RECORD 2020/6

EASTERN GOLDFIELDS GREENSTONE GEOCHEMICAL BARCODING PROJECT: NOTES TO ACCOMPANY 2020 DATA RELEASE

by
RH Smithies and JR Lowrey

Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

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Geological Survey of Western Australia

MINISTER FOR MINES AND PETROLEUM
Hon Bill Johnston MLA

DIRECTOR GENERAL, DEPARTMENT OF MINES, INDUSTRY REGULATION AND SAFETY
David Smith

EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY AND RESOURCE STRATEGY
Jeff Haworth

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zone 51. All locations are quoted to at least the nearest 100 m.

EXPLORATION
INCENTIVE
SCHEME

Cover image: Packing up the campsite in a claypan about 5 km south of Minilya in the southern Pilbara (photo by Olga Blay)

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Available with the PDF online as an accompanying digital resource

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Background

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).

The following Record accompanies the initial release of the geochemical data collected as part of the barcoding project. This dataset (Appendix 1) can be accessed from the Geological Survey of Western Australia's (GSWA) eBookshop as a Microsoft Excel workbook, which 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.

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

Sample selection and analytical techniques

Dataset content

The dataset presented here (Appendix 1) contains only those samples collected or re-analyzed specifically for the barcoding project. Other data produced by 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 Appendix 1 (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 Fe_2O_3T. All major element concentrations and totals are calculated and reported both considering and ignoring analytical loss on ignition (LOI), the prefix 'a' (e.g. $aSiO_2$) denoting a concentration recalculated volatile free. No other derived
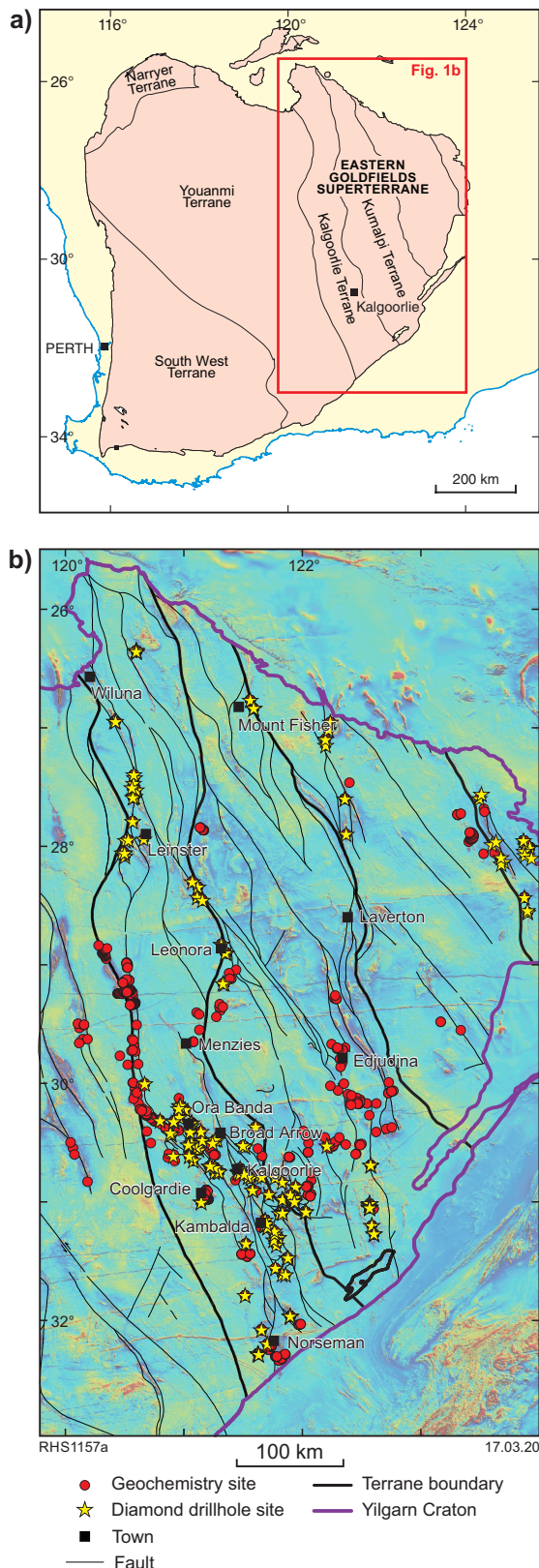
Figure 1. **Eastern Goldfields greenstone geochemical barcoding project area overview and sample localities: a) location map of the study area; b) aeromagnetic image of the Eastern Goldfields Superterrane showing the locations of samples used for this study. Note that many sites represent the location of a diamond drillhole, cores from which commonly produced several samples. Hence, a single point (or symbol) may represent several samples**

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 Excel spreadsheet 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. $aSiO_2$, 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, visually, 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 aMgO >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 aMgO 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:

  - aNa_2O+aK_2O >5 wt% or <0.5wt%

  - aAl_2O_3 <10 wt% or >20 wt%

  - $aMgO$ <3 wt%

  - $aFeOT$ ($aFe_2O_3T/1.1113$) <5 wt% or >20 wt%

  - $aTiO_2$ >1.75 wt%.

    Exceptions are:

    - where aNa_2O+aK_2O >5 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 $aTiO_2$ >1.75 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 aAl_2O_3 content means that analyses of some plagioclase-porphyritic to megacrystic basalts are designated as 'problematic data'. In such cases the aAl_2O_3 filter is ignored.

- Remaining basaltic rocks with $aTiO_2$ >1.75 wt% 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 to $aTiO_2$, such that:

  - LTB = $Th/aTiO_2$ ≥0.001 and ≤0.83; $Nb/aTiO_2$ ≥1.25 and ≤2.77; $Zr/aTiO_2$ ≥40 and ≤75; $La/aTiO_2$ ≥0.001 and ≤5.55

  - ITB = $Th/aTiO_2$ >0.83 and ≤2.86; $Nb/aTiO_2$ >2.77 and ≤4.44; $Zr/aTiO_2$ >75 and ≤92; $La/aTiO_2$ >5.55 and ≤11.11

  - HTSB = $Th/aTiO_2$ >2.86 and ≤6.66; $Nb/aTiO_2$ >4.44 and ≤7; $Zr/aTiO_2$ >92 and ≤133.3; $La/aTiO_2$ >11.11 and ≤28.57

  - EMI = $Th/aTiO_2$ >6.66; $Nb/aTiO_2$ >7; $Zr/aTiO_2$ >133.3; $La/aTiO_2$ >28.57.

- Individual samples classified based on one or more ratio might be classified differently based on another of the critical ratios (for example, a sample classified as ITB based on its $Th/aTiO_2$ 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 aP_2O_5 >0.25 wt% and Ba >400 ppm (empirically identified lower limits for such rocks) and the rock descriptions were examined for indications of lamprophyric textures.

- Analyses initially designated as 'problematic data' based only on aNa_2O+aK_2O >5 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, La/Nb <~1.5; to date no analysis clearly has such attributes). If not, 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 to $aTiO_2$ (i.e. were strongly enriched in Th, Nb, Zr and light rare earth elements [LREE]) and had aP_2O_5 >0.25 wt% and Ba >400 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 $aSiO_2$ ≥58 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 volcaniclastic ('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 ($aSiO_2$ 58–63 wt%), dacitic ($aSiO_2$ 63–68 wt%) and rhyolitic ($aSiO_2$ 68–77 wt%). Additional categories were established for peraluminous felsic rocks (ASI >1.2) and silicified felsic rocks ($aSiO_2$ >77 wt%), these being regarded as either altered or clastic/epiclastic based mainly on the rock description and lithological association.

Analytical methodology

Nearly all samples reported here were analyzed 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 data potentially attributable to variations in analytical procedure. The data reported here include 178 analyses of powders or crushed rock from the GSWA Western Australian Geochemistry database (WACHEM; <www.dmirs.wa.gov.au/launch/geochemistry>), representing 5% of the total samples. Many of these samples were pulverized using a tungsten carbide mill, and we do not report W for that subset of data. The other 3382 samples (the vast 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 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 analyzed 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 disc and reported as element oxides. A fragment of each disc was then ablated by laser and analyzed by induced coupled plasma mass spectrometry (LA-ICP-MS) for 49 of the 52 minor elements. Gold, Pd and Pt were analyzed 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 81 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, Tl, 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, (analysis1 – analysis2)/(analysis1 + 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. The exceptions are As, Cu and Zn, which agree to within 5–10% of their indicative values, and Bi and Mo, which agreed poorly by comparison, with 18% and 12% HARD, respectively. In terms of precision, the relative standard deviation (RSD), or covariance, for analysis of OREAS 24b is ≤2% RSD for major and minor elements and ≤10% RSD for most trace elements. The exceptions are As, Be, Bi, Cu, Ge and Zn, with RSD ≤20%. 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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