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EASTERN GOLDFIELDS GREENSTONE GEOCHEMICAL BARCODING PROJECT – NOTES TO ACCOMPANY 2021 DATA RELEASE

by
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EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY AND RESOURCE STRATEGY
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Cover image: Wave and wind sculpted stromatolites at Flagpole Landing, Hamelin Pool in the world heritage site of Shark Bay, Western Australia (photo courtesy of Heidi Allen, DMIRS)

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Available with the PDF online as an accompanying digital resource

Eastern Goldfields greenstone geochemical barcoding dataset

Eastern Goldfields greenstone geochemical barcoding project — notes to accompany 2021 data release

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Abstract

The Eastern Goldfields greenstone geochemical barcoding project, an initiative under the Exploration Incentive Scheme (EIS), aims to provide a high-quality whole-rock geochemical dataset that significantly aids in investigating stratigraphic links within and between greenstone belts, particularly where primary geological context (mainly outcrop) is limited. The project seeks to substantially increase the amount of publicly available, high-quality, multi-element geochemical data from igneous lithologies forming greenstone stratigraphy, targeting diamond drillcores that sample the most geologically well-constrained parts of various greenstone belts. Through detailed geochemical sampling of diamond drillcore, we aim to establish a geochemical ‘barcode’ of the stratigraphy (including local variations) in these better-known sections of greenstone belts. This information, in turn, can help inform stratigraphic interpretations of less well-understood regions, based on the degree of confidence to which geochemical correlations can be made. It is also expected that this significant increase in the amount of publicly available high-quality data will lead to a significant increase in the understanding of the evolution of Archean greenstone belts, of Archean crust in general and of related mineral systems. Much of the sampling to date has been undertaken in the Kalgoorlie–Kambalda region but has extended to other parts of the Eastern Goldfields Superterrane where opportunities have presented, including where EIS Co-funded diamond drillholes are located (Fig. 1).

This Record accompanies the second annual release of the geochemical data collected as part of the barcoding project and includes all newly acquired geochemical data ($n = 1889$) from the previous year, as well as the data released in the previous 2020 data release ($n = 3560$; Smithies and Lowrey, 2020). The dataset (Appendix) is fully attributed with the sample details required for a range of uses, potentially beyond the scope of the project. This Record and accompanying dataset will be updated and re-released annually. Separate Records will continue to present interpretations of these data in line with the aims of the Eastern Goldfields greenstone geochemical barcoding project. Published Records relating to this project include:

- Record 2017/7 Towards a geochemical barcode for Eastern Goldfields Superterrane greenstone stratigraphy – preliminary data from the Kambalda–Kalgoorlie area
- Record 2018/15 A new look at lamprophyres and sanukitoids, and their relationship to the Black Flag Group and gold prospectivity
- Record 2020/6 Eastern Goldfields geochemical barcoding project: notes to accompany 2020 data release.

KEYWORDS: Archean, greenstone, whole-rock geochemistry, Yilgarn Craton

Sample selection and analytical techniques

Dataset content

The dataset in the Appendix contains only those samples collected or re-analysed specifically for the barcoding project. Other data produced by the Geological Survey of Western Australia (GSWA) and various universities and research organizations are available in published literature or in publicly available online datasets but are not reproduced in this dataset. The dataset includes whole-rock major and trace element data primarily covering supracrustal igneous (or meta-igneous) lithologies, including high-level (subvolcanic) intrusive rocks and volcaniclastic rocks. Most samples were collected from diamond drillcores, including co-funded EIS cores, donated company cores and cores to which various mining or exploration companies

have provided access. A list of cores that were sampled is provided in the Appendix (under the spreadsheet labelled ‘DDH details’). This list includes details relating to the location, length and average or initial orientation of the drillholes. Where orientation details are unavailable, the drillhole is assumed to be vertical. The sampling interval (length/depth in the relevant core) is noted for all drillcore samples.

In circumstances where access to diamond core is limited, and where outcrop sampling provides suitably fresh sample material, outcrop samples have been taken and are denoted as such in the dataset.

Each sample is accompanied by a geological description (‘Sample description and details’). These are largely uncorrected or unedited notes made at the time of sampling.

For all samples, analyses for iron did not involve determination of ferric and ferrous proportions and all iron (total) is reported in the ferric state, denoted as $\text{Fe}_2\text{O}_3\text{T}$.

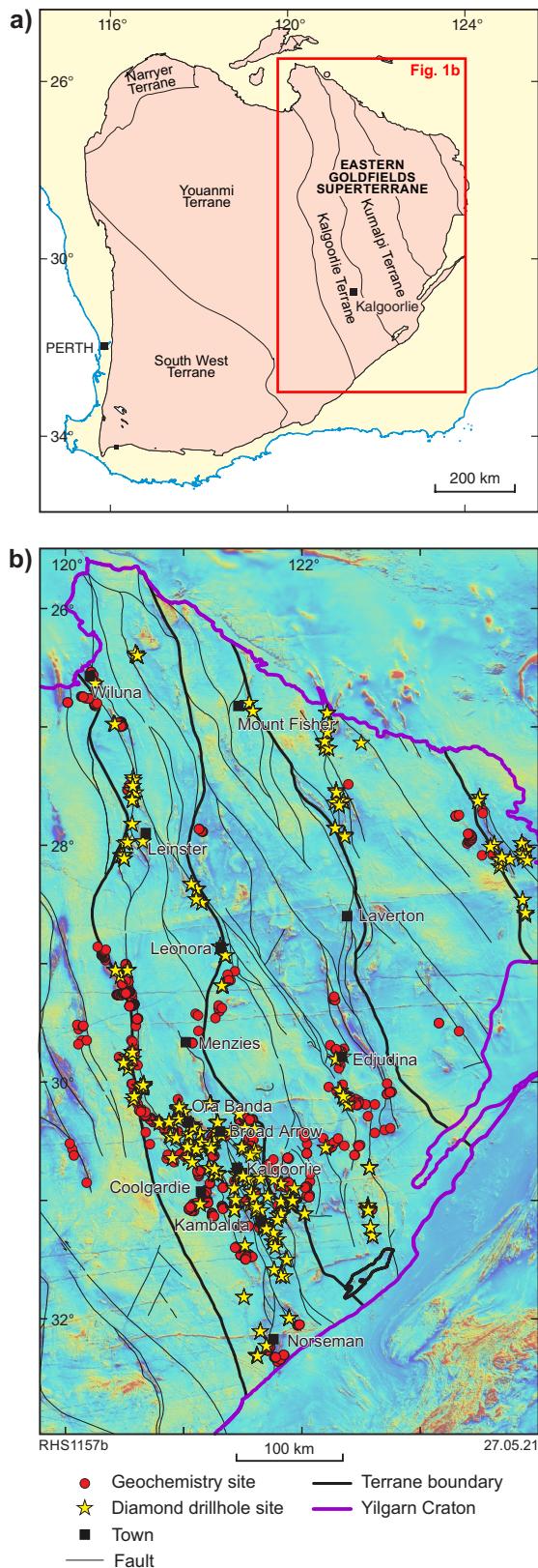


Figure 1. Eastern Goldfields greenstone geochemical barcoding project area overview and sample localities: a) location map of the study area; b) aeromagnetic image of the Eastern Goldfields Superterrane showing the locations of samples used for this study. Note that many sites represent the location of a diamond drillhole, cores from which commonly produced several samples. Hence, a single point (or symbol) may represent several samples

All major element concentrations and totals are calculated and reported both considering and ignoring analytical loss on ignition (LOI), the prefix 'a' (e.g. $a\text{SiO}_2$) denoting a concentration recalculated volatile free. No other derived values (e.g. ratios) are provided except for Mg# (molecular Mg/[Mg/Fe]; with Fe calculated as Fe^{2+}) and the Aluminum Saturation Index (ASI; molecular Al/[Ca+Na+K]).

Chemical classification of the data

A column is provided in the Appendix labelled 'Preferred chemical classification'. This combines a brief lithological description ('Lithological type', derived mainly from 'Sample description and details') with the results of a simple in-house chemical classification protocol. This classification scheme represents only a 'first-pass' means of subdividing the data into broadly similar groups and is more useful for the mafic rocks than for the ultramafic and felsic rocks. The spreadsheet 'lith types' provides a further explanation of the terminology and parameters used to derive the 'Preferred chemical classification'.

Mafic and ultramafic rocks

For classification and screening of rocks of broadly mafic to ultramafic compositions, we have slightly modified the approach used by Barnes et al. (2012). In particular, the maximum SiO_2 content used to identify rocks of broadly basaltic composition was raised from 56 to 58 wt% (only volatile-free major element concentrations, i.e. $a\text{SiO}_2$, were used). Hence, our reference to 'basalt' incorporates the silica range for basalt, basaltic andesite and the lower silica range for andesite. This modification recognizes that even diamond drillcore samples from the Eastern Goldfields Superterrane, and particularly in regions close to known mineralization, are commonly hydrothermally altered, often with moderate effects on the concentrations of important major elements. This alteration is often not obvious during visual inspection of samples prior to selection for analyses. All samples collected as part of the Eastern Goldfields greenstone geochemical barcoding project represent what are, based on visual assessment, the least-altered examples of lithologically, texturally and mineralogically homogeneous intervals of core. Nevertheless, it is not uncommon that one or more samples within a group taken from within a lithologically uniform segment of drillcore has anomalous concentrations of SiO_2 (e.g. above the 56 wt% maximum value of Barnes et al., 2012) or other major elements, despite being visually indistinguishable from other samples in that group. The approach used by Barnes et al. (2012) allows for expansion of these parameters for classification of various basaltic rock types, since it primarily uses variations in ratios of incompatible trace elements (Ti, Th, La, Nb, Zr) that are relatively immobile during hydrothermal alteration.

The following screens were used:

- Rocks with $a\text{MgO} > 18$ wt% are designated as 'komatiite' or 'peridotite' and then either low-Al or high-Al if mantle-normalized Al/Ti is $0.58 - 0.7$ or $0.7 - 1.0$, respectively.

- Rocks with $a\text{MgO}$ 10–18 wt% and with mantle normalized Al/Ti 0.75 – 1.1 are designated as 'komatiitic basalt/HTSB' (HTSB = high-Th siliceous basalt, see below) and then 'komatiitic basalt' if closely associated with komatiite, or HTSB if closely associated with other HTSB.
- Basaltic rocks were ignored and their 'Preferred chemical classification' designated 'problematic data' if values fell in any of the following ranges:
 - $a\text{Na}_2\text{O}+a\text{K}_2\text{O} > 5 \text{ wt\%}$ or $< 0.5 \text{ wt\%}$
 - $a\text{Al}_2\text{O}_3 < 10 \text{ wt\%}$ or $> 20 \text{ wt\%}$
 - $a\text{MgO} < 3 \text{ wt\%}$
 - $a\text{FeOT} (\text{aFe}_2\text{O}_3/\text{T})/1.1113 < 5 \text{ wt\%}$ or $> 20 \text{ wt\%}$
 - $a\text{TiO}_2 > 1.75 \text{ wt\%}$.

Exceptions are:

- where $a\text{Na}_2\text{O}+a\text{K}_2\text{O} > 5 \text{ wt\%}$ was the only basis for questioning the analysis and these were subsequently examined to determine if the rock was an alkali basalt (of which none have been identified to date) or an 'enriched mafic to intermediate rock' [EMI]; see below)
- where the analysis was also questioned because $a\text{TiO}_2 > 1.75 \text{ wt\%}$, in which case the sample was further examined to determine if it was a primary high-Ti mafic rock (including a granophyre)
- where the upper limit of 20 wt% for $a\text{Al}_2\text{O}_3$ content means that analyses of some plagioclase-porphyritic to megacrystic basalts are designated as 'problematic data'. In such cases the $a\text{Al}_2\text{O}_3$ filter is ignored
- Remaining basaltic rocks with $a\text{TiO}_2 > 1.75 \text{ wt\%}$ need to be treated with caution and are designated as 'high Ti'.

Basalts were further divided into the Low-Th Basalt (LTB), Intermediate-Th Basalt (ITB), High-Th Siliceous Basalt (HTSB) (Barnes et al., 2012) and enriched mafic to intermediate rocks (EMI) based on their ratios of Th, Nb, Zr and La against $a\text{TiO}_2$, such that:

- LTB = $\text{Th}/a\text{TiO}_2 \geq 0.001$ and ≤ 0.83 ; $\text{Nb}/a\text{TiO}_2 \geq 1.25$ and ≤ 2.77 ; $\text{Zr}/a\text{TiO}_2 \geq 40$ and ≤ 75 ; $\text{La}/a\text{TiO}_2 \geq 0.001$ and ≤ 5.55
- ITB = $\text{Th}/a\text{TiO}_2 > 0.83$ and ≤ 2.86 ; $\text{Nb}/a\text{TiO}_2 > 2.77$ and ≤ 4.44 ; $\text{Zr}/a\text{TiO}_2 > 75$ and ≤ 92 ; $\text{La}/a\text{TiO}_2 > 5.55$ and ≤ 11.11
- HTSB = $\text{Th}/a\text{TiO}_2 > 2.86$ and ≤ 6.66 ; $\text{Nb}/a\text{TiO}_2 > 4.44$ and ≤ 7 ; $\text{Zr}/a\text{TiO}_2 > 92$ and ≤ 133.3 ; $\text{La}/a\text{TiO}_2 > 11.11$ and ≤ 28.57
- EMI = $\text{Th}/a\text{TiO}_2 > 6.66$; $\text{Nb}/a\text{TiO}_2 > 7$; $\text{Zr}/a\text{TiO}_2 > 133.3$; $\text{La}/a\text{TiO}_2 > 28.57$.

Individual samples classified based on one or more ratios might be classified differently based on another of the critical ratios (for example, a sample classified as ITB

based on its Th/TiO_2 ratio might be classified as LTB based on its La/aTiO_2 ratio). In cases where the classification is not unique, available lithological relationships were also considered (i.e. whether the sample was directly associated with LTB or ITB) in assigning samples to a specific group. Enriched mafic to intermediate rocks have compositions broadly equivalent to calc-alkaline lamprophyres. The analyses of rocks classified as EMI based on one or more of the critical ratios were additionally examined to ensure that they had $a\text{P}_2\text{O}_5 > 0.25 \text{ wt\%}$ and $\text{Ba} > 400 \text{ ppm}$ (empirically identified lower limits for such rocks) and the rock description were examined for indications of lamprophyric textures. Analyses initially designated as 'problematic data' based only on $a\text{Na}_2\text{O}+a\text{K}_2\text{O} > 5 \text{ wt\%}$ and not subsequently designated as 'high-Ti' were further examined to determine whether they had other compositional attributes of alkali basalts (e.g. high Ti, $\text{La}/\text{Nb} <\sim 1.5$) but to date no analysis clearly has such attributes. Analyses were also examined to determine if they exceeded the upper limits for classification of HTSB in terms of ratios of Th, Nb, Zr and La against $a\text{TiO}_2$ (i.e. were strongly enriched in Th, Nb, Zr and light rare earth elements [LREE]) and had $a\text{P}_2\text{O}_5 > 0.25 \text{ wt\%}$ and $\text{Ba} > 400 \text{ ppm}$, in which case they were designated as 'EMI-like'. Analyses designated as 'EMI-like' were further examined to determine if they had other compositional attributes of lamprophyres or compositionally similar, but more siliceous, rocks such as sanukitoids, and lithological descriptions were examined for any mention of primary hornblende or of alteration.

Felsic rocks

Samples with $a\text{SiO}_2 \geq 58 \text{ wt\%}$ were broadly subdivided based on their rock description into:

- 'Granite', if medium or coarse grained and not clearly a dyke
- 'Felsic dyke', if clearly a dyke or if fine to medium grained and clearly intrusive
- volcanic or volcanioclastic ('Felsic vol/volclas'), where there was evidence supporting that interpretation
- 'Felsic', where it was not clear if the rock was intrusive or extrusive.

Rocks were further divided based on SiO_2 content, into andesitic ($a\text{SiO}_2$ 58–63 wt%), dacitic ($a\text{SiO}_2$ 63–68 wt%) and rhyolitic ($a\text{SiO}_2$ 68–77 wt%). Additional categories were established for peraluminous felsic rocks ($\text{ASI} > 1.2$) and silicified felsic rocks ($a\text{SiO}_2 > 77 \text{ wt\%}$), these being regarded as either altered or clastic/epiclastic based mainly on the rock description and lithological association.

Analytical methodology

Nearly all of the 5446 analyses reported here were analysed at a single commercial laboratory (Bureau Veritas [BV] Minerals Pty Ltd) employing a single set of analytical procedures, outlined below. This approach minimizes the potential for any variation in the dataset potentially attributable to variations in analytical procedure.

The dataset reported here includes 176 analyses of powders or crushed rock from the GSWA **Western Australian Geochemistry database** (WACHEM), representing 5% of the total samples. Many of these samples were pulverized using a tungsten carbide mill and their determined concentrations of tungsten (W) and cobalt (Co) were spuriously high due to contamination, so we do not report either element for that subset of data. The other 5370 samples (the majority) were collected by GSWA geologists from drillcore and outcrops for the purposes of the geochemical barcoding project. Samples were visibly inspected and any weathering or excessive vein material was removed. Each sample was crushed either in-house or by BV Minerals, in both cases using a plate jaw crusher and low-Cr steel mill to produce a pulp with a nominal particle size of 90% <75 µm. A representative pulp aliquot was analysed for 13 elements as major and minor components, mass loss on ignition (LOI) and 52 elements as trace elements. Major and minor elements were determined by X-ray fluorescence (XRF) spectrometry on a fused glass disk and reported as element oxides. A fragment of each disk was then ablated by laser and analysed by induced coupled plasma mass spectrometry (LA-ICP-MS) for 49 of the 52 minor elements. Gold, Pd and Pt were analysed on a separate pulp aliquot by Pb collection fire assay and ICP-MS.

Data quality was monitored by 'blind' insertion of sample duplicates (i.e. a second aliquot of pulp or finely crushed material) at a rate of 1 per 10 unknown samples, as well as GSWA internal reference materials and certified reference materials (OREAS 24b; www.ore.com.au), also inserted at a rate of 1 per 10 unknown samples. BV Minerals also conducted repeat analyses of samples, variably certified reference materials and blanks. An assessment of accuracy and precision was made using data for 124 analyses of OREAS 24b, determined during the analysis of samples for the geochemical barcoding project itself. For analytes where the concentration is at least 10 times the lower level

of detection (all analytes except Ag, Cd, Cl, In, Re, Sb, Te, Ti, W) a measure of accuracy is provided by the agreement between the average determined value and the certified value according to half absolute relative difference (HARD); that is, $(\text{analysis1} - \text{analysis2}) / (\text{analysis1} + \text{analysis2})$ (Stanley and Lawie, 2007). The average of measured concentrations for major and minor elements agree to within 1% of their certified values. The average of measured concentrations for most trace elements agree to within 3% of their certified or 'indicative' values. In terms of precision, the relative standard deviation (RSD), or covariance, for analysis of OREAS 24b is $\leq 3\%$ RSD for major and minor elements. For trace elements with certified values greater than 10 times the lower analytical detection limit, most have RSD $\leq 5\%$ (Ba, Ce, Co, Cs, Cu, Dy, Er, Ga, La, Nb, Nd, Ni, Pr, Rb, Sm, Sr, Tb, Th, U, Y, Yb, Zr) and most of the remaining trace elements have RSD between 5 and 10% (Bi, Cr, Eu, Gd, Hf, Ho, Lu, Mo, Pb, Sc, Ta, Tm, V, Zn), except for Sn (15% RSD). Similar levels of agreement were found for parent–duplicate pairs. All blank values were less than three times the lower level of detection.

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