Review of Austin et al. manuscript essd-2023-464, “Integration by design: Driving mineral system knowledge using multi modal, collocated, scale-consistent characterization”

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With an extraordinary collection of 1590 well-chose rock samples from in and around 20 mineral deposits from the Conclurry District in NE Australia, the authors have compiled a consistent set of geological, geochemical, and petrophysical measurements. Drawing on a decade of work, the resulting data set is a globally unique resource to test a whole range of exploration vectors in a geologically complicated region.

There are a few cases of this approach taken on individual deposits. I am particularly thinking of the Canadian Mining Innovation Council’s “Footprints Project”, focused on 3 individual deposits. While many exploration vectors were developed through that project, the unified approach was not as well-achieved as in Austin’s manuscript.

The complete data set is easy to download and analyse. I can attest to the quality of the petrophysical data, and their relationship to the pXRF chemistry. The Henkel plot (logarithm of magnetic susceptibility against density) is quite fantastic, with the IOCG deposits, like Ernest Henry and SWAN, plotting just above the Quartz-Feldspar-Calcite + Magnetite line of Enkin et al. (2020), in a similar manner to our Great Bear Magmatic Zone samples. I explored the chemical relationships a bit, and see the expected anticorrelation of density with Silicon concentration, and the correlation of magnetic susceptibility with iron. I was pleasantly surprized to see how well the electric conductivities plotted against density. I had given up on using electromagnetic measurements of conductivity in my lab, but I have never had such an excellent collection of mineralized samples.

Dear Randy and collaborators,

Thank you for the positive feedback on the Cloncurry Metal data. We really value your perspective as a pioneer of this kind of approach.

Your feedback in relation to density measurements, intrinsic susceptibilities, maps and graphs are all valuable. I believe these can all be easily addressed with minor revision.

Best Regards,

Jim austin (on behalf of the team)

I appreciated the descriptions of the lab methods, however I believe there are more details to include in the density section. The Conclurry samples are not very porous, however the method of weighing the immersed samples can be quite sensitive, and should be described.

> Thank you, Randy. It is a good point and probably something I felt was going into too much detail. I didn't give much thought to the accuracy of the text when I edited this from previous reports written by my old lab tech. But I have extensively rewritten that section to better define what we are measuring, ie. SGs and to state that our samples are effectively non-porous and hence the distinction between dry and saturated densities is moot. I included a figure of the scale too.

Note, I disagree with the statement (Line 365): "Users should be aware that the instrument can realistically only measure 10 cm^3 samples up to susceptibilities up to ~2.25 SI. In some cases, particularly in magnetite-rich or mussketovite-rich ironstones, susceptibilities are likely much higher, probably in the range of 10-20 SI (Clark, 1988)." We are not interested in the intrinsic magnetic susceptibility of rocks, but rather the external susceptibility which is limited by their demagnetization field. The only way to get magnetic susceptibilities above 3 SI is for the magnetite grains to be elongated – which happens to a small degree in IOCG magnetite metasomatism. But there is no apparent problem with the reported measurements.

> Randy, I accept your point here, it is worth clarifying the difference between the intrinsic and measured susceptibilities, but I also feel that our results are supressed due to instrument limitations as well. Hopefully I have addressed both in the re-write below.
>
> Users should be aware that magnetite-rich rocks with susceptibilities greater than 0.1 SI (especially above 1 SI) the self-demagnetisation effect considerably suppresses the intrinsic magnetic susceptibility of a rock (e.g., Austin et al., 2012. The measured magnetic susceptibilities reported in Austin et al. (2024) incorporate the intrinsic susceptibility and suppression due to the self-demagnetising field. However, our measurements are also limited by the measurement range of the MFK-1A instrument which can realistically only measure 10 cm3 samples up to susceptibilities of approx. 2.25 SI. Measurements of the most magnetite-rich and/or mushketovite-rich ironstones (which may have intrinsic susceptibilities of 10-20 SI; Clark, 1988) are likely beyond the detection limits of the instrument, and may therefore be supressed to some degree.

I believe the geological map (Figure 3) would be improved with some age information,

I've provided some age information and generally improved the key significantly. I've also tweaked the map a little to make it clearer.

and the symbology in Figure 4 should be described with a legend.

The symbology for Figure 4 is described in the top third of the figure itself. But perhaps I should have pointed this out in the caption. Caption now reads:

Figure 1: Condensed and simplified tectonic, metasomatic, depositional, magmatic and metallogenic history of the Cloncurry District mineral system (upper 5 panels), and the processes observed at each of the deposits and prospects discussed in the study (modified from Austin et al., 2016g).

I feel the eight deposit-scale maps (Fig.s 5-12) are of less value, and could be moved to an electronic supplement.

I feel like these maps are useful to illustrate the different types of sampling conducted, so I've kept the four which are illustrative of the four different sampling styles, but have made them clearer, and more similar in style.

Figure 14 would be improved if the Magnetic Susceptibility were plotted on a logarithmic scale (a Henkel plot).

Randy, I feel like this is a bit of a personal preference thing. I personally prefer to use a linear plot for ore deposits as it gives me a clear idea of the magnetite trend as a linear. I have modified the text a bit to at least address the subject and also have tried to incorporate some of your positive comments on the correlation between our datasets (I will do thi more fully for the petrophysics papers which are long overdue.

Magnetic susceptibility is commonly plotted relative to density to compare the properties of different deposit types (Figure 14), and their alteration haloes (Figure 15). A linear plot is used for ore deposits mainly because it provides a clear indication of the relative magnetic mineral contents relative to a linear magnetite trend (Figure 14). A Henkel plot (logarithm of magnetic susceptibility against density; Enkin et al., 2020) is used to better differentiate more weakly magnetic samples from the alteration footprint (e.g., Figure 15). The data correlate well with similar studies, e.g., the Big Bear IOCG deposits (Enkin et al., 2016). IOCG deposits (e.g., Ernest Henry and SWAN) plot just above the Quartz-Feldspar-Calcite + Magnetite line of Enkin et al. (2020).

The important context for this paper is outlined in the multidisciplinary Venn diagram (Fig. 25), its description. The authors are perfectly correct that combinations of different techniques should be done on a consistent set of samples

to have confidence in the relationships. The scaling involved in different geological and geophysical analyses have to take a consistent approach as argued in this manuscript. And finally, the paper promotes the multidisciplinary approach, which is an essentially human ability, to be more successful with a new generation of mineral exploration.

"The dataset that presented here, provides a unique opportunity to examine this complex mineral system through quantitative and scale-consistent means. We believe that this style of dataset is a pre-requisite to gain useful quantitative insights into the Cloncurry District, which will, hopefully, lead to some step changes in how we explore in this highly complex piece of the Earth's crust."

Thank-you for giving me the opportunity to read this paper and examine its data set. This will be a reference paper in many complementary fields.

Review of Hanna Leväniemi

Well done by the author team for putting together this extensive dataset – it must have taken a lot of effort, and as highlighted by some commentary in the manuscript, combining data from different sources and time periods may be challenging. The outcome seems coherent, and the data collection has been systematic enough (some minor variation in the equipment, but these are addressed in the manuscript).

I do like the “integrated by design” approach and agree with the authors that too often are geodata combined without considering the differences in scales, resolution, and data type (for example, direct measurement data vs interpreted data such as inversion).

> Dear Hanna,
>
> Thanks so much for the kind words of encouragement. This was a super difficult project to put together, and I think we've barely skimmed the surface in terms of what can be done with the data. I found your review extremely constructive review and whilst I can't deal with all of the points you raised specifically here, I do feel they're certainly valid, and I will deal with them as best I can.
>
> The point about volumes, surfaces and point sources not being equivalent to is an issue, and one I have addressed in another project to some degree. I could definetly add further text in that area.
>
> I take your point on data sparsity, but we're kind of in a position where, we are only ever going to have 0.000001% of the system. Sparsity is function of resolution, budget, workforce and access. We generally can't do much about any of these, but they are the biggest factors.
>
> The thinking behind our approach here is really to re-engineer the process, make it about physics which is scalable, not geochemistry which is not. If we establish the geophysical properties of the system through considered representative sampling and can link it with larger scale structure and geophysics the sparsity is not as much of an issue. We're trying to make sparsity irrelevant by capturing the critical elements at an appropriate scale, going down in scale to go up using geophysics. It has its flaws, but it is fundamentally different to interpolation and kriging, which is more like going down in resolution to go up in scale. It is worth raising this point about sparsity, and more specifically this slightly different approach to dealing with it.

I think I can address all the other issues you spotted.

Thanks so much,

Hope you and the Team in Finland are doing well.

Jim

With the approach taken by the authors, we are likely as close to being able to integrate various datasets seamlessly as we'll be able to get with current technologies.

However, I would argue that also this approach is not fully scale-consistent: for example, bulk density of a sample may not correspond to pXRF data, which is a point measurement in comparison. I think this has probably a small overall effect in the results, as the sample selection has been done carefully and samples are representative (and hopefully quite homogeneous), but all in all, I think this uncertainty should still be addressed, as it could have perhaps even significant effect in the data quality in similar future campaigns, if not considered in sample selection and preparation.

Addressed in line203-206

collocated, characterisation of a suite measurable parameters and at a consistent scale but on different volumes (ranging between palaeomagnetic plugs, and pXRF spots in volume; see figure 4). By systematic sampling we can ensure samples are homogeneous and representative of the system and circumvent the volume issues between integrated data types to a large degree.

All in all, it's an impressive dataset with a supportive manuscript. The final data excel needs some attention and minor fixes, see the notes below. This is not an exhaustive listing, and I suggest the data file could be inspected once more for possible inconsistencies.

Specific comments

Introduction

- I would suggest tightening (shortening) the Introduction a bit, I think it could be done without losing any information.

It is a bit lengthy I agree, but important, and given Ive been asked to add material too, I've tried to make it feel better proportioned by re-arranging a few parts and introducing a new section; Background which deals with data, scaling and integration issues.

- The complexity levels listed in the introduction are 1) variable precision, 2) variable scale, and 3) multi-dimensionality. Sparsity is mentioned as a factor added by the third dimension (line 66 onward). I suggest sparsity could be an item on its own and deserves more attention. After all, also in the Cloncurry dataset the data may be at times sparse either due to sampling or to data acquisition.

I've introduced this concept of sparsity then discussed it briefly in the introduction, and provided some numbers and graphs to illustrate that we have to just accept it and re-engineer the problem.

Given you believe the intro is already too long, but that I also need to add aspects such as sparsity and MPM etc, I felt the best option was to re-orgaise the paper so that the intro is shorter, but then discuss these issues and the others already outlines under a "Background" section.

- The introduction mentions (line 100) statistical approaches as the common way to use complex datasets. However, in mineral exploration mineral prospectivity modelling (MPM) is probably more common, although data uncertainty estimations are still not always considered, but literature on that is available, too. I suggest you could use here an example from mineral exploration, not reservoir modelling.

I've discussed Prospectivity modelling now.

- It would be useful to the reader to be able to make the mental shift from general geoscientific dataset description to mineral exploration clearer in the Introduction.

Technically there's no real difference in the data per se, but there is a major difference in the application. I've alluded to this in the paragraph on Sparsity:

Sparsity is a major factor for any sample-based analyses (e.g. geochemistry, petrophysics) in geosciences in general, but particularly for applied geoscience, e.g., mineral exploration.

- In general, the Introduction has quite few literature references. Has anything similar been done anywhere? What are the preceding studies? How does this database compare globally?

  I've added a lot more references to the introduction including some previous work done by Canadian and Finish surveys.

- Fig. 2 would benefit from adding scales to especially B) and C), as scale is a critical topic here. Note that in the figure, the letters A, B, C are missing.

  I've added some scales, but have added far more on scales, including relative volumes etc in a new figure.

- From line 130 onward it would be h elpful to mention the general location (Mount Isa region, Australia) of the deposits here, when they are first introduced.

  This is more-or-less illustrated by the loco on the map, but nevertheless have included (NW Queensland)

Rest of the manuscript

- I agree with the comment by the other reviewer: the deposit pictures could be transferred to additional material. 2D images of 3D models are always tricky, and there are several ways these figures could be improved (resolution, overlapping texts, inconsistent visualisation of sampling etc.), but I know it's very time-consuming. The figure captions are also not quite consistent in style. As additional material I think they would be ok. Figure 10 is especially difficult for me to translate into mental 3D.

  I feel like these maps are useful to illustrate the different types of sampling conducted, so I've kept the four which are illustrative of the four different sampling styles, but have made them clearer, and more similar in style.

- Page 7 discusses the sampling and the limitations within. I think occasional inconsistent areal coverage or sample spacing and occasional challenges in representativity may be relevant for data sparsity (see above). (This is just an additional comment on sparsity, no need to fix anything).
- Chapter 3.1 Sample preparation: it was unclear to me (until further chapters) whether all sample types were finally prepared similarly into c. inch-by-inch samples. I understand they were, but this could be clarified, as line 330 states that the 25-mm samples were prepared, which I took to mean the sample type 1 (25-mm diamond cores). But the block samples were also drilled with the 25-mm dill, and line 330 then means all sample types?

I've added a line saying:

Blocks and diamond drill core samples were prepared re-drilled into 25 cm diameter cores (to match the hand-drill samples) and all 25cm cores were sawn into 22 mm long segments referred to as paleomagnetic plugs or 'rounds' (Figure 12c).

- The manuscript (line 400 and Figure 25 y-axis) and the dataset (see below) at times seem to indicate that induced magnetization equals to magnetic susceptibility. This should be corrected.
    - Took me a while to figure out what you mean here Hanna. I think you mean we should not be using "magnetic susceptibility" for a Koenigsberger ratio, but rather "induced magnetisation". You are 100% correct. I've removed the (J/K) at line 400, left the explanation as "Koenigsberger ratio (high ratio of remanent to induced magnetization)," in the first instance and deleted it from the graph.
- Line 491: the explanation "simple excel spreadsheet" is not clear to me in this context

Does this make it clearer?

    - The Cloncurry METAL "database" (Austin et al., 2024) is therefore provided as a single spreadsheet.
- Some more information could be added on the measurement procedure chapters
    - what was the gamma-ray measurement time and how was the small sample size taken into account
    - line 566 "collected over 300 second (5 minute) run-time".
    - what was the measurement time on pXRF? Were the samples measured once or averaged from several measurements?
    - The pXRF drift was monitored – was there any?

      Added: Analytical beam times were 20 seconds and utilized a 10 kV and 40 kV beam in Geochem mode. Measurements were checked against 5 known (matrix-matched) diamond core standards and a silica blank to check efficacy and instrument drift during data acquisition. However the data presented in the database (Austin et al., 2024) is uncalibrated against the standards as the instrument measurements closely matched the standard values.

    - Are the resined samples marked somehow in the database?
    - We didn't incorporate data from resined surfaces

Technical corrections

Manuscript

- Line 135: “all major techniques used in mineral exploration” could be “all major techniques used in rock material analysis in mineral exploration” or something similar (bit more specific)
- in mineral exploration and deposit characterisation (is that better?) the data can also be used to better utilise larger scale techniques
- Line 140: I don’t understand the “mining space”
- How about “mineral resources sector”??
    - Line 194 extra comma? That is OK I think
- Ch3.1 NQ and HQ could be explained
    - NQ (48 mm diameter) or ¼ HQ (63 mm diameter)
- Line 335: there is no Figure 13c. AMS already defined.
    - I changed the figure reference and figure
- 22 caption text should probably say 0.132 instead of 0.123
    - I suspect you are correct, changed accordiningly

Dataset

- There are two figures at the end of the datafile on the complete database file (cf. cells N1460 and N1550), at a glance they look like some QA/QC plots and if not necessary, can be removed

    A simple oversight on my part. These have been removed.

- What is column T? The header says “0.00” (cell T1)

    This is the Std Dev. Amended. I’ve also amended the titles to SG, since that is what the measurements really are.

- I would prefer unique column names – there are two columns named “N” and two columns named “Mean length (%)”, and they will be hard to process and distinguish from each other with, for example, Python or similar, or any software.

    Fair point. I figured people would probably understand in the context of the table, but looking at it with fresh eyes I can see it would be a bit confusing to new users. I’ve Amended so all column headers are unique and consistent, and I found a few other issues in the process.

- Personally I would prefer kg/m^3 as the density unit (SI convention)

  I take the point, BUT virtually nobody uses the SI convention for density, mainly because its more intuitive to use the number that is 1000 time smaller. It just makes more sense IMHU and I have always used g/cm3. So I have not changed that, but I have added a sentence on this topic, noting the SI convention in the text.

  "Densities should be stated in SI units (kg/m3) but are typically reported as g/cm3 (three orders of magnitude smaller) mainly for ease of use."

- The description for column "Q bulk" is misleading, as it incorrectly suggests induced magnetization equals to magsus: "Koenigsberger ratio: Ratio of Remanent Magnetisation (mean NRM) to Induced Magnetisation (mean magnetic susceptibility)". The calculation seems to be okay, i.e., NRM to induced magnetization.

  Yes, fair enough. I've removed the oversimplification from the column and added a more accurate description to "explanatory notes"

- For pXRF data, it would be useful to explain in the descriptions what <LOD means, for users not familiar with geochemical data

  I've added "<LOD indicates that the quantity of the element was below the detection limits of the instrument, and likely not present"

- The hyperspectral data columns are named with the wavelength number without any letters except for "350 nm" and "2500 nm". Consistency would make automated processing more straightforward.

  I've removed the "nm" from 350 nm and 2500 nm and dealt with that in the explanatory notes.

- The description sheet contains descriptions "Reflectance measured in the 350 nm wavelength band" and "Reflectance measured in the 351 nm wavelength band" for channel names "Wavelength 350 nm" and "351", respectively. It could be clarified that these are examples of channel names (i.e., not all spectral channels are included in the descriptions). Moreover, there is no data column "Wavelength 350 nm" but "350 nm".

  I thought the "etc" was sufficient, but I've added "and so on for many many columns. And added a note below: " you may want to delete this raw spectral data unless you intend to use it.