability of the region is robust with respect to recently published cover models. In particular, we emphasise that exploration undercover in the North Australian Craton should not be discredited on the basis of simplistic depth-of-cover heuristics. Modest Tennant Creek–style deposits make economically valid exploration targets, and may continue to be viable at lower grades.

Although our conclusions are robust, the accuracy of our results depends on the quality of available cover thickness models. From this perspective, cover thickness models represent critical research infrastructure for minerals exploration and underscore the importance of predictive modelling algorithms. Our results will change over time, and there is an ongoing need to update our cost models, infrastructure datasets and cover thickness estimates.

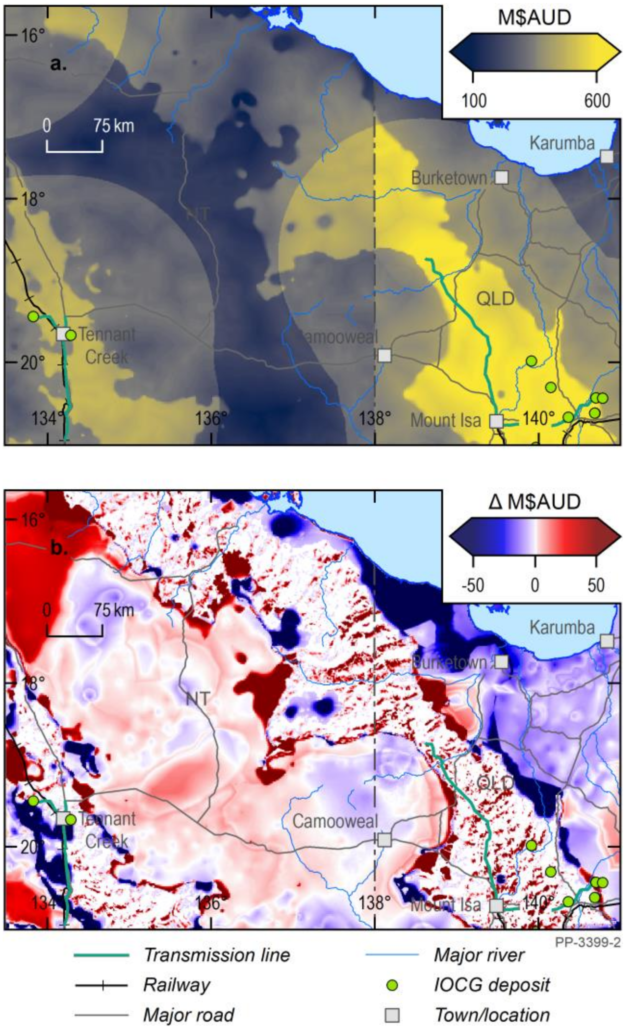


Figure 2 Results in the Tennant Creek – Mount Isa region. (a) Net present value, as for Figure 1, but using the cover thickness model of Czarnota et al. (2019). (b) Change in calculated net present value under different cover thickness models, presented as results using Czarnota et al. (2019) minus results using Frogtech (2005).

Acknowledgements

This work is the product of a Geoscience Collaboration Project between Geoscience Australia and Monash University. D. Huston developed the economic fairways concept. D. Huston, A. Schofield and A. Budd provided helpful reviews of this abstract. S. van der Wielen, C. McKenna and M. Deepika collaborated in the development of the online tool. S. McAlpine and L. Wallace coordinated contracts for this work. This abstract is published with the permission of the CEO of Geoscience Australia.

eCat: 133681, doi: 10.11636/133681

References

ACIL Allen Consulting, 2020. *Exploring for the Future program: return on investment analysis*, Geoscience Australia, Canberra.

Bonnardot M.-A., et al., 2020. Mapping the cover in northern Australia: towards a unified national 3D geological model. In: Czarnota K., et al. (eds.), *Exploring for the Future: extended abstracts*, Geoscience Australia, Canberra, 1–6.

Burt K., Lockyer C., McShane K. & Fong O. T. (eds.), 2012. *Cost estimation handbook*, Monograph 27, Australasian Institute of Mining and Metallurgy, Melbourne.

Camm T. W., 1991. *Simplified cost models for prefeasibility mineral evaluations*, United States Department of the Interior.

Carter P. G., 2011. Selection process for hard-rock mining. In: *SME mining engineering handbook*, Society for Mining, Metallurgy, and Exploration, 357–76.

Compston D. M., 1995. Time constraints on the evolution of the Tennant Creek Block, northern Australia. *Precambrian Research* 71:107–29.

Czarnota K., et al., 2019. *Depth to pre-Neoproterozoic rocks between Tennant Creek and Mount Isa: a preliminary model*, Record 2019/14, Geoscience Australia, Canberra.

Dulfer H., et al., 2016. *Potential for intrusion-hosted Ni-Cu-PGE sulfide deposits in Australia: a continental-scale analysis of mineral system prospectivity*, Record 2016/01, Geoscience Australia, Canberra.

Frogtech, 2005. *OZ SEEBASE Phanerozoic Basins Study*, public domain report to Shell Development Australia.

Hoggard M., et al., in press. Global distribution of sediment-hosted metals controlled by craton edge stability. *Nature Geoscience*.

Ley-Cooper Y. & Brodie R. C., 2020. AusAEM: imaging the near surface from the world's largest airborne electromagnetic survey. In: Czarnota K., et al. (eds.), *Exploring for the Future: extended abstracts*, Geoscience Australia, Canberra, 1–4.

Mathews E., et al., 2020. Putting all your EGGS in one basket: the Estimates of Geological and Geophysical Surfaces database. In: Czarnota K., et al. (eds.), *Exploring for the Future: extended abstracts*, Geoscience Australia, Canberra, 1–4.

McFadden P., et al., 2012. *Searching the Deep Earth: a vision for exploration geoscience in Australia*, UNCOVER Exploration Geoscience Research, Australian Academy of Science, Canberra.

Murr J. et al., 2020. Tennant Creek – Mount Isa IOCG mineral potential assessment. In: Czarnota K., et al. (eds.), *Exploring for the Future: extended abstracts*, Geoscience Australia, Canberra, 1–4.

Skirrow R. G., 2000. Gold–copper–bismuth deposits of the Tennant Creek district, Australia: a reappraisal of diverse high-grade systems. In: Porter T. M. (ed.), *Hydrothermal iron oxide copper–gold and related deposits: a global perspective*, vol. 1, PGC Publishing, 149–60.

Skirrow R. G., et al., 2019. Mapping iron oxide Cu–Au (IOCG) mineral potential in Australia using a knowledge-driven mineral systems-based approach. *Ore Geology Reviews* 113:103011.

Taylor H., 1977. Mine valuation and feasibility studies. In: Hoskins J. R. & Green R. W. (eds.), *Mineral industry costs*, Northwest Mineral Association, Spokane, 1–17.

Walsh S., Northey S. A., Huston D. L., Yellishetty M. & Czarnota K., 2020. Bluecap: a geospatial model to assess regional economic viability for mineral resource development. *Resources Policy* 66:101598.

Wilford J., et al., 2020. Uncover-ML: a machine learning pipeline for geoscience data analysis. In: Czarnota K., et al. (eds.), *Exploring for the Future: extended abstracts*, Geoscience Australia, Canberra, 1–4.

Wyborn L. A. I., Heinrich C. A. & Jaques A. L., 1994. Australian Proterozoic mineral systems: essential components and mappable criteria. *Australasian Institute of Mining and Metallurgy Publication Series* 5/94:109–15.