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

RECORD 2017/16

DATA METHODOLOGIES APPLIED IN THE WESTERN AUSTRALIAN DIAMOND EXPLORATION PACKAGE

by
MT Hutchison

Geological Survey of Western Australia

EXPLORATION INCENTIVE SCHEME

DATA METHODOLOGIES APPLIED IN THE WESTERN AUSTRALIAN DIAMOND EXPLORATION PACKAGE

Frontispiece: Run-of-mine production from Ellendale 9 post-acid cleaning and showing the range of size, morphology, and colour of production, 2008 (photograph by MT Hutchison)

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

Record 2017/16

DATA METHODOLOGIES APPLIED IN THE WESTERN AUSTRALIAN DIAMOND EXPLORATION PACKAGE

by
MT Hutchison

Perth 2018

Geological Survey of Western Australia

REFERENCE
The recommended reference for this publication is:
Hutchison, MT 2018, Data methodologies applied in the Western Australian diamond exploration package: Geological Survey of Western Australia, Record 2017/16, 24p.

National Library of Australia Card Number and ISBN 978-1-74168-779-8

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94).

EXPLORATION INCENTIVE SCHEME

Published 2018 by Geological Survey of Western Australia
This Record is published in digital format (PDF) and is available online at <www.dmp.wa.gov.au/GSWApublications>.

Further details of geological products and maps produced by the Geological Survey of Western Australia are available from:
Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459 Facsimile: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications

Cover image: Elongate salt lake on the Yilgarn Craton — part of the Moore–Monger paleovalley — here viewed from the top of Wownaminya Hill, 20 km southeast of Yalgoo, Murchison Goldfields. Photograph taken by I Zibra for the Geological Survey of Western Australia

Contents

Figure

Tables

Data methodologies applied in the Western Australian diamond exploration package

by

Hutchison, MT

Abstract

The Geological Survey of Western Australia's Diamond exploration and prospectivity data package compiles over 40 years of diamond exploration data. In addition to samples derived from Western Australia's established diamond mining areas at Ellendale and Argyle, a wide coverage of regional exploration data extending to the boundaries of the State is included. The database follows a similar methodology of attribution and has a compatible structure to the Diamond Exploration Database of the Northern Territory, allowing direct comparison of data throughout the North Australian Craton. The diamond exploration and prospectivity data package is the first of its kind to collate diamond exploration data statewide in a publicly accessible fashion. It incorporates the locations of over 88 000 diamond exploration samples. Associated with these samples are over 30 000 good-quality chemical analyses of mineral separate grains integrated into a standardized framework presented herein.

In total, 524 discrete in situ bodies, which in principle have diamond potential (kimberlites, lamproites, ultramafic lamprophyres, and carbonatites) have also been compiled in the diamond exploration and prospectivity data package. With 114 confirmed to be diamondiferous, this part of the database considerably expands upon previous compilations of relevant Western Australian rocks, including the Geological Survey of Western Australia's MINEDEX database and Bulletin 132. As a companion, 127 emplacement age determinations from 63 bodies are reported, encompassing most of the geographic extent of Western Australia's known rocks with diamond potential.

Analyses of the Western Australian data allow for an understanding of the exploration history in areas of known occurrences and identification of considerable gaps in the exploration coverage within areas of diamond potential. The Diamond exploration and prospectivity data package stands as a means to support and encourage future diamond exploration in the State in addition to providing a rigorous framework suitable for the establishment of diamond exploration databases elsewhere.

KEYWORDS: databases, diamonds, diamond exploration, mineral deposits, lamproite, kimberlite, lamprophyre, indicator minerals, chromite, chrome diopside, garnet, picroilmenite, microdiamonds

Introduction

According to Kimberley Process Certification Scheme statistics, Australia is estimated to have produced approximately 11% of the global rough diamond production by weight in 2015, ranking it fourth in the world after the Russian Federation, Botswana, and the Democratic Republic of Congo. There is currently only one producing mine in Australia, the Argyle mine exploiting the AK1 olivine lamproite. Both the Argyle diamond mine and the recently closed Ellendale diamond mine (which exploited the Ellendale 4 and Ellendale 9 olivine lamproites) are associated with Proterozoic mobile belts surrounding the currently unexposed Kimberley Craton of Western Australia. Diamondiferous kimberlites are also known from locations within the craton itself, which is understood to be underlain by Archean lithospheric mantle (Graham et al., 1999). Old, cold, and thick cratonic roots provide the most abundant source of diamonds exploited worldwide.

Away from thick cover, Western Australia hosts approximately 696 000 km^2 of onshore, exclusively Archean rocks and 439 000 km^2 Paleoproterozoic rocks. In total, pre-1.6 Ga rocks comprise around 45% of the onshore area of the State. Most notable due to their size are the Youanmi Terrane, Eastern Goldfields Superterrane, and South West Terrane of the Yilgarn Craton (Wyche et al., 2012), the Kimberley Basin of the North Australian Craton (NAC) (Tyler et al., 2012), and the Pilbara Craton (Hickman and Kranendonk, 2012). Even among Western Australia's orogenic belts and sedimentary basins, most are also believed to be underlain by thick, Archean lithospheric mantle (Gun and Meixner, 1998; Kennett et al., 2013). Hence, much of Western Australia comprises of the lithospheric conditions conducive for diamond formation.

For diamond exploitation it is also important that host eruptives are not inaccessible due to overlying younger rocks. Certainly, some diamondiferous rocks in Western Australia are very young (e.g. 17 Ma old eruptives are known from the Noonkanbah field of the west Kimberley; Phillips et al., 2012). However, even considering the full range of emplacement ages of diamondiferous rocks, many parts of the State exhibit a solid surface geology sufficiently old to allow any diamondiferous intrusive rocks to be near surface. Western Australia has by no

means been exhaustively explored. Hence, both theory and precedent support potential future economic diamond discoveries in much of the State.

Western Australia benefits from having experienced continuous diamond exploration since the early 1970s (Tyler, 1987; Smith et al., 1990), generating in excess of 4200 company reports citing diamond as a commodity of interest. Early work involved Stockdale Prospecting Ltd (De Beers Group), CRA Exploration Pty Ltd, and Ashton Mining NL (both now Rio Tinto Exploration Pty Ltd) who undertook reconnaissance stream sediment sampling across much of northern Australia (Jaques et al., 1986).

The diamond exploration and prospectivity data package (referred to throughout this project as DED; GSWA, 2018) aims to collate as much publicly available sampling data, reflecting as much of Western Australia's diamond exploration history as possible. Aside from basic information, such as sample locations and diamond and indicator mineral recovery data, a large number of additional data fields have been populated. These include original datum information, sampling screen sizes and concentrate weights, and information on associated mineral phases, useful for prospecting for other commodities. A detailed breakdown of the mineral phase subtype is included, using mineral chemistry in conjunction with contemporary kimberlite and mantle mineral classification schemes, such as Grütter et al. (2004) and Wyatt et al. (2004). Locations of samples taken for bulk chemical analysis and full diamond descriptions complement the primary indicator mineral data. In total, the database comprises 164 fields for unique types of data, not including record identifiers. An interpretation of the data, incorporating discussion of successes and failures of historical exploration methods applied to Western Australia and a prospectivity model is provided in Hutchison (2018).

Terminologies

Mineral phases used in the course of diamond exploration are interchangeably called 'diamond indicators', 'kimberlite indicators', and sometimes 'mantle indicators'. Hence, databases incorporating corresponding data are consequently often referred to by similar names. The chemistry of some phases, such as some garnets, can be directly attributed to a likely syngenetic association with diamond. However, some other phases, such as ilmenites, provide information on a likely association with kimberlite, but no direct information on its diamond potential. Yet, other phases, such as olivine with particular compositions, are evidence of a mantle origin, but reveal little of the likely association with the types of magmatism usually associated with diamond deposits. However, all relevant phases with the various pieces of information they provide, usefully contribute to a picture of the diamond potential of a particular area.

Although the majority of Western Australian diamond exploration has focused on indicator minerals, as it has done elsewhere in Australia (Hutchison, 2011, 2012) and beyond (Fipke et al., 1995), other geochemical data such as bulk rock and sediment chemistry (Singh and Cornelius, 2006) and plant chemistry are useful in contributing to a picture of diamond potential. Where relevant, such samples are also referred to in the current study. Hence, given the range of types of information presented, the all-encompassing term DED is adopted.

Primary magmatic sources of diamonds have traditionally been thought to be restricted to kimberlites. However, diamonds exist as xenocrysts, sometimes in economic concentrations, in lamproites (e.g. the AK1 pipe at Argyle; Jaques et al., 1986) and ultramafic lamprophyres (such as aillikites; Hutchison and Frei, 2009). Australia provides some of the more striking examples, demonstrating the true range of rock types within which diamonds can be transported to the Earth's surface.

The distinctions between aillikite and some kimberlites are very subtle and can only be discerned by detailed petrology of fresh samples. Furthermore, the term 'kimberlite' can be subdivided into 'Type-I' and 'Type-II' kimberlites, the latter term being typically regarded as equivalent to the rock type 'orangeite' (Mitchell, 1995). Due to the complexity and often subtlety required to correctly identify diamond host rocks, a practical field term is useful in the common absence of a true petrological classification. With the exception of lamproites, which, when not strongly weathered, can be separately identified, it is common to refer to primary igneous diamond host rocks as 'kimberlites' or 'kimberlitic rocks'. Although using the same word as both a field term and a precise petrological term can cause confusion, particularly when rigorous classification is important, this is the accepted practice within the industry. Other terms have been used; for example, the De Beers Group of companies, including Stockdale Prospecting Ltd, have routinely used the term 'para-kimberlite' to refer to rocks which have no formal petrological classification, but may be kimberlites. Where it arises in the DED, the term 'kimberlite' is used without prejudice and as originally reported. Users of the database should be aware that in many, but not all cases, the term is used as a field term. Given the deep and pervasive extent of weathering throughout Western Australia, it is conceivable that in some cases the term may also be used to refer to rocks that in their pristine forms are actually lamproites or lamprophyres.

Diamond itself is one in the range of minerals indicative of the diamond potential of a prospect. Hence, diamond is generally implied where the term 'indicator mineral' is used. However, in some cases it is useful to distinguish between diamond and nondiamond indicator minerals. An example of this is the database field <TOTIND_EXD> where diamond is specifically excluded. In this and similar cases, the exclusion of diamond is made clear in the field definitions.

Understanding the USB product

Files constituting the database and accompanying this Record have been assigned to the eight principal folders described in Table 1. The product comprises copies of pre-existing Geological Survey of Western Australia (GSWA) files of relevance to diamond exploration, such as geological and geophysical maps and GIS layers, and the files unique to the database itself. The core DED data reside in seven MS Excel (.xlsx) files, which have associated data dictionaries and GIS layer files derived from these.

Folders

\ARCMAP folder

The ARCMAP folder contains the file 'gswa.mxd'. This is the primary ESRI ArcMap document 'front-end' to the database in ESRI ArcGIS format. The file opens either directly from relevant ESRI software and references various files contained in the subfolders of the \ARCMAP folder. These provide the geological and geographical context of the data, in addition to aspects of the data presented as thematic and geographically referenced layers.

The \ARCMAP folder is subdivided into a folder containing small-scale background spatial data (\OVERVIEW) and a folder (\SHAPEFILES) containing the principle spatial data of the package. In addition to spatial data and queries deriving from the core MS Excel files of the DED, four further GIS files are included which are unique to the DED and are described in Table 2. Included are buffer zones describing areas within and outside 20 km from known sample locations, locations of De Beers Group tenements, outlines of selected diamond-prospective in situ occurrences, and the results of a regional prospectivity ranking following Hutchison (2018). The De Beers Group tenements are included, because these companies explored almost exclusively for diamonds. Given that their full database of sample locations has not been made publicly available, the layer serves as an alternative means of visualizing where this major group explored. Similar tenement layers are not provided for other companies because, with few exceptions, exploration projects have been focused on multiple commodities. Hence, such spatial tenement data would present a misleadingly large coverage. However, among background spatial data, WAMEX report polygons are provided, which can be queried based on the commodity of interest when required.

All contextual data are provided in the USB in their most current forms. However, the background data provided represent a small portion of the geotechnical, geological, geophysical, and geochemical data, incrementally updated and available online from the GSWA via the interactive geological map (GeoView.WA) available at <www.dmp.wa.gov.au/GeoView> and the GSWA Data and Software Centre website at <https://dasc.dmp.wa.gov.au/dasc>.

Queried data

The thematic GIS layers within the ESRI ArcGIS project are designed to be self-explanatory. They query the DED data in a fashion that draws attention to geographic areas exhibiting a variety of properties suggesting diamond potential. The thematic layers included in the project are described in Table 3.

Although some basic concepts, such as indicator recovery per kilogram, microdiamond and macrodiamond recovery, and the relative proportions of specific mineral chemical classifications are presented as thematic maps, users of the USB product are encouraged to use the large quantity and variety of data available to create queries suitable for their own particular requirements. It should be emphasized that considerable scope exists within the data to conduct sophisticated statistical treatments and quality control filtering.

Table 1. Principal subdivision of files provided in this USB product

FOLDER	*Description of contents*
\ARCMAP	Contains the database data presented as ESRI ArcGIS format, including thematic maps elucidating key aspects of the data
\DATABASES	Contains MS Excel spreadsheets constituting all of the diamond exploration data in their original, captured form
\DOCUMENTS	Contains data dictionaries defining the format of the data and metadata files, describing the rules and any assumptions applied during the population of records in particular fields
\IMAGES	Contains raster maps representing geological, geographical, and geophysical data supporting the DED data and referenced in GIS layers
\MAPINFO	Contains the database data presented in MapInfo format (v10), including thematic maps elucidating key aspects of the data
\RESOURCES	Support files for GeoMap.WA functionality
\SOFTWARE	Software useful for reading supplied PDF files and delivering the DED and associated layers in a standalone GIS format
\WEB	Support files for autorun.exe functionality

Table 2. DED-unique spatial layers

Layer	*Description*
DED_WA_De_Beers_Group_Tenements	Boundaries of historical De Beers Group tenements (including Stockdale Prospecting Ltd and selcted joint venture licenses). Unlike other explorers, the De Beers Group explored almost exclusively for diamonds. Short of the full dataset of the De Beers Group's sample locations being available, the layer provides a robust picture of areas where their diamond sampling took place.
DED_WA_Explored	Areas within onshore Western Australia which lie within a 20 km radius of a sample location identified in file 'DED_WA_BASICS.xlsx'. This file includes an inverse selection representing underexplored areas. The significance of a 20 km radius as a cutoff is fairly arbitrary, but it is at the upper limit of the expected chromite survival distance and serves as a visual estimate of the sphere of relevance for individual samples.
DED_WA_Occurrences_Outlines	Spatial information describing at or near-surface outlines of selected in situ occurrences of diamond-prospective bodies referenced in the file, DED_WA_Occurrences.xlsx.
DED_WA_Regional_Prospectivity	Flattened and partially simplified (orogenic regions largely removed) copy of onshore layers constituting the 1:10 000 000 tectonic map of Western Australia (modified from Martin et al., 2016). The layer is colour coded according to relative prospectivity for diamonds and following the methodology described in Hutchison (2018). Most prospective regions (coloured dark brown) are ranked '1' and least prospective regions (coloured purple) are ranked '13'.

Table 3. Thematic GIS layers elucidating various aspects of the exploration data

Layer	*Shapefile*	*Notes*
Microdiamonds	DED_WA_BA_ind_micro.shp	Indicates the locations of reported microdiamonds with the symbol size reflecting their abundance in each sample
Macrodiamonds	DED_WA_BA_ind_macro.shp	Indicates the locations of reported macrodiamonds with the symbol size reflecting their abundance in each sample
Indicator minerals	DED_WA_Bulk_Analyses_Indicators.shp	Represents the occurrences of visually identified nondiamond indicator minerals as pie charts subdivided on the basis of phase with the radius proportional to total number of grains reported
Diamond concentration	DED_WA_BA_ind_dia.shp	Represents diamond-bearing samples with symbol sizes proportional to total diamonds recovered per kg of sample
Nondiamond concentration	DED_WA_BA_ind_nondia.shp	Represents samples with nondiamond indicators, identified visually and with symbol sizes proportional to the total indicators recovered per kg of sample
Chemical indicators – clinopyroxene	DED_WA_BA_ind_CPX.shp	Represents the occurrences of chemically identified indicator clinopyroxenes as pie charts subdivided on the basis of classification
Chemical indicators – orthopyroxene	DED_WA_BA_ind_OPX.shp	Represents the occurrences of chemically identified indicator orthopyroxenes as pie charts subdivided on the basis of classification
Chemical indicators – Ilmenite	DED_WA_BA_ind_ILM.shp	Represents the occurrences of chemically identified indicator ilmenites as pie charts subdivided on the basis of classification
Chemical indicators – garnet	DED_WA_BA_ind_GT.shp	Represents the occurrences of chemically identified indicator garnets as pie charts subdivided on the basis of classification
Chemical indicators – spinel	DED_WA_BA_ind_SP.shp	Represents the occurrences of chemically identified indicator spinels as pie charts subdivided on the basis of classification

\DATABASES folder

The DATABASES folder provides a large quantity of geological data of relevance to the diamond explorer. The data are contained in the root directory and a further 11 subfolders. Most data derive from pre-existing GSWA databases, such as the locations of mines and associated infrastructure (\MINEDEX_CSV), geochronology data (\GAGEOCHRON_CSV), and submitted statutory company reports (\WAMEX_REPORTS_CSV). However, the core the DED data reside in the \DIAMOND_EXPLORATION_DATA subfolder. MS Excel files are provided in the MS Excel open spreadsheet XML file format (.xlsx). Users of older formats who are unable to open or convert these files are directed to the same data incorporated into the equivalent MapInfo (.dat) or ESRI ArcGIS (.dbf) files. The MS Excel files constitute the definitive locations for data unique to the DED and from which ESRI ArcMap and MapInfo format files have been subsequently derived. The data contained in these files are described in Table 4. Associated pre-existing GSWA databases are provided as comma separated value (.csv) files and in MS Access 2007 (.mdb) format.

The DED MS Excel files have been constructed in a fashion to minimize repetition of data fields. Consequently, for example, location coordinates are only provided in root files on which others depend. The DED is split into two groups of files (Fig. 1): those relating to exploration samples where location data are held in the root file 'DED_WA_BASICS' and those relating to attributes of in situ diamond-relevant bodies where the root files are 'DED_WA_OCCURRENCES' and 'DED_WA_INFERENCES'. All data files incorporate unique reference keys for each record. The <SAMPLEID> field provides a unique numerical identity for each sample and the <INDID> field provides a unique identity for each subsample. For in situ bodies, the <OCCURID> field constitutes the primary key allowing a link to geochronology data. The unique keys allow cross-referencing of data between files. However, the GIS folders (/ARCMAP and /MAPINFO) provide various layer files where cross-referencing queries of the data matching some key concepts from the various data files have been already made.

Each data file has a corresponding data dictionary file entitled 'Dictionary_*.xlsx', where the star symbol '*' represents the name of the data file to which it refers. Data dictionaries describe the structure of each file, brief definitions, and formatting rules applied to each field, and any rules regarding mandatory population or controlled vocabularies for each field. These rules also apply to the GIS data files. Additional data dictionaries are included for various GIS layers and are provided as supporting datasets.

\DOCUMENTS

The DOCUMENTS folder contains metadata files, reports of relevance to Western Australia's diamond exploration, various geological maps in PDF format, the accompanying interpretative document to the DED, and this explanatory document.

A summary document entitled 'Data Dictionary', which is based on files in subfolder \DATABASES\DIAMOND_EXPLORATION_DATA\ and specific to the shapefiles is provided in subfolder \DOCUMENTS\METADATA\ (file: 'DataDictionary.pdf'). This file does not list the full controlled vocabularies described in the 'Dictionary_[NAME].xlsx' files. Metadata files are provided in subfolder \DOCUMENTS\METADATA specific to various layers and in the summary document (file: 'Metadata.pdf'). They broadly follow the Australia New Zealand Land Information Council (ANZLIC) format. Where necessary, they expand upon the data dictionaries by providing fuller descriptions of rules, assumptions, and any known shortcomings encountered during the population of data fields. Metadata files also define the numerical codes representing various concepts that are required as abbreviations in numerical data fields. Many of the key concepts described by metadata files are discussed in this document.

\IMAGES

The IMAGES folder contains raster maps representing geological, geographical, and geophysical background data in JPEG 2000 (.jp2) and MapInfo (.tab) format.

\MAPINFO folder

The MAPINFO folder contains the file 'gswa.wor'. This is the primary MapInfo workspace for the DED and opens directly from applicable MapInfo data. It references various files contained in the folders \MAPINFO and \IMAGES. These files deliver the data as thematic and geographically referenced layers in addition to their geological and geographical context. Specific files equivalent to each of the core MS Excel data files located within subfolder \DATABASES\DIAMOND_EXPLORATION_DATA are provided. They have been generated following the rules described in the equivalent MS Excel data dictionary files.

In addition to spatial data deriving from the core MS Excel files of the DED, four further GIS files unique to the DED are included and described in Table 2. These comprise a file showing buffer zones describing areas within and outside 20 km from known sample locations, outlines of selected diamond-prospective in situ occurrences, locations of De Beers Group tenements, and the results of regional prospectivity ranking following Hutchison (2018). The De Beers Group tenements are included because these companies explored almost exclusively for diamonds. Given that their full database of sample locations has not been made publicly available, this layer provides an alternative means of visualizing where this major group has been explored. Tenement layers are not provided for other companies because, with few exceptions, exploration projects were focused on multiple commodities. Therefore, such spatial data would provide a misleadingly large coverage. However, WAMEX report areas are provided and these can be queried based on commodity of interest when required. All contextual data are provided in their most current forms. However, the

Table 4. Primary data files

Data file	*Description of contents*
DED_WA_BASICS.xlsx	Source of basic location, sample description, and data source information for samples recovered in the course of Western Australia's diamond exploration
DED_WA_BULK_ANALYSES_Indicators.xlsx	Sample processing, methods, and recovery results from samples and subsamples tested for indicator minerals, including diamond in the course of Western Australia's diamond exploration
DED_WA_GRAIN_ANALYSES_Maj_Chem.xlsx	Source of mineral chemical data derived from individual mineral grains picked from samples recovered in the course of Western Australia's diamond exploration
DED_WA_GRAIN_ANALYSES_Diamond.xlsx	Source of descriptive information for individual diamond crysts picked from samples recovered in the course of Western Australia's diamond exploration
DED_WA_OCCURRENCES.xlsx	Locations and physical characteristics of definitively identified in situ occurrences of rocks which in principle may have an affiliation with diamond, viz. kimberlites, lamproites, ultramafic and leucite lamprophyres, and carbonatites
DED_WA_OCCURRENCES_AGES.xlsx	Determinations of emplacement age of occurrences
DED_WA_INFERENCES.xlsx	Locations and physical characteristics of inferred in situ occurrences of rocks which in principle may have an affiliation with diamond, viz. kimberlites, lamproites, ultramafic and leucite lamprophyres, and carbonatites

background data provided represent a small portion of the geotechnical, geological, geophysical, and geochemical data, incrementally updated and available online from the GSWA via GeoView.WA.

Queried data

As for the ESRI ArcGIS project, the thematic layers within the MapInfo workspace are designed to be self-explanatory and to query the DED in a fashion to emphasize geographic areas showing diamond potential. Querying thematic layers in MapInfo with such a large dataset requires significant computing time. Hence, queries matching location data have been pre-run with associated MapInfo files generated. These files are entitled 'DED_WA_BA_[NAME].tab'. Thematic layers included are the same as for the ESRI ArcMap document and are as described in Table 3 where the shapefiles (.shp) all have equivalent MapInfo files.

While some basic concepts, such as indicator recovery per kilogram, microdiamond and macrodiamond recovery, and the relative proportions of specific mineral chemical classifications are presented in map form, users of the USB product are encouraged to use the large amount and variety of data available to create queries consistent with their own interests. Considerable scope exists within the data to conduct sophisticated statistical treatments and quality control filtering.

\RESOURCES

Support files for the GeoView.WA functionality of the USB product are contained in the RESOURCES folder.

\SOFTWARE

Software for reading PDF files and GSWA's proprietary GeoMap.WA GIS software for viewing, querying, and printing Western Australia's geology and resource information are provided in the SOFTWARE folder.

\WEB

The WEB folder contains files associated with the internet-style HTML pages of the product, which are accessed through the 'Autorun.exe' file in the root directory.

Database structure

Within the context of the two groups of the DED MS Excel files (regarding samples and in situ bodies), the individual files constituting the DED were created in a structured fashion that provides a consistent link between each file. Figure 1 summarizes the contents and describes the relative associations of each core file. Each record within each file has its own numerical identifier, unique within each spreadsheet. Furthermore, each sample has an associated and unique numerical key, <SAMPLEID>, which links through each file to entries within the core file 'DED_WA_BASICS' and also a subsample ID (<INDID>), which links from MS Excel file 'DED_WA_BULK_ANALYSES_Indicators'. As such, the files in the \DATABASES folder can readily be adopted into database software, such as MS Access, DataShed, or Oracle according to the structures established by individual users of the data.

Rules, assumptions, and identified shortcomings of the data are discussed in the following sections and presented in a comprehensive fashion in data dictionary and metadata files located in the \DATABASES\DIAMOND_EXPLORATION_DATA and \DOCUMENTS folders of the USB product. Field names referred to hereafter follow the formats of the core MS Excel files as defined in associated data dictionaries. For software compatibility reasons some of these field names have been altered (i.e. capitalized and truncated) for the generation of shapefiles, as documented in the 'Data Dictionary' document (file: 'DataDictionary.pdf') in subfolder \DOCUMENTS\METADATA\. Correlations between MS Excel and shapefile field names should be self-explanatory.

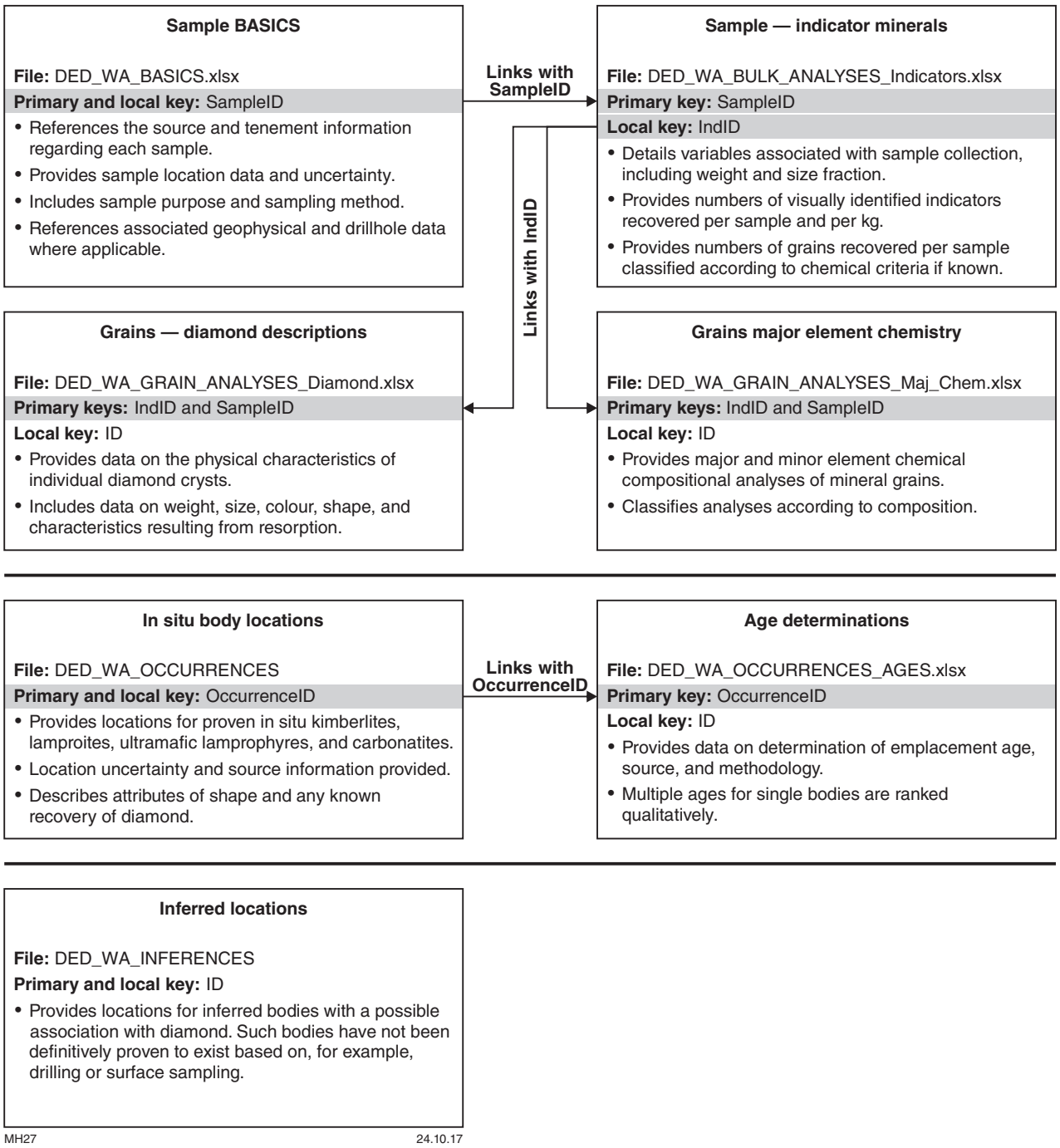

Figure 1. Structure of the Diamond exploration and prospectivity data package. The MS Excel spreadsheets located in the directory 'DATABASES\DIAMOND_EXPLORATION_DATA\' contain the control data and source MS Excel spreadsheets. They are the definitive locations for diamond exploration data captured into the package. Data dictionary files allow the MS Excel file field names to be linked to the TAB and shapefile field names if original source data are required

Primary key – <SAMPLEID>

In order to readily discriminate various principal sources of data within the database, primary key <SAMPLEID> values have been assigned in batches, as described in Table 5.

700 000-series Astro Mining NL database records derive from projects described in the following company reports: Barlee – A57959 to A57969, A59350, and A60268; Drysdale (Kimberley) – A48488 and A52139; Merredin – A59424; Nabberu – A58969; Sandstone – A53926 to A53931; West Leonora – A56508. These and other company reports referred to in the DED ('A-number reports') can be located in GSWA's WAMEX online database <www.dmp.wa.gov.au/WAMEX>.

Regarding the 900 000-series records, Department of Mines, Industry Regulation and Safety's (DMIRS) historical exploration activity (EXACT) database <https://dasc.dmp.wa.gov.au/dasc/> was maintained between 1995 and 2010. It comprises 430 556 records of exploration activity locations extending back to early reported explorations. For diamond exploration, company report data were recorded as points and as lines and polygons in cases where sample locations were either not known or too numerous to be captured digitally (in which case the associated polygon refers to the boundary of the related tenements). Only point data referencing diamond in the EXACT database has been incorporated into the DED.

In some cases <SAMPLEID> numbers appear to be missing. This is because during the compilation of data, particular samples may have been assigned multiple <SAMPLEID> values. This arises, for example, when the same sample has been reported in more than one company report. Where obvious repeats have been identified these have been removed from the final database in order to ensure that statistics involved in the numbers of samples are as accurate as possible. A small number of records have also been removed as they were found to be in error or lie too far outside the borders of Western Australia to be of relevance.

Field population rules

General population rules

The 164 fields comprising the database provide a large platform to incorporate diamond exploration data. However, because data have been compiled from numerous sources, many may have their own priorities in terms of data acquisition. Hence, for any one record many fields may not be populated. There are various reasons for these omissions. For example, diamond descriptions are not available for diamond-absent samples and drillhole depths are not available for surface samples. However, omissions are also present where the data are not reported in the source or, during the population of the DED, have been deemed to be too time consuming to scrutinize the source. In this case the term 'Not_Assessed' is used. Where there are omissions, users of the database are directed to the original data sources, such as company reports, where a more detailed picture of the acquired data may be available. All records have location information attributed and other mandatory fields are described in the accompanying data dictionaries. Useful, but often unreported fields include minimum sieve sizes, dense fraction concentrate weight, occurrences of non-traditional indicator phases, and mineral chemical quality control and classifications. Where possible, the original sample location coordinates are provided in order to minimize any of the uncertainty occasionally associated with reprojection of sample coordinates.

Considerable efforts have been made to assess and improve the quality of data obtained from the various sources. Sample locations have been regarded to be of highest importance and have been given particular attention. Examples of quality control include verification against primary sources for samples which plot in unexpected places, such as offshore areas. There is a small number of genuine offshore samples. However, numerous land-derived sample coordinates obtained from third party sources corresponded to offshore locations before being corrected. Numerous other samples were identified to have been reported with the incorrect UTM zone or with typographic errors. Assumptions in making corrections are provided in 'Comment' fields. However, users of the database are referred to primary data sources in cases of uncertainty.

Blank fields do exist for the following reasons: either the data has been deliberately omitted (because it was not reported or queried) or the particular field is not of relevance to the record in question. Where a blank field represents unassessed data, such data may or not be available in the original data source referred to. It should not be assumed that blank fields mean that the information does not exist.

In MS Excel, for example, text can be recorded in otherwise numerical fields for ease of presentation and manipulation of the data. However, it should be noted that some MS Excel formulae do not adequately discriminate between text and zero values or blank cells. For fields which largely contain numerical data, particularly if entries are likely to be subjected to statistical testing, these are formatted as numerical fields. Blank entries are not used in fields that are defined as being numerical. This is because MapInfo converts all blank entries of imported data into zeros. This is inappropriate for fields where it is critical to distinguish between blanks and zeros. For example, there is a clear distinction between a sample that was processed and yielded zero diamonds and a sample for which this information is either not available or was not assessed. A series of numerical codes in the form of negative integers have therefore been used to represent various concepts relating to otherwise blank numerical fields. These codes are summarized in Table 6.

In numerical fields, which would normally be blank, entries are represented by the number '-333' to denote the status of 'Not_Assessed'.

Table 5. Assignment of <SAMPLEID> records

Number range	*Data source*
1–10 278	Samples derived manually from submitted company reports and other sources as distinct from those acquired in batch form from existing datasets.
600 001–623 597	Samples extracted by querying GSWA's 'Downhole and Surface Geochemistry' database, which relies exclusively on data from submitted company reports.
700 001–732 099	Samples derived from compilation of Astro Mining NL exploration data. The <SAMPLEID> is identical to Astro Mining NL's database <ID> field with the mathematical addition of 700 000. Due to the fact that 3344 samples in the Astro Mining NL database provided do not derive from Western Australia, the 700 000-series records are not consecutive.
800 001–802 217	Samples from the AXIS Group database.
900 001–928 144	Samples derived from DMIRS EXACT database.
950 001–950 038	Important samples in reports referenced by EXACT, but missing from the EXACT database.

Table 6. Numerical codes to represent text in numerical fields

Code	*Definition*
-111	Not applicable. For example, an entry in <GT_G10> (counts of chemically determined G10 grains) where no garnets were recovered from the sample.
-222	Not possible to calculate. For example, an entry in <DIAM_PKG> (total diamonds per kilogram) where the sample weight is unknown.
-333	Not assessed. Such a field has not been populated because the relevant data source has not been searched for the presence or absence of applicable data. In such cases the database user is directed to the referenced data source.
-555	Analyte not determined. This code applies specifically to mineral chemical fields (e.g. <SiO_2>) where a particular analyte has not been measured, as opposed to returning a zero or 'below detection limit' value.
-666	Sample derives from an EXACT database record where the associated report describes the presence of nondiamond indicator minerals from at least one sample. The code implies that while the sample in question may or may not be indicator-positive, it derives from a report where some samples are indicator-positive. The database user is therefore directed to the original company report in order to determine the identity of positive and negative samples.
-999	Not reported. This code denotes that the field cannot be populated because the data source does not mention data applicable to the field. It should therefore not be assumed that any result is zero.

Distinctly different from blank (or '-333') entries, the term 'Not_Reported' in non-numerical fields indicates that the data has been searched for, but it is not present in the data source. Such entries establish that it is unnecessary to refer to the original source to investigate the presence of these data. Entries in numerical fields use the number '-999' to denote the status of 'Not _Reported'.

In some cases, it is desirable to specifically note that a particular field is not applicable to a particular record. This is true particularly for numerical fields where blanks cannot be used. In text fields, terms like 'Not_Applicable' are used. For numerical fields the number '-111' is used to denote the status of 'Not_Applicable'.

Entries in fields that are defined as numerical use the number '-222' to denote 'Not_Calculable'. This code indicates that the data reported do not allow for such a calculation to be made. For example, where sample weight is neither reported nor can be reasonably estimated, recovery of diamonds per kg of sample is not calculable.

While numerical codes are useful, particular care should be taken to remove them from extracts of the data before statistical calculations are made.

Field-specific population rules

Basic data – DED_WA_BASICS

The 'DED_WA_BASICS' file provides the basic sample location data and reference to its source. Selected fields within this file which warrant detailed explanation further to that provided in the data dictionaries are as follows.

Sample names (<SOUSAMPNA>)

Wherever possible, reported sample names are exactly as reported in the data source. In very rare cases, where prohibited characters are used, these have been replaced by suitable alternatives.

Records in the DMIRS EXACT database do not include sample names, only locations and general descriptions of results reported in each company report. Subsequently, EXACT records incorporated into the DED, constituting <SAMPLEID> entries in the 900 000 series, usually have <SOUSAMPNA> entries in the form of 'EXACT_Does_not_Report'. However, in cases where recourse has been made to the original source report to correct an error in the

EXACT record or investigate a particularly notable series of samples, the <SOUSAMPNA> field may have been correctly attributed.

Location data (<LONGITUDE>, <LATITUDE>, <PUBYEAR>, <ORIG_LONG>, <ORIG_LAT>, <ORIG_X>, <ORIG_Y>, <ORIGZONE>, <ORIGDATUM>, <LOCMETHOD>, and <LOC_ ACC>)

Sample location information that can correctly direct an explorer to a sample site, either in person or through a GIS package, is a core component of the DED. A number of factors influence the accuracy of location data. Many older company reports provide location data only as graphical representations on maps plotted at various scales. In such cases, sample locations have been captured by means of georeferencing and in some cases also by rectifying maps. Notes are made in the <LOCMETHOD> field to this effect. Hence, in addition to the often unknown accuracy of the reported data themselves, the process of estimating locations from maps introduces further uncertainty. Irrespective of the format in which the data was presented, pre-GPS location information was almost always achieved by cross-referencing topographic features with their representations on published government maps. Although GPS determinations were made in the early 1980s the technology does not appear to have been in common use until at least 1990. The DED provides an estimate of the uncertainty of location data through the <LOC_ACC> field. Where this information is not reported, data users should consider the age of the sample (<PUBYEAR>) and any other relevant information to assess the usefulness of positional data to their specific needs. Except in cases where accurately described and identifiable geographic features can be established, as a general rule of thumb, pre-1990 location data should not be expected to have a precision better than 100 m.

Further uncertainties have been introduced due to changes in mapping protocols. The Australian Geodetic Datum 1984 (AGD84) was adopted by some Australian States and Territories, superseding the previously used AGD66 reference datum. However, at that time there was considerable discussion concerning the need for Australia to adopt a geocentric datum, using the Geodetic Reference System 1980 (GRS 80) rather than the Australian National Spheroid. Partly because of uncertainty over the future use of the spheroid, some explorers adopted the change while others did not. A further argument used in favour of ignoring AGD84 was that the maximum difference between locations described by AGD84 and AGD66 within Western Australia is only 6 m. Shortly afterwards Australia adopted the Geocentric Datum of Australia 1994 (GDA94). This datum is based on the GRS 80 ellipsoid and for the purposes of geological locations can be considered to be identical to the World Geodetic System 1984 (WGS 84). In fact, locations at the Earth's surface differ by less than 10 mm between these two ellipsoids. While latitudes and longitudes are based directly on the appropriate datum, typically the metric map system is used for geological work throughout Australia. The Map Grid of Australia 1994 (MGA94) is based on GDA94 and likewise the Australian Map Grids AMG66 and AMG84 correspond to the datums of AGD66 and AGD84, respectively. Western Australia lies within Zones 49, 50, 51, and 52, with the boundaries located at longitude 114°, 120°, and 126°, respectively.

Irrespective of the official use of different projection systems, the various companies operating within Western Australia had their own policies or occasionally adopted apparently random procedures for using a specific projection. For example, Paradigm North Pty Ltd were still using AMG66 for their Wolf Creek project until at least 2005, the Paramount Mining Corporation Ltd was using AMG66 in 2010 on sheet EDMUND, and De Beers Australia Exploration Ltd used AMG66 in the Fortescue Basin in 2004. By contrast, the De Beers Group used AMG84 in the Hamersley Range in 2007, but was using GDA94 on the exposed Pilbara Craton in 2001.

Although the DED captures location data as originally reported (referencing the particular datum and projection), all locations are also presented in their equivalent decimal latitude and longitude coordinates in GDA94. The GDA94 coordinates (presented in fields <LATITUDE> and <LONGITUDE>) are the definitive locations, which have been used for all spatial queries and layers in the DED. Using a consistent projection system for the database is important for presenting an internally consistent picture of exploration in Western Australia. However, in addition to the number of projection methods used, company reports often present an additional problem by occasionally quoting AMG rather than AMG66 or AMG84. In such cases AMG66 is assumed to be the projection system, which has a maximum error of only 6 m to the datum. The source of other data is quoted as WGS84, in which case it is has been assumed to be equivalent to GDA94. This assumption should create only insignificant errors. GDA94 is based on GRS 80, which only differs from WGS84 in the sixth decimal place of inverse flattening, giving rise to a difference in UTM coordinates of less than 1 cm. However, often (i.e. in approximately 16% of data manually captured from company reports) no projection system is stated at all. In this case an educated guess about the correct projection has to be made, where it has to be assumed that pre-1994 data utilizes the AMG66 coordinate set (subject to a 6 m uncertainty) and post-1994 data are based on GDA94. This assumption is contentious as many government agencies did not fully adopt GDA94 until the early 2000s. For the post-1994 data the differences between GDA94 and AMG66 result in location uncertainties of up to 150 m, as noted in the 'Comment' fields. Hence, users of the DED requiring higher accuracies than within the nearest 150 m are urged to inspect entries for reported datum (<ORIGDATUM>) and accuracy (<LOC_ACC>).

Composite sample locations (<LONGITUDE>, <LATITUDE>, <LOCAT_TYPE>, <ORIG_ LONG>, <ORIG_LAT>, <ORIG_X>, <ORIG_Y>, <ORIGZONE>, <ORIGDATUM>, <LOCMETHOD>, and <LOC_ACC>)

It is common for companies to process composite samples over considerable lengths of drillcore. However, some companies have created composite samples incorporating

material from a sometimes wide range of geographical locations. Treatment of the data resulting from such a sampling methodology presents particular problems. A consistent approach for treating composite samples has been applied to reduce the degree of uncertainty to a minimum. In terms of locations, problems arise in connection with assigning location data and even more seriously with mineral recovery data. Composite samples are identified by an entry in the <LOCAT_TYPE> field in the form of 'Composite_xx', where 'xx' denotes an integer representing the number of samples in the composite. Where individual sample names are known, they are itemized in the 'Comment' fields. In some cases, a central coordinate is reported and this is the information given in the database. For example, sometimes five-fold composite samples are reported to have been taken in a four-pointed star shape with a portion of the composite taken at a central location. In other cases, the coordinate quoted is an estimate of the most representative geographical location of the components of the composite sample. Extensive use of the 'Comment' fields has been made to describe the assumptions used in generating the reported coordinates.

A second type of composite-style samples derives from some records extracted from the DMIRS EXACT database. EXACT records are identifiable by <SAMPLEID> fields ranging from 900 001 to 950 038. EXACT records, in their original form, comprise point locations usually obtained by digitizing and georeferencing submitted maps. In addition to not reporting sample names, EXACT does not attribute processing results to individual sample locations. Rather, each location derived from a particular company report has been assigned the same comment describing any indicator mineral recovery from the whole report. EXACT records originating from a single company report are in effect composite samples where the component locations contributing to the composite are represented by multiple records.

Sample material (<SAMP_MATRL>)

The controlled vocabulary of <SAMP_MATRL> provided in the file 'Dictionary_DED_WA_BASICS.xlsx' provides a self-explanatory description of the content of this field. It is notable that wherever possible, discrimination between current and paleodrainages has been made when populating the DED. In cases where this has not been possible or practical, such samples are simply referred to as 'alluvial'. Furthermore, samples attributed to Astro Mining NL occasionally refer to 'Sand'. It is unclear whether the term refers to dune material (loam) or sand from other settings, such as rivers. Hence, the ambiguous term 'Cover-Sand' is retained for these particular samples. Astro Mining NL also uses the terms 'GS' and 'CHEM' with reference to sample material. However, these are understood to represent 'geochemical sample' and 'chemical sample', respectively, and hence relate to sample purpose. These terms have been removed from field <SAMP_MATRL>.

Trap quality (<TRAP_QUAL>)

Trap quality is a subjective term. Classification schemes exist in the academic literature (Muggeridge, 1989, 1995) and some companies have also attempted to standardize their terminologies. However, there is likely to be a large variability in what constitutes various trap site qualities in different areas and between and within companies. Due to the importance of trap site quality, the field has been assigned a controlled vocabulary and where necessary reported terms have been modified to the closest apparent fit to the controlled vocabulary. Astro Mining NL typically quotes the quality of trap sites according to ratings on a scale from '0' to '9'. A rating of '0' refers to loam, allowing the assumption that a rating of '9' therefore corresponds to the best quality sample sites. Furthermore, reports describing traps as 'Fair', such as Geotech International Pty Ltd, have been assigned to the term 'Moderate'.

Sample purpose (<SAMPURPOSE>)

The majority of diamond exploration samples within Western Australia were collected for the purpose of separating indicator minerals whether or not diamond itself. Nevertheless, a significant number of samples were collected for other reasons, most commonly for bulk chemical analyses. The <SAMPURPOSE> field describes the intent for processing the sample. Most data reported as 'Bulk_Chemistry' and its derivatives are the results of chemical testing provided in the referenced data source. The DED does not capture the results of the chemical analyses of such sampling.

Drillhole samples (<COLMETHOD>, <COMPHOLEID>, <DRILHOLEID>, <DEPTHFROM>, and <DEPTHTO>)

The database refers to numerous samples taken from drillholes, as identified in the field <COLMETHOD>. Basic data and indicator mineral recovery data, where applicable, are provided by the database in the same fashion as samples acquired by other means. However, DMIRS provides a separate drillhole database, providing more detailed technical and lithological information for some drillholes which can be accessed via GeoView. WA. Drillholes present in both databases may be cross-referenced using the <DRILHOLEID> field.

Indicator recovery data – DED_WA_BULK_ANALYSES_Indicators

The 'DED_WA_BULK_ANALYSES_Indicators' file provides information on the methods applied and the results of sample processing. Selected fields within this file which warrant detailed explanation further to that provided in the data dictionaries are as follows.

Subsample fields (<INDID>, <SAMPLEID>, <SOUSAMPNA>, and <SOUSUBSAMP>)

During the course of exploration most companies have chosen to assign separate sample numbers to samples destined for different testing methods, but which derived from the same location. These are treated as subsamples, which accounts for the occurrences of multiple records in 'DED_WA_BULK_ANALYSES_Indicators' data file referencing the same <SAMPLEID> entry. Hence, <SAMPLEID> is not a unique key in the 'DED_WA_BULK_ANALYSES' file. Instead, <INDID> is used for uniquely identifying records. It is common, for example, for two separately labelled loam samples to have been taken from the same site, one for bulk chemistry and the other for indicator mineral separation. There are other cases where samples have been subdivided after collection, either by simple manual splitting or designating different size fractions for different types of analyses. In addition to the above example, it has been standard practice for some companies to use the 0.1 – 0.25 mm or 0.3 mm size fraction for caustic fusion separation of diamond and the larger size fraction to nondiamond indicator mineral separation. So-called 'slimes', typically also sub-0.1 mm in size, are sometimes assigned to bulk chemical analysis. To tackle these subdivisions of samples, in addition to the <SOUSAMPNA> field, the 'DED_WA_BULK_ANALYSES_Indicators' data file introduces the subsample identification field <SOUSUBSAMP>. Occasionally, the subsample name has been assigned by the submitting company. However, more commonly, the <SOUSUBSAMP> field has been adapted on the basis of a description of the subsample processing method and, if known, a processing batch number assigned by the processing laboratory. For consistency, all subsample labels are retained in identical forms throughout all daughter data files as described in Figure 1. However, the <INDID> unique field provides the simplest method to link to daughter files regarding subsamples, rather than having to link both the <SAMPLEID> and <SOUSUBSAMP> fields together.

Sample weights (<SAMPLEWT>, <SAMPLEVOL>, and <NUMBAGS>)

Although the number of indicator minerals recovered is a key component of the database, arguably of greater importance is an understanding of the number of indicators recovered per kg of sample. Such a variable removes the bias introduced by sample size and provides a better reflection of proximity to source. Hence, of critical concern is a comprehensive population of the <SAMPLEWT> field. Although sample weights are usually reported, particularly for loam samples, there are cases when volume (<SAMPLEVOL>) or numbers of bags collected (<NUMBAGS>) instead have been reported. Due to the importance of populating the <SAMPLEWT> field, in such cases, an estimate of sample weight is made based on assumptions of standard sample density or bag weight.

Stockdale Prospecting Ltd reports a standard bag of stream sediment to contain 10 L and weighing 15–18 kg (Duncan, 1995). For the small numbers of samples where volume rather than weight is reported, an average of 1.65 kg/L is assumed in the population of the <SAMPLEWT> field. This applies to both hand samples and bulk samples.

With respect to bag numbers, Astro Mining NL data in the 700 000-series report 423 hand samples with the number of bags and their estimated weight being reported. Based on this data, the average bag weight is 22.2 kg, which is very similar to the equivalent 22.5 kg from the Northern Territory diamond exploration (Hutchison, 2011). Hence, in cases where the number of bags is quoted and the sample weight is not otherwise mentioned, 22.2 kg per bag is an estimate for hand sample weight and this value then populates the <SAMPLEWT> field.

Where sample weight is calculated rather than reported, a reference is made in the 'Comment' fields. While allowing variables, such as indicators per kilogram to be calculated, numbers derived in this manner should be treated with caution and errors may be as high as a factor of three.

Composite sample constituents (<SAMPLEWT>, <SAMPLEVOL>, <NUMBAGS>, <CONCENTWT>, <MICONCWT>, <CONCWTOBS>, and sample results fields)

Close attention has been paid to the treatment of composite samples, which is particularly true for fields in the 'DED_WA_BULK_ANALYSES_Indicators' file. Variables relating to the constituent components of composite samples have only rarely been reported. Consequently, the usual assumption is that each composite component has the same weight. Hence, the <SAMPLEWT>, <SAMPLEVOL>, <NUMBAGS>, <CONCENTWT>, <MICONCWT>, and <CONCWTOBS> fields are populated by the total quoted values divided either by the number of samples or, if known, in relative proportion based on sample weight.

Users of the database may encounter non-integer entries for indicator counts. However, inspection of the records will demonstrate that many of these entries derived from composite samples. A similar method to the population of weight-related fields has been used to populate sample results fields, such as <MACRO>, <CHROMITE>, and <SP_CID>. For example, a composite sample from which 125 indicator chromites have been recovered with a known central sample weight of 25 kg and a weight of 10 kg for the four satellite sample components would return four records reporting 19.23 spinels and one record reporting 48.08 spinels. It is not satisfactory having to report fractions of an indicator mineral. However, it is considered to be a more useful reflection of the likely constituents of the samples to assign positive recovery to all components of a composite sample rather than arbitrarily to one. Such a method of subdivision is applied both to visually identified indicator grains, in addition to grains identified by means of mineral chemical analyses.

A relatively small number of EXACT records derive from company reports where diamonds have been recovered ('diamond-positive'). Such reports are considered to be particularly important for the DED. Hence, in the bulk of these cases correct sample names have been assigned and individual counts of diamonds and indicator minerals have been entered in the appropriate fields for the actual diamond-positive samples. Exceptions happen with large datasets. Inspection of the data reveals that a large abundance of diamond-positive samples have been reported in the central Kimberley. Examples are <SAMPLEID> entries 914 492 to 914 873 which derived from company report A46377. In addition to these exceptions, numerous records in the EXACT database derive from company reports with no diamonds reported, but with other indicator minerals. Due to the large number of such samples, in most cases it proved to be impractical trying to identify which specific locations were indicator-positive or to establish the number of indicators recovered. Such recovery results have been handled in the same way as genuine composite samples that do not reveal from which component indicator minerals derived. In cases in which the total number of grains of a specific indicator phase have been reported in the EXACT database, these integers have been divided by the total number of samples and the resulting fraction assigned to the appropriate field. Hence, a series of EXACT records where the source report describes 125 indicator chromites and five samples, each of the five records would have a value of '25' entered into its <CHROMITE> field. In cases where the EXACT database refers to an unquantified number greater than one of a particular indicator mineral recovered (e.g. 'spinels'), unless the report has been queried directly, a conservative estimate (i.e. '2') has been made which was subsequently divided by the number of samples. The 'Comment' fields were extensively used to describe the assumptions made in each case. The drawback of this approach is the creation of false positive sample locations. However, such samples can usually be readily identified by their fractional recovery numbers and definitely by descriptions in 'Comment' fields. The advantage of this approach is that certain statistical calculations can be made with the data without incurring errors. Summation of indicator numbers and calculations of indicator concentrations can be made with confidence, for example, EXACT records with <SAMPLEID> values from 914 492 to 914 873. In this case the number of macrodiamonds assigned to each record is 0.0027. While this part of the Kimberley region would appear to be misrepresented when plotting diamond-positive samples, when samples are plotted thematically based on diamond counts, the impact of the false positives is lessened. The statistical integrity of the data is of high importance. Hence, it was decided that the attribution of fractional counts to all samples within each group of the EXACT records provided a better solution than assigning full counts to each record or full counts to an arbitrary record. Users of the database are cautioned to be careful to discriminate between genuine indicator-positive samples and those generated from EXACT records. It is therefore advisable to refer to source reports. In case of concern about the data correctness it is recommended to filter out EXACT and other additional non-integer indicator count-containing records entirely or treat them separately from other data.

Mesh sizes (<MESHUPPOBS> and <MESHLOWOBS>)

To be consistent with how the original data are usually reported, the <MESHUPPOBS> field usually quotes the largest sieve size with which grains were captured for mineralogical observation. Consequently, the maximum dimension of the largest grain size is unknown, but is likely only to be slightly larger than the largest sieve size used.

Similarly, the quoted value for <MESHLOWOBS> is the smallest sieve size with which grains were captured for mineralogical observation. Hence, this value represents the true smallest size of the grains studied.

Particular care has been applied in populating the sieve size ranges for each sample with the ranges from which indicator grains were picked. For example, it is common for a sample to be sieved at <2 mm in the field (commonly referred to by diamond explorers as '-2 mm'), whereas concentrates and indicators were only generated from the <1 mm fraction. The latter value is the one which would be entered into the <MESHUPPOBS> field.

Concentrate weights (<CONCENTWT>, <MICONCWT>, <CONCWTOBS>, and <PROCMETHOD>)

Among indicator recovery results, laboratories usually report concentrate weights. Sometimes these are subdivided according to the method applied and in some cases fractional quantities of recovered concentrates are observed. In the DED, values are assigned to each concentrate weight field to the extent possible. In the absence of specific reference to methylene iodide (MI) separation, data are assigned to the <CONCENTWT> field. It can generally be assumed that values in the <CONCENTWT> field represent the weight in grams after chemical density separation with tetrabromoethane (TBE) or a similar density separation agent which was used for the recovery of the indicators. However, attention is drawn to the <PROCMETHOD> field to determine further details of the processing methodology. In some cases it has been reported that only a proportion of the recovered concentrate was selected for mineral picking. In these cases the full concentrate weight has been reported with notes included in the 'Comment' fields. The use of such comments provides an important quality control on any calculations related to concentrate weight.

Diamond recovery data (<MACRO>, <MICRO>, <MACRODEFN>, <DIAMWT>, <DIAMRESULT>, and <DIAMDESCYN>)

Some diamond recovery has only been reported in terms of weight, listed in field <DIAMWT> and expressed in metric carats (mct)*. Assuming a specific gravity for diamond of 3.51 and a square sieve aperture, a perfect octahedral-shaped diamond passing through a 0.5 mm sieve would weigh 0.00103 mct. On the other hand, a cubic-shaped diamond with the same specific gravity passing through the same sieve aperture would weigh 0.00219 mct. Hence, an average macro–micro cutoff

* 1 mct equals 0.2 g

weight of 0.0016 mct (0.0003 g) is assumed for assigning such diamonds to a size classification in the <MACRO> or <MICRO> fields in the database.

The <DIAMRESULT> and <DIAMDESCYN> fields are provided in order to rapidly identify diamond-positive samples and those with diamond descriptions documented in the DED without recourse to numerical querying. The diamond results field <DIAMRESULT> is particularly useful because the DED includes some rare records in the 'DED_WA_BULK_ANALYSES_Indicators' file, where counts of diamonds are not reported for diamond-positive samples. Such records emerge where a sample is known to be diamond-bearing, but the data has been provided in a different form. Examples include grade samples where data are reported as carats per tonne and therefore a value for the number of diamonds cannot be obtained. Hence, in filtering the DED for diamond-positive samples, the <DIAMRESULT> field should be used in preference over <TOT_DIAM>.

Microdiamond/macrodiamond definition (<MACRODEFN>, <TOT_DIAM>, and <DIAM_PKG>)

In conjunction with the number of micro- and macrodiamonds recovered, field <MACRODEFN> allows the definition of the microdiamond/macrodiamond subdivision. This field was provided as there is neither an Australian nor an international standard for the definition of a macrodiamond. The closest to a standard would perhaps be the requirement that in order to be termed 'macrodiamond' all three axial dimensions of a diamond have to be >0.5 mm. Nevertheless, this would require that each stone has to be physically measured. Despite numerous company reports on microdiamond or macrodiamond recovery, almost none of them define these terms. Where such information is given, examples include 'one dimension >0.5 mm', 'captured on the 0.5 mm sieve', or simply '0.5 mm'. De Beers Australia Exploration Ltd (Mitchell, 1999) and Striker Resources NL (Garton, 2003) use a diameter of 0.4 mm as the cutoff size for macrodiamonds. In the earlier years of exploration in Australia, Ashton Mining NL often quoted a 0.4 mm diameter cutoff, which in fact related to whether or not a stone would pass through a US 40 mesh sieve (425 µm square mesh). Through such a mesh a 0.6 mm × 0.4 mm × 0.4 mm diamond could readily pass, which would then be classed as a microdiamond. Carnegie Minerals NL, for example, used a 0.6 mm diameter cutoff to define macrodiamonds (Geach, 1997). In the Northern Territory Lee et al. (1997) reported Merlin microdiamonds within the size range from 0.1 to 0.8 mm. For populations of diamonds that fall far outside the definition boundary, the details of how these boundaries are defined are academic. However, a threshold cutoff diameter of 0.5 mm falls comfortably within the upper size ranges, which may be expected from an exploration sample that was collected within several kilometres of a primary diamond source. Hence, a consistent definition of the terms micro- and macrodiamond is therefore important. Given that such a definition is rarely provided and that there is no rigorous research to support the frequently quoted contention that microdiamonds are easily transported by wind, but macrodiamonds are not, the use of the <TOT_DIAM> or <DIAM_PKG > fields is recommended as it avoids the issue of the microdiamond classification.

Visually-identified indicator counts – nondiamond (<CHROMITE>, <GARNET>, <PICROILM>, <CHROMEDIOP>, and <OTHERINDIC>)

In the database, as a general rule, the fields <CHROMITE>, <GARNET>, <PICROILM>, <CHROMEDIOP>, and <OTHERINDIC> are all populated with indicator counts as determined by visual inspection. Because chromite is generally the only traditional (kimberlite-derived) indicator mineral which is resistant enough to sustain transport over any significant distance from its source area in Australia (Towie et al., 1994; Reddicliffe, 1999), laboratories exercise considerable care in applying visual criteria to discriminate kimberlite-sourced ('indicator') chromite from other types. The field <CHROMITE> is used in cases when there is a legitimate possibility that the grain may be a genuine indicator. Otherwise, the <UNRESCHROM> and <NK_CHROMIT> visual identification fields are used. The field <OTHERINDIC> is populated for phases which were identified as indicator minerals, but did not fall into any of the other four above-mentioned fields. In such cases the minerals are identified in the 'Comment' fields.

Other visually-identified minerals (<OTHERINDIC>, <OTHERMIN1>, <OTHERMIN2>, and <OTHERMIN3>)

Worldwide the traditional mined sources of diamond are kimberlites, accounting for the very large majority of diamonds produced. Western Australia hosts diamondiferous kimberlites. However, diamondiferous, ultramafic lamprophyres and lamproites have been the sources of all of the State's current and historical diamond production. Lamproites, in particular, often contain rather different mineralogies in comparison to kimberlites. Anyhow, the indicator mineral field names <CHROMITE>, <GARNET>, <PICROILM>, and <CHROMEDIOP>) represent the minerals which have almost exclusively been targeted during diamond exploration in Western Australia. Despite the fact that Western Australia is the world's fourth largest diamond producer by virtue of lamproite rather than kimberlite, to date diamond exploration through mineral processing has leaned heavily towards a kimberlite rather than lamproite model. To a large extent, the indicator mineral protocols applied in Western Australia have been adopted with little modification from successful methodologies employed in southern Africa and more recently in the Canadian Arctic (Fipke et al., 1995). However, non-Australian diamondiferous provinces can be quite different from Western Australia. In Canada, for example, the diamond-associated minerals derive almost exclusively from kimberlite. In addition, many diamond provinces have been subject to weathering regimes different from Western Australia. Hence, exploration methodologies developed elsewhere in the world are not necessarily suitable in Western Australia without modification.

Some minerals such as zircon and tourmaline have been identified as being important in the exploration for kimberlites (Belousova et al., 2001) and lamproite (Fipke, 1994). Methodologies for exploration targeting lamproite mineralogies in Western Australia are underdeveloped. However, to a limited extent, explorers have been aware of their value. Hence, allowances have been made in the DED to also deal with these cases. Mineral counts are recorded in the <OTHERINDIC> field when identified as prospective or in <OTHERMIN1>, <OTHERMIN2>, and <OTHERMIN3> when not discriminated. Furthermore, the minerals recorded in fields <OTHERMIN1> to <OTHERMIN3> are significant to prospectors interested in commodities other than diamond. In this context the most notable commodity is gold, with 262 records reporting on gold recovery, without even including EXACT-derived entries.

Indicator mineral statistics (<TOT_DIAM>, <MACRO_PKG>, <MICRO_PKG>, <DIAM_PKG>, <TOTIND_EXD>, and <INDIC_PKG>

Arguably, the calculation of the number of indicators per gram of heavy mineral concentrate may be a better indication of proximity to source than indicators per kg of total sample. However, the significant variability of size fraction, processing methods, and picking protocols introduces too many variables to satisfactorily remove their influence. Hence, the variable which was identified to represent the indicator mineral concentration is the ratio of <TOTIND_EXD> to <SAMPLEWT>, which is represented by the <INDIC_PKG> field. Similar calculations were made for microdiamonds, macrodiamonds, and total diamonds.

Chemically-derived indicator mineral counts (<SP_*> fields, <OPX_*> fields, <GT_*> fields, <ILM_*> fields, and <CPX_*> fields)

Chemically-derived indicator mineral counts fields reflect the number of distinct mineral grains per sample (and subsample), having particular indicator mineral chemistries (i.e. analyses with 'YES' in the <INDICATOR> field in file 'DED_WA_GRAIN_ANALYSES_Maj_Chem'). Indicator mineral counts derive from all applicable parts of composite grains, but exclude repeat analyses. For example, a composite grain of garnet and Cr-diopside with one analysis being classified as 'GT_G9', one as a 'GT_G10' and one as a 'CPX_CGP' composition, would return the numeral '1' in the <GT_G10> field, '0' in the <GT_G9> field (i.e. a repeat count of the same grain), and '1' in the <CPX_CGP> field. This methodology prevents that grains are being counted more than once, and also ensures that all phases of interest are represented. It is evident from the example that when different parts of a grain result in different mineral classifications of the same mineral phase, the most favourable is represented in the counts of mineral classifications. If it is possible to identify that the core and rim of the same grain has been measured, although noted accordingly in the 'DED_WA_GRAIN_ANALYSES_Maj_Chem' file, such analyses are treated as repeat analyses.

It is notable that only mantle-derived garnets that fall into the G3 and G4 fields are counted in the <GT_G3> and <GT_G4> fields in the 'DED_WA_BULK_ANALYSES_Indicators' file. Hence, crustal-derived garnets, otherwise falling into the G3 and G4 compositional fields (analyses with 'NO' in the <INDICATOR> field), in the file 'DED_WA_GRAIN_ANALYSES_Maj_Chem' are not counted in the <GT_G3> and <GT_G4> fields in the DED.

Although the chemically-defined mineral classifications fields, such as <SP_CID> and <SP_GT_PER> provide high-value data, the number of grains chosen for chemical analysis is arbitrary and usually does not reflect the abundance of a particular indicator within a sample. Therefore, unlike a field such as <INDIC_PKG>, which is a useful prospectivity variable, a calculation of a number of CID spinels per kg of sample, for example, is largely meaningless. Hence, despite the drawbacks of visual determinations of indicator minerals, fields such as <CHROMITE> give a better indication of the abundance of indicators within a sample than, for example <SP_CID>.

When populating mineral chemical fields with data it became clear that the mineral chemistry was reported for some records where no entry of a visual identification of the particular phases was recorded. In some cases this may have been due to a phase appearing as part of a composite grain during the chemical analysis. However, in other cases this issue arose from shortcomings in the data capture or initial data reporting. In order to ensure that a record with indicator chemistry appears as positive when filtering is performed on the basis of visual indicator picks, all records that returned a higher value in the chemically-derived field had that value included in the equivalent indicator field. For example, a record which reported <CHROMITE> as '1', but mineral chemical analysis which reflected <SP_CID> as '1' and <SP_GT_PER> as '2' would have had the <CHROMITE> field amended to '3'.

It is not appropriate to assign the numeral '0' to a mineral class for minerals which have not been observed to exist in the sample. In such cases, the mineral class field is populated with the code '-111'. This convention allows the user to query mineral class fields to ascertain whether or not a particular mineral has been searched for by means of chemical analysis in a sample and therefore discriminate cases where the mineral is actually absent from those samples or where it has not been considered.

Major and minor element data – DED_WA_GRAIN_ANALYSES_Maj_Chem

It is not uncommon for visually identified phases later to be re-assigned on the basis of mineral chemical data. Examples from the DED include Cr-diopsides later being identified as andradite (garnet group) (Barnes, 1995). Ilmenites and chromites are also commonly confused with each other. Although expensive compared to visual identification, mineral chemical data in most cases are considered to be the preferred method for discriminating diamond-relevant from non-indicator grains. The file 'DED_WA_GRAIN_ANALYSES_Maj_Chem' provides individual mineral chemical analyses for discrete mineral

phases. Each record provides a single analysis, although where averaged analyses are reported, it is noted in the 'Comment' fields to draw attention to this fact.

Composite samples (<SAMPLEID> and <INDID>)

If not known from which component of the composite sample a particular grain is derived, the grain is assigned to the first sample component which also assigns its SampleID number. The 'DED_WA_BULK_ANALYSES_ Indicators' file considers mineral counts assigned for each component of the composite, both visually and chemically. The added complexity of reproducing the same chemical analyses numerous times is therefore avoided.

Analysis names (<GRAIN>)

The <GRAIN> field has been populated using the grain identifier used in the source report and has been amended with various suffixes where required. Repeat analyses have been identified where two or more closely similar analyses were reported with identical grain identifications. In such cases, a suffix such as '_repeat1' is applied to the <GRAIN> name to indicate repeat analyses. These repeats are not included in the counts of chemically-defined indicators in the file 'DED_WA_BULK_ANALYSES_ Indicators'. Repeat analysis suffixes sometimes also apply to grains where a core and rim have been measured. Attention is drawn to these cases in the 'Comment' field and care should be taken by users of the DED not to calculate mineral chemical averages from such core/rim repeat analyses.

Although indicator minerals are picked visually as discrete grains during the course of mineral chemical analyses, composite grains are occasionally found and the different components are being analysed. Such grains are annotated in the <GRAIN> field and include suffixes such as '_phase2' with a further '_repeat' suffix added if necessary. Examples of composite grains are Cr-diopside with chromite, ilmenite with diopside, ilmenite with chromite, andradite with chromite, and biotite with garnet. Rarely, mineral inclusions within other grains (as distinct from composite grains) are reported, such as rutile within ilmenite. Analyses of different phases comprising composite grains and inclusions are distinct from repeat analyses. Therefore, where composite and inclusion grains are identified, each distinct mineral phase is used to populate the chemically-derived indicator counts reported in the 'DED_WA_BULK_ANALYSES_Indicators' file.

Analysis location (<ANALYS_LOC>)

Data from Astro Mining NL include grain names with the suffix 'c'. These are assumed to be grain core analyses. The suffix 'r' could be interpreted to represent a repeat analysis. However, most analyses with the suffix 'r' have a corresponding suffix 'c'. Therefore the suffix 'r' is assumed to refer to an analysis on a grain rim.

Analysis quality (<VAL_ANALYS>, <MINERAL>, <MIN_CLASS>, and <TOTANALYTE>)

All records have been subjected to a first pass quality control based on analyte totals. Such quality assessment does not have the same rigour as the inspection of analyte uncertainties and the reproduction of standards as part of the analytical session. However, it is an industry-standard approach. Short of calculation of stoichiometry it can also be readily applied to mineral chemical data with little context. For each analysis the <VAL_ANALYS> field has a 'YES' or 'NO' entry, and only analyses with analyte totals ranging from 96 to 102 wt% are considered to be acceptable. These analytical limits can readily be achieved with wavelength-dispersive spectrometry (WDS). They also encompass the majority of analyses performed with energy-dispersive spectrometry (EDS) considered acceptable. For analyses with totals under 96 wt% the results may be considered acceptable, depending on the phase analysed. Acceptable thresholds for specific phases are described in Table 7. Furthermore, stoichiometry has not been calculated in all cases, but where it has been identified that an analysis has an acceptable analyte total but also poor stoichiometry, it has been rejected.

For some poor analyses where the <VAL_ANALYS> field is populated with 'NO' there is sufficient chemical data to support a reasonable mineral identification. In such cases a mineral name is provided in the <MINERAL> field, otherwise the mineral is described as 'Unknown'. However, as mineral classification requires high-quality data, mineral classifications are not provided for poor analyses. In this case, the <MIN_CLASS> field is populated with the term 'Poor-Analysis'.

Mineral identification (<MINERAL> and <MIN_CLASS>)

The mineral phase identity and classifications fields <MINERAL> and <MIN_CLASS> derive from major and minor element analyses. Data presented in field <MIN_ CLASS> have been used to populate the chemically-derived mineral counts fields for records in the 'DED_ WA_BULK_ANALYSES_Indicators' file.

The <MINERAL> field identifies the mineral phase. Its attribution is based on quantities of various analytes falling within certain ranges and in combinations consistent with accepted norms for minerals. Subdivisions of the <MINERAL> field are similarly based on threshold limits of various elements. Amphibole, feldspar, and mica subdivisions follow established criteria. Definitions of other subdivisions of the field <MINERAL> are provided in Table 8. Poor analyses may be attributed with a <MINERAL> name if sufficient data are available for a confident identification. If an analysis cannot be attributed with a mineral name, but an important analyte is present, names like 'Unknown-Nb' will be allocated.

Table 7. Acceptable analyte totals based on mineral phase

Mineral phase	*Analysis total (wt%)*	*Mineral phase*	*Analysis total (wt%)*
Default	96–102	Phlogopite[d]/other micas[b]	90–96
Apatite[a]	94–100	Picroilmenite[e]	94–100
Carbonate, perovskite	Variable	Pseudobrookite[f]	93–99
Chlorite[b]	87–93	Spinel[g]	95–101
Other exotic OH-minerals	Variable	Magnetite/ulvöspinel[h]	90–93
Hematite[c]	87–90	Tourmaline[i]	82–91

NOTES: (a) When H_2O is quoted, otherwise 91 to 97 wt%, accounting for the possible presence of CO_2
(b) When H_2O is not quoted
(c) Hematite analyses without Fe_2O_3 quoted
(d) After Mitchell (1986)
(e) When Fe_2O_3 is not quoted, otherwise 96 wt%
(f) Pseudobrookite analyses would typically show good stoichiometry or a total of <97 wt% as distinct from ilmenite
(g) Spinels other than magnetite when FeO >20 wt% and Fe_2O_3 is not quoted, otherwise 96 wt%
(h) Magnetite/ülvospinel analyses without Fe_2O_3 quoted
(i) To account for boron, lithium, and when H_2O is not quoted. Tourmalines are distinguished from micas with low analytical totals (i.e. poor analyses) by having >1 wt% Na_2O.

The <MIN_CLASS> field provides a further subdivision employing a mineral classification scheme commonly used in diamond exploration. Typically, attribution of the <MIN_CLASS> field requires a more sophisticated processing of mineral chemical data, such as stoichiometric calculations, recasting of iron oxidation, and comparison with complex subdivisions of compositional space. Numerous classifications schemes exist for different minerals. However, for the DED, one scheme (as referred to in the data dictionaries) has been chosen for each mineral type, either because of the scheme's strong reliance on Australian data or its prominence among other international exploration schemes. In assigning a <MIN_CLASS> term, <MINERAL> subdivisions have been variously either applied or ignored. For instance, all ilmenites regardless of their variety (e.g. picroilmenites and 'Ilmenite-picro') have been considered equal when applying a <MIN_CLASS> term. This is because the classification scheme used takes account of the 'picro-' or 'non-picro-' designation of the data in each case. However, for spinels only chromites (with the exception of the Al-chromite 'SP_AC') and Mg,Cr,Al-spinel ('SP_MCAS') have been subdivided while other spinels were classified 'SP-Crustal'.

Mineral classifications are provided for guidance. When using the data, users of the DED are advised to consider the assumptions that were applied when populating the data fields and the evolving nature of such classification schemes with regard to diamond exploration.

<MINERAL> field – garnet

Garnets are subdivided into the groups 'garnet' (pyrope, almandine, and grossular garnets and 'andradites' ('Garnet_Andradite', 'Garnet_Andradite-Cr', and 'Garnet_Andradite-Cr-Ti'). Members of the 'garnet' group are typically considered as possible indicator minerals.

<MINERAL> field – ilmenite

By definition the mineral picroilmenite contains >5 wt% MgO. This value has commonly been accepted (Mitchell, 1986; Kerr et al., 2000; Wyatt et al., 2004), even though it is empirical and appears to be largely arbitrary (B Wyatt, 2010, personal comm.). Many kimberlites have ilmenite with <5% MgO (including Kirkland Lake and Iron Mountain) (D Schulze [University of Toronto] 2010, personal comm.) and a substantial amount of ferric iron. In the light of these arguments there is discussion to adopt a 3 wt% MgO threshold as the cutoff limit. However, as all ilmenite analyses have an indicator classification applied to them in field <MIN_CLASS>, irrespective of the <MINERAL> subdivision, any statement about the cutoff threshold applied to the picroilmenite subdivision is largely academic.

<MINERAL> field – kirschsteinite

Kirschsteinite is a Fe-analogue of monticellite. It is a very rare mineral that is present in meteorites. It has also been proposed that it exists as a groundmass phase in the Kotakonda kimberlite, India (Chalapathi Rao et al., 1996). However, mineral chemical analyses based on standard analytes fail to discriminate kirschsteinite from andradite garnet. In the absence of crystallographic data, the mineral at Kotakonda that is assumed to be 'larnitic kirschsteinite' is therefore more likely to be andradite. Mineral chemical analyses of the kirschsteinite–andradite type (SiO_2 34 wt%, Fe_2O_3 32 wt%, and CaO 34 wt%) appear in the Northern Territory (Hutchison, 2011) where they have been described as monticellite. The term 'kirschsteinite' has been retained in the DED structure for future use. However, all records with this form of analysis have been reported as 'Garnet_Andradite'.

Table 8. Chemical criteria for the subdivision of <MINERAL> field terms

Mineral subdivision	*Criteria*	*Mineral subdivision*	*Criteria*
Diopside-Cr	Cr_2O_3 >1.0 wt%	Orthopyroxene-Al	Al_2O_3 >1.0 wt%
Diopside-Al	Al_2O_3 >10.0 wt%	Phlogopite/biotite[a]	Phlogopite MgO/(MgO + FeO) >0.357
Diopside-Al-Cr	Al_2O_3 >10.0 wt% and Cr_2O_3 >1.0 wt%	Pseudobrookite-Cr	Cr_2O_3 >0.2 wt%
Garnet_Andradite-Cr	Cr_2O_3 >1.0 wt%	Rutile-Fe	FeOtotal >15.0 wt%
Garnet_Andrarite-Cr-Ti	TiO_2 >1.0 wt% and Cr_2O_3 >1.0 wt%	Rutile-Nb	Nb_2O_5 >10.0 wt%
Ilmenite-altered	FeOtotal >53.0 wt%	Tetraferriphlogopite[b]	Al_2O_3 <2.0 wt%
Ilmenite-picro[c]	MgO >5.0 wt%		
Subdivision	*Phase*	*Criteria*	
SP-MC[d]	Mg-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥40.0, TiO_2 <1.0, ZnO <1.0	
SP-ZMC[e]	Zn,Mg-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥40.0, TiO_2 <1.0, ZnO ≥1.0	
SP-CH[e],[f]	Chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# <40.0, TiO_2 <1.0, ZnO <1.0	
SP-ZCH[e]	Zn-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# <40.0, TiO_2 <1.0, ZnO ≥1.0	
SP-TCH[d]	Ti-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# <40.0, TiO_2 ≥1.0, ZnO <1.0	
SP-ZTCH[e]	Zn,Ti-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# <40.0, TiO_2 ≥1.0, ZnO ≥1.0	
SP-FTCH[e]	Fe,Ti-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# <40.0, TiO_2 ≥1.0	
SP-TMC[d]	Ti,Mg-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥40.0, TiO_2 ≥1.0	
SP-FTMC[e]	Fe,Ti,Mg-chromite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# ≥40.0, TiO_2 ≥1.0	
SP-MAC[e]	Mg,Al-chromite	Cr# <60.0, Cr# ≥20.0, Cr_2O_3 ≥15.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥40.0, TiO_2 <1.0	
SP-TMAC[e]	Ti,Mg-Al-chromite	Cr# <60.0, Cr# ≥20.0, Cr_2O_3 ≥15.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥40.0, TiO_2 ≥1.0	
SP-AC	Al-chromite	Cr# <60.0, Cr# ≥20.0, Cr_2O_3 ≥15.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# <40.0, TiO_2 <1.0	
SP-TAC[e]	Ti,Al-chromite	Cr# <60.0, Cr# ≥20.0, Cr_2O_3 ≥15.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# <40.0, TiO_2 ≥1.0	
SP-FMAC[e]	Fe,Mg,Al-chromite	Cr# <60.0, Cr# ≥20.0, Cr_2O_3 ≥15.0, $Fe^{3+}/\sum Fe$ >0.4, Mg# ≥40.0, TiO_2 <1.0	
SP-TFMAC[e]	Ti,Fe,Mg,Al-chromite	Cr# <60.0, Cr# ≥20.0, Cr_2O_3 ≥15.0, $Fe^{3+}/\sum Fe$ >0.4, Mg# ≥40.0, TiO_2 ≥1.0	
SP-MCAS[g]	Mg,Cr,Al-spinel	Cr# <20.0, Cr# ≥8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥40.0, TiO_2 <1.0	
SP-TMCAS[e]	Ti,Mg,Cr,Al-spinel	Cr# <20.0, Cr# ≥8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥40.0, TiO_2 ≥1.0	
SP-AS	Al-spinel	Cr# <8.0, Al_2O_3 ≥45.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≥30, TiO_2 <1.0	
SP-TMFAS[e]	Ti,Mg,Fe,Al-spinel	Cr# <8.0, Al_2O_3.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# ≥30.0, TiO_2 ≥1.0	
SP-HER	Hercynite	Cr# <8.0, Al_2O_3 ≥45.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# <30.0, TiO_2 <1.0, ZnO ≤15.0	
SP-GHN[e]	Gahnite	Cr# <8.0, Al_2O_3 ≥45.0, $Fe^{3+}/\sum Fe$<0.4, Mg# <30.0, TiO_2 <1.0, ZnO >15.0	
SP-CMGT	Cr-magnetite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ >0.4, Mg# ≤30.0, TiO_2 <1.0	
SP-TCMGT	Ti,Cr-magnetite	Cr# ≥60.0, Cr_2O_3 >8.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# ≤30.0, TiO_2 ≥1.0	
SP-MCMGT	Mg,Cr-magnetite	Cr# ≥60.0, Cr_2O_3 >8.0, Cr_2O_3 <40.0, $Fe^{3+}/\sum Fe$ >0.4, Mg# >30.0, TiO_2 <1.0	
SP-FMC[e]	Fe,Mg-chromite	Cr# ≥60.0, Cr_2O_3 ≥40.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# >30.0, TiO_2 <1.0	
SP-MGT	Magnetite	Cr_2O_3 <8.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# ≤30.0, TiO_2 <5.0	
SP-TMGT	Ti-magnetite	Cr_2O_3 <8.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# ≤30.0, TiO_2 ≥5.0	
SP-MTMGT	Mg,Ti-magnetite	Cr_2O_3 <8.0, $Fe^{3+}/\sum Fe$ ≥0.4, Mg# >30.0, TiO_2 ≥5.0	
SP-ULV	Ulvöspinel	Cr_2O_3 <8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# ≤30.0, TiO_2 ≥15.0	
SP-MULV	Mg-ulvöspinel	Cr_2O_3 <8.0, $Fe^{3+}/\sum Fe$ <0.4, Mg# >30.0, TiO_2 ≥15.0	

NOTES:
(a) With all Fe recast as FeO
(b) After Mitchell (1995)
(c) Referred to as 'picroilmenite' in the text

Spinel subdivisions follow the methodology of Taylor (WR Taylor [Elkedra Diamonds NL] 2010, personal comm.) modified from Ramsay (1992) and as reported in Denny (1998). Spinel subdivision names are abbreviations deriving from 'SP' for 'spinel' and their associated phase names.
(d) High priority indicator mineral
(e) Possible indicator mineral
(f) CH refers to $FeCr_2O_4$ in the strict sense, i.e. Cr-spinels with dominant $FeCr_2O_4$ end member composition
(g) Mg,Cr,Al-spinel is usually a crustal phase and has been interpreted as such for numerous Western Australia examples. However, the EMU-1 kimberlite pipe in the Northern Territory hosted such a grain (Hutchison, 2011); hence, MCAS grains have been considered for further classification in field <MIN_CLASS>.

All variables are expressed as wt% with the exception of $Fe^{3+}/\sum Fe$, which is based on charge-balanced cation calculations of stoichiometric analyses, where $\sum Fe$ represents $(Fe^{2+} + Fe^{3+})$; Cr# = 100 × $Cr/(Cr + Al)_{cations}$ and Mg# = 100 × $Mg/(Mg + Fe^{2+})_{cations}$

<MINERAL> field – pseudobrookite

Cr-absent ferropseudobrookite and pseudobrookite (sensu stricto: $Fe^{3+}Ti_2O_5$) are interpreted to be oxidation products of common ilmenite. Further weathering as is common in the tropical environments, which have affected much of Western Australia, produces leucoxene. However, the Cr-bearing ferropseudobrookite end member $Fe^{2+}Ti_2O_5$ (>0.2 wt% Cr_2O_3 and generally >60 wt% TiO_2) is most likely to be an extreme weathering product of titaniferous Cr-spinel and/or Cr-bearing picroilmenite. In fact, many ferropseudobrookites recovered in Northern Territory samples have octahedral habits, interpreted to be pseudomorphs after Cr-spinel (WR Taylor [Elkedra Diamonds NL] 2010, personal comm.).

<MINERAL> field – spinel

The spinel subdivisions (Table 8) follow a modified version by Ramsay (1992), developed by Taylor (WR Taylor, 2010, personal comm.) and reported in Denny (1998), which is based on a large dataset of Australian crustal- and mantle-derived spinels. In his very comprehensive assessment of mostly Australian mantle indicator minerals, Ramsay (1992) concluded that spinel compositions more satisfactorily discriminate diamond potential from nondiamond potential sources than garnet classification. He showed that garnet peridotites almost exclusively contain spinels with <35 wt% Al_2O_3 and >45 wt% Cr_2O_3, and diamond-associated spinels almost always have TiO_2 compositions of <0.5 wt%. However, cation ratios provide the most robust discriminatory criteria with no overlaps between garnet peridotite/diamond-associated spinels (Cr# [= 100 × Cr/(Cr + Al) cations] >55) and spinel/plagioclase peridotites. Diamond-associated harzburgitic spinels showed Cr# >75.

Taylor (WR Taylor, 2010, personal comm.) modified the Al_2O_3 cutoff to 40 and 45 wt% on the basis that the 35 wt% threshold (Ramsay 1992) was modelled on specific, well-characterized minerals rather than exploration-style populations. Similarly, Ramsay (1992) used a 1 wt% TiO_2 discriminant, which separates alkali basalts from tholeiitic/arc-related basalts and a $Fe^{3+}/\sum Fe$ ratio of 0.4, which captures FMQ (fayalite–magnetite–quartz) buffer grains in addition to more oxidized phases as would be typical of high-pressure phenocrysts. In contrast, Taylor (WR Taylor, 2010, personal comm.) used a more restrictive minimum Cr# value of 60, as otherwise numerous basaltic and layered-intrusion origin Cr-spinels would overpopulate the dataset.

Among the spinel subdivisions, a number of chromites are defined on the basis of their Zn content. A Zn overprint can be acquired by hydrothermal activity within kimberlites, probably during serpentinization, but this is rare compared to greenschist-facies Zn overprints. In some areas of the NAC it is common to find populations of indicator grains with Zn overprints. These are interpreted to have been derived from the erosion of Proterozoic kimberlites in the basement, because they are often found where populations of diamonds with annealed, brown radiation damage spots are also found (WR Taylor, 2010, personal comm.).

<MINERAL> field – element-attributed unknowns

The term 'Unknown' is occasionally used with a prefix, noting a particularly abundant element of interest. As no formal definitions are applied, attention to any unknown phase of interest to specific elements is achieved. Examples for this mineral group include 'Unknown-Ni' analyses with good analysis totals (96 to 102 wt%) and over 10 wt% NiO, 'Unknown-V' analyses with good analysis totals and about 20 wt% V_2O_3, and 'Unknown-Nb' with poor analyses totals (under 96 wt% or over 102 wt%; likely to be accounted for by unanalysed elements) with Nb_2O_5 contents of about 50–80 wt%.

<MIN_CLASS> field – clinopyroxene

Clinopyroxene classification follows the methodologies of Ramsay (1992) and Ramsay and Tompkins (1994) which are based on Cr_2O_3 and Al_2O_3 content.

<MIN_CLASS> field – garnet

Prior to classification, all garnet analyses have been reprocessed to convert any Fe_2O_3 (and combined Fe_2O_3/FeO) to FeO. Garnet classification for pyrope/grossular garnets follows the methodology of Grütter et al. (2004) described in Table 9. With the exception of andradites (<MINERAL>, entries 'Garnet_Andradite', 'Garnet_Andradite-Cr', and 'Garnet_Andradite-Cr-Ti'), this classification scheme has been applied to all garnets for which mineral chemistry has been acquired. The large majority were identified visually as being indicators. The Grütter et al. (2004) D-classification relies on an accurate measurement of MnO (where MnO is <0.36 wt% for the lower Cr and G10 analyses) and Na_2O (where Na_2O is >0.07 wt% for the G3, G4, and G5 classifications) and as such would typically require measurement by electron probe microanalyzer (EPMA) analysis. The possibility of 'D' designation in the database is not considered for analyses acquired by EDS or scanning electron microscope (SEM) techniques. The analytical method and laboratory facility for each analysis is presented in the <PROVIDNAME> and <INSTR_TYPE> fields. Even for good analyses (<VAL_ANALYS> field with 'YES') where a 'D' designation can be made, Grütter and Quadling (1999) concluded that although 0.07 wt% Na_2O in eclogitic garnet is commonly used as a cutoff limit for potentially diamond-associated eclogites, garnets from graphitic eclogites can range from 0.03 to 0.20 wt% Na_2O with three-quarters of quoted graphite-association analyses having >0.07 wt% Na_2O. Hence, the eclogitic D-classification, where applied, cannot be used as a fail-safe criteria for diamond association.

Garnets classified as G3 or G4 and with concentrations of MnO >1 wt%, FeO >25 wt%, or MgO <4 wt% are regarded as crustal-derived and are noted as such in 'Comment' fields.

<MIN_CLASS> field – ilmenite

The ilmenite classification follows the methodology by Wyatt et al. (2004) where, based on their TiO_2 and MgO compositions, ilmenites are subdivided into kimberlitic,

Table 9. Description of <MIN_CLASS> names for garnets

Classification	*Petrological association*	*Classification*	*Petrological association*
G0	Unclassified	G5D[(b)]	Pyroxenitic, websteritic, and eclogitic (diamond facies) – with higher Fe than moderate- to low-Cr G9 garnets
G1	Low-Cr megacrysts	G9	Lherzolitic
G3[(a)]	Eclogitic	G10	Harzburgitic
G3D[(b)]	Eclogitic (diamond-facies)	G10D[(b)]	Harzburgitic (diamond facies)
G4[(a)]	Pyroxenitic, websteritic, and eclogitic – with Cr lower than G9 garnets and overlapping with low-Ca eclogitic garnets	G11	High-Ti peridotitic
G4D[(b)]	Pyroxenitic, websteritic, and eclogitic (diamond-facies) – with Cr lower than G9 garnets and overlapping with low-Ca eclogitic garnets	G12	Wehrlitic
G5	Pyroxenitic, websteritic, and eclogitic – with higher Fe than moderate- to low-Cr G9 garnets		

NOTES: Following the classification scheme of Grütter et al. (2004)
(a) Some garnets which are classified as G3 or G4 are crust-derived and therefore not considered to be indicators
(b) D-classification relies on precise measurement of MnO and Na_2O. As such they would typically require measurement by EPMA analysis. The 'D' designation is not considered for analyses in the DED that were acquired by EDS (aside from high-precision EDS performed at the Australian National University) or SEM techniques.

nonkimberlitic, and intermediary associations. The position of Wyatt et al.'s (2004) ILM-Kim/ILM-Inter subdivision is defined by the line of best fit:

TiO_2 wt% = 25.4062 + 6.1433 × MgO wt% – 0.4187 × (MgO wt%)^2 + 0.0106 × (MgO wt%)^3

<MIN_CLASS> field – orthopyroxene

The orthopyroxene classification is based on Al_2O_3, SiO_2, MgO, and FeO contents and follows the methodologies by Ramsay (1992) and Ramsay and Tompkins (1994). Ramsay and Tompkins (1994) do not consider orthopyroxenes with MgO/(MgO + FeO) ratios of under 0.7. Such grains are designated 'OPX-Undefined'.

<MIN_CLASS> field – spinels

All non-chromite spinels, aside from Mg–Cr–Al-spinels and Al-chromite, are considered to be crustal-derived and, hence, are classed as 'SP-Crustal'. Remaining grains are classified according to the methodology by Grütter and Apter (1998). Their modified chromite in the diamond 'SP-CID' boundary is defined as follows:

TiO_2 <0.6 wt%, Cr_2O_3 wt% <68.2 – (3.5 × TiO_2 wt%), Cr_2O_3 >62 wt%, 10.4 wt% <MgO <16.5 wt%, and Fe_2O_3 <6 wt%

As opposed to the spinel peridotite field, the chromite in garnet peridotite field ('SP-Gt-Per') is defined as follows:

TiO_2 <1.0 wt%, then Cr_2O_3 wt% <68.2 – (3.5 × TiO_2 wt%), or where

TiO_2 >1.0 wt%, then Cr_2O_3 wt% <66.0 – (3.5 × TiO_2 wt%).

In order to apply the SP-CID test for analyses in which Fe_2O_3 has not been determined, Fe_2O_3 has been calculated stoichiometrically. Chemical analyses which fail the SP-CID test solely on the basis of calculated or reported Fe_2O_3 are automatically assigned to the 'SP-Gt-Per' field. Grütter and Apter (1998) demonstrated that numerous barren kimberlites contain chromites whose compositional range overlaps the CID field, which is often used by explorers as a proxy for diamond-associated rocks. Hence, caution needs to be exercised when using CID-classified analyses in order to indicate a definitive association with diamond.

Mantle-derived chromites which fail the SP-CID and SP-Gt-Per tests are unclassified ('SP-Unclassified').

Indicator status (<INDICATOR>)

As the principal aim of file 'DED_WA_GRAIN_ANALYSES_Maj_Chem' is to provide indicator mineral data, the field <INDICATOR> has been included. Conditions where analyses are considered to be from indicators or non-indicators are described in Table 10 and take account of <MINERAL> and <MIN_CLASS> designations.

As some mineral classification schemes apply an empirical approach to an indicator designation (Grütter et al., 2004), it would be unwise to preclude all non-indicators from further consideration. Furthermore, the chemical criteria discriminating indicators from non-indicators evolve with time. Hence, users of the database are advised to consider the assumptions made for current schemes and the possibility of new or alternative mineral classification methods that may alter the indicator designation of the data.

Included among major element data are a number of records of grains deliberately sampled from country rock sources. These all appear as non-indicators in the <INDICATOR> field and their sources are described in the 'Comment' fields. Particularly for spinels, which constitute the most common indicator minerals in Western Australia, discrimination among different crustal, mantle, and kimberlite/diamond associations is not a simple task.

The provision of definitive background grains should assist users of the database in establishing a starting point for discrimination of their own exploration data specific to Western Australia.

<INDICATOR> field – clinopyroxene

Clinopyroxene from garnet peridotite (CPX-CGP) and eclogitic, megacrystic, and cognate clinopyroxene (CPX-CPP) are considered to be favourable indicators for a diamond association. Spinel peridotite association (CPX-CLS) composition grains are not considered to be indicators.

<INDICATOR> field – corundum

Corundum is not considered to be an indicator phase because of its ubiquity with many crustal rocks. However, because it is reported from some lamproites (Fipke, 1994) its presence may be of interest.

<INDICATOR> field – garnet

Due to the small number of grains encountered, their similarity to kirschsteinite, and their occasional association with lamproite, andradite garnets are considered to be potential indicators and are identified as such. It has to be considered that andradite garnets may derive from crustal sources, hence, an association with potentially diamond-bearing rocks is not guaranteed.

Garnets classified as G3 or G4 and with concentrations of MnO >1 wt% or FeO >25 wt% or MgO <4 wt% are regarded as crustal and are therefore not considered to be indicators (HS Grütter [BHP Billiton World Exploration Inc.] 2011, personal comm.). Such analyses are assigned a 'NO' in the <INDICATOR> field and are not included in the mineral counts provided in G3 and G4 fields in the 'DED_WA_BULK_ANALYSES_Indicators' file. Text is also added in the 'Comment' fields indicating the crustal assignment criteria.

Garnets classified as eclogitic G3, G4, and harzburgitic G10, especially those with a 'D' suffix, are regarded as being particularly indicative of an association with diamond. G1, G5, G5D, G9, G11, and G12 garnets are also all classed as indicator minerals (see Table 9). However, much of the classification scheme by Grütter et al. (2004) is empirical, with boundaries between fields based on the capture of 80 to 90% of grains with particular characteristics. Consequently, G9 garnets, for example, should not necessarily be considered to be poorly-prospective for diamonds. In fact, numerous examples of diamondiferous kimberlites and lamprophyres contain garnet populations dominated by G9 rather than G10 garnets (Hutchison and Frei, 2009). It is notable that the G9/G10 ratio of Northern Territory's Merlin kimberlite-sourced garnets is close to 11.0 (Reddicliffe, 1999). Of all reported grain analyses, G9s constitute 47% of those falling into either the G9 or G10 fields.

<INDICATOR> field – ilmenite

Wyatt et al. (2004) stressed the point that boundary lines between ilmenite compositional fields may lie at parallel, but slightly offset locations for specific populations of ilmenites. Therefore, for the purposes of populating the DED, both ILM-Kim and ILM-Inter classifications are considered to be indicators. Hence, users of the database are cautioned that the designation of this group as an indicator mineral may therefore lead to a larger data yield. It should also be noted that although the quoted boundaries constrain compositions associated with kimberlites reasonably well, significant proportions of the population of some non-kimberlite sources of ilmenites (e.g. melnoites, alnöites, and basanites) fall into the ILM-Kim field. Hence, the classification scheme captures kimberlitic ilmenites, but does not necessarily preclude ilmenites from some other sources.

Table 10. Designation of analyses as indicators and non-indicators

Phase	*Indicator*	*Phase*	*Indicator*
Poor analyses[a]	NO	Ilmenite – ILM-N-Kim	NO
Amphibole, staurolite, sphene, quartz, hematite, feldspar, rutile, corundum, chlorite, columbite, and pyroxenoids	NO	Ilmenite – ILM-Inter and ILM-Kim	YES
Tourmaline[b]	YES	Pseudobrookite	NO
Garnet – G0 and crustal G3 and G4	NO	Pseudobrookite-Cr	YES
Garnet – all other garnet classifications and Garnet_Andradite	YES	Mica – phlogopite and tetraferriphlogopite	YES
Spinel – ulvöspinels, magnetites, hercynite, Al-spinel and Al-chromite end-members, and unclassified	NO	Mica – all other mica classifications	NO
Spinel – all other spinel classifications	YES	Monticellite and kirschsteinite	YES
Olivine[c]	YES	Clinopyroxene – CPX-CGP and CPX-CPP	YES
Orthopyroxene – OPX-OGM, OPX-OGP, OPX-ODH, and OPX-ODL	YES	Clinopyroxene – CPX-CLS	NO
Orthopyroxene – OPX-OEC, OPX-OSP, and OPX-Undefined	NO		

NOTES: (a) Records where the 'Valid_Analysis' field is 'NO'
(b) Many tourmalines are not diamond-relevant. However, their occurrence in lamproites merits particular attention to be applied to this phase.
(c) Olivines are not typically of high enough analysis quality to discriminate their source. However, because they are not abundant all grains are designated as indicators.

<INDICATOR> field – Nb-rutile

Nb-rutile is not identified as an indicator mineral in the DED although its presence should merit attention.

<INDICATOR> field – orthopyroxene

Grains with compositions falling in the diamond lherzolite (OPX-ODL), diamond harzburgite (OPX-ODH), on-craton diamond peridotite (OPX-OGP), and garnet peridotite and on-craton megacrysts (OPX-OGM) fields are considered to be indicators. Spinel-lherzolite (OPX-OSP) and eclogite/pyroxenite (OPX-OEC) association compositions and 'Undefined' compositions, where MgO wt%/(MgO wt% + FeO wt%) <0.7 are not considered indicators.

<INDICATOR> field – pseudobrookite

Due to the fact that Pseudobrookite-Cr is most likely to be an extreme weathering product of titaniferous Cr-spinel and/or Cr-bearing picroilmenite it is considered to be an indicator mineral. Hence, occurrences of Pseudobrookite-Cr are also counted in the <OTHERINDIC> field of the 'DED_WA_BULK_ANALYSES_Indicators' file.

<INDICATOR> field – spinel

The Mg–Cr–Al-spinel (SP-MCAS) and all chromites, excluding Al-chromite (SP-AC) are considered to be indicator minerals. Hence, all spinel classifications (SP-CID, SP-Gt-Per, and SP-Unclassified), aside from SP-Crustal, are populated with 'YES' in the <INDICATOR> field.

<INDICATOR> field – tourmaline

Tourmaline is classified as an indicator due to the prevalence of tourmaline-bearing lamproites in Western Australia. However, not all tourmalines that appear in the database should be considered having derived from lamproites. In fact, false positives are expected to arise from this determination. In the absence of a mature visual discrimination test for lamproite-derived tourmalines it is important to draw attention to this phase.

Analytes (<SiO_2>, etc.)

Entries are as reported except for data with over four decimal places, which are truncated. In fact, it is unlikely that there are any cases where analytical precision justifies four decimal places. Users of the database are encouraged to consider similar analytical precision, particularly when using such analyses.

Analyte concentrations are expressed as positive numbers. In some cases, sources have reported negative numbers which reflect concentrations below a certain detection limit. Detection limit concentrations are handled in the DED with the analyte field populated with '0' and known detection limits quoted in the 'Comment' fields.

Diamond description data – DED_WA_GRAIN_ANALYSES_Diamond

The diamond description file reflects the range of physical criteria for diamond crysts reported in company submissions. Some companies only report carat weight or diamond size, either by direct measurement of the various axes or by discrimination based on sieve size. Other companies have provided more comprehensive descriptions, incorporating colour, shape, surface, and internal features. Fields have been designed to subdivide descriptions into features, reflecting colour (<DIAMCOLOUR>), shape as a result of growth and resorption (<DIAM_CRYST>), discrete surface features (<DIAM_SURF>), and the effects of brittle deformation (<DIAM_CLEAV>). Reported data have been re-arranged where appropriate to fit these fields. Hence, data can be reasonably easily filtered to provide an idea of the extent to which diamond crystals have been compromised within their magmatic transport media (<DIAM_CRYST>) or during emplacement (<DIAM_CLEAV>), and the length of time they may have resided in sediments rather than their primary hosts (<DIAMCOLOUR>).

Although attempts have been made to make the descriptive terms for various criteria more consistent, entries largely reflect the actual terms reported. Care should therefore be taken when, for example, comparing crystal shapes between samples, as explorers may not have used internally or externally consistent definitions of descriptive terms.

Size classification (<MACROMICRO>)

In order to establish consistency, a macrodiamond or microdiamond classification has been applied on the basis of the physical properties of each diamond reported. This classification is distinct from the one used by the reporting company. The criteria used for defining a macrodiamond is a weight of ≥0.0016 mct or the stone has been captured on a sieve with diameter of ≥0.5 mm, or else the largest dimension reported is ≥0.5 mm. Note that the application of this test has resulted in the reclassification of some diamonds which had previously been reported to be microdiamonds being reclassified as macrodiamonds and vice versa.

In situ occurrences – DED_WA_OCCURRENCES

All locations of primary occurrences of rocks of interest to diamond prospectors ('occurrences') are compiled in file 'DED_WA_OCCURRENCES'. All associated coordinates have been verified by GPS-based ground-truthing, reference to original company reports, peer-reviewed publications, or geophysical data, such as aeromagnetic surveys or satellite imagery. The 'DED_WA_OCCURRENCES' dataset represents a significant

advance over prior datasets, which sometimes included the locations of the same rock bodies, but in which the location uncertainty commonly has been considerably larger. An example includes the DMIRS MINEDEX database which has been updated to be consistent with the locations in the 'DED_WA_OCCURRENCES' dataset. While occurrences within the DED have been designed as a standalone product, for the purposes of cross-reference, all entries have been assigned a MINEDEX number and new records incorporated into the MINEDEX database. Caution should be applied when using the MINEDEX database in conjunction with the DED. This is because MINEDEX includes many additional entries in which the commodity of interest is 'Diamond', but which are not primary rock bodies. Examples include infrastructure, inferred bodies (in the DED covered in the 'DED_WA_INFERENCES' file), positive surface samples, geophysical anomalies, and other targets. In MINEDEX the nature of these entries is often not immediately obvious. Hence, while the database provides an additional tool for explorers, particularly for underexplored locations, the data need to be treated with caution. It is also worth noting that in MINEDEX an 'Occurrence' is a positive identification of a commodity of interest, which would be diamond. This is distinct from an 'Occurrence' as it is used in the DED. It constitutes an in situ body with diamond potential, which may or not have been proven to host that commodity. The DED uses the field <DIAM_GRADE> to provide information on diamond testing. Where an entry is '0', the rock body has been tested and found to be barren. Untested rock bodies are populated with 'Not_Reported'.

Notes (<COMMENTS>)

References to 'Bulletin 132' refer to Jaques et al. (1986).

Acknowledgements

The structure of the DED relies heavily on that designed previously for the Northern Territory. In that regard, Dan Schulze, Bruce Wyatt, and Herman Grütter are all gratefully acknowledged for their invaluable discussions regarding mineral chemistry, particularly Wayne Taylor, who also provided a great deal of support with respect to the spinel chemistry. Lynton Jaques is thanked for feedback regarding database structure and data interpretation. For the Western Australian DED specifically, Joyce Edmonds (GSWA) contributed extensively to acquisition of data and is warmly thanked. Considerable efforts were assigned to soliciting structured data from surrendered tenements from the De Beers Group of companies and Rio Tinto Exploration Pty Ltd, following their invaluable cooperation with the Northern Territory database and their central position in Western Australia's diamond exploration and mining — but information was not received for inclusion in this Western Australian study. John Chapman and Paul Agnew (Rio Tinto Exploration Pty Ltd) are thanked for their initial enthusiasm for collaboration. Mark Mitchell (De Beers Australia Exploration Ltd), Mike Kammermann and Jim Wright (Axis Consultants Pty Ltd), Grant Boxer (Astro Mining NL), and Tom Reddicliffe (GeoCrystal Ltd) all contributed greatly from their wealth of compiled data, expertise, and/or knowledge of Western Australia's diamond exploration. Roger Clifton (Northern Territory Geological Survey) is thanked for producing contoured maps of diamond concentration akin to his work on Northern Territory data. Bram Janse, Grant Boxer, Lynton Jaques, and Stephan Myer are gratefully acknowledged for considerable discussion and data sharing of Western Australia's in situ and inferred rock bodies. Finally, the stimulating discussions among Western Australia's diamond explorers at the regular Friday lunch in Subiaco assisted greatly in supporting the development of the DED project. All participants are warmly thanked.

References

Barnes, KR 1995, Annual report for Exploration Licence E46/322 for the period ending March 1995: Company report to the Department of Mines and Petroleum A44879, 43p.

Belousova, EA, Griffin, WL, Shee, SR, Jackson, SE and O'Reilly, SY 2001, Two age populations of zircons from the Timber Creek kimberlites, Northern Territory, as determined by laser ablation, ICP-MS analysis: Australian Journal of Earth Sciences, v. 48, p. 757–765.

Chalapathi Rao, NV, Reed, SJB, Pyle, DM and Beattie, PD 1996, Larnitic kirschsteinite from the Kotakonda kimberlite, Andhra Pradesh, India: Mineralogical Magazine, v. 60, p. 513–516.

Denny, M 1998, Major and trace element discrimination of chromian spinel with particular application to the provenance of diamond indicator chromite: Australian National University, Canberra, BSc (Hons) thesis (unpublished).

Duncan, D J 1995, Final report exploration licences 09/488 and 489: Company report to the Department of Mines and Petroleum, A45304, 10p.

Fipke, CE 1994, Significance of chromite, ilmenite, G5 Mg-almandine garnet, zircon and tourmaline in heavy mineral detection of diamond bearing lamproite, *in* Diamonds: characterization, genesis and exploration *edited by* HOA Meyer and OH Leonardos: Companhia de Pesquisa de Recursos Minerais, CPRM Special Publication, v. 1B Jan/94, p. 366–381.

Fipke, CE, Gurney JJ and Moore RO 1995, Diamond exploration techniques emphasising indicator mineral geochemistry and Canadian examples: Geological Survey of Canada, Ottawa, Ontario, Bulletin 423, 86p.

Garton, G 2003, Annual report for M80/490, 491, 492, 493 Ashmore diamond project, Drysdale (SD 52-09) 1:250 000, North Kimberley, Western Australia: Company report to the Department of Mines and Petroleum, A66099, 15p.

Geach, C 1997, Annual report to the Department of Minerals and Energy Western Australia Exploration Licence E 80/1768: Company report to the Department of Mines and Petroleum, A51837, 26p.

Geological Survey of Western Australia 2018, Diamond exploration and prospectivity of Western Australia: Geological Survey of Western Australia, digital data package.

Graham, S, Lambert, DD, Shee, SR, Smith, CB and Reeves, S 1999, Re–Os isotopic evidence for Archean lithospheric mantle beneath the Kimberley block, Western Australia: Geology, v. 27, p. 431–434.

Grütter, HS and Apter, DB 1998, Kimberlite- and lamproite-borne chromite phenocrysts with "diamond-inclusion"-type chemistries, *in* Extended abstracts 7th International Kimberlite Conference *edited by* JJ Gurney, JL Gurney, MD Pascoe and SH Richardson: 7th International Kimberlite Conference 1998, Cape Town, South Africa, p. 280–282.

Grütter, HS and Quadling, KE 1999, Can sodium in garnet be used to monitor eclogitic diamond potential?, *in* Proceedings of the 7th International Kimberlite Conference, Vol. 1 *edited by* JJ Gurney, JL Gurney, MD Pascoe and SH Richardson: 7th International Kimberlite Conference 1998, Red Roof Design, Cape Town, South Africa, p. 314–320.

Grütter, HS, Gurney, JJ, Menzies, AH and Winter, F 2004, An updated classification scheme for mantle-derived garnet, for use by diamond explorers: Lithos, v. 77, p. 841–857.

Gun, PJ and Meixner, AJ 1998, The nature of the basement to the Kimberley Block, northwestern Australia: Exploration Geophysics, v. 29, p. 506–511.

Hickman AH and Van Kranendonk MJ 2012, Early Earth evolution: evidence from the 3.5–1.8 Ga geological history of the Pilbara region of Western Australia: Episodes, v. 35, p. 283–297.

Hutchison, MT 2011, Northern Territory diamond exploration database: Northern Territory Geological Survey Digital Information Package DIP-011, DVD-ROM with Explanatory Notes (vers. December 2011).

Hutchison, MT 2012, Diamond exploration and prospectivity of the Northern Territory: Northern Territory Geological Survey, Record 2012-001, 64p.

Hutchison, MT 2018, Diamond exploration and prospectivity of Western Australia: Geological Survey of Western Australia, Report 179, 70p.

Hutchison, MT and Frei, D 2009, Kimberlite and related rocks from Garnet Lake, West Greenland, including their mantle constituents, diamond occurrence, age and provenance: Lithos, v. 112, p. 318–333.

Jaques, AL, Lewis, JD and Smith, CB 1986, The kimberlites and lamproites of Western Australia: Geological Survey of Western Australia, Bulletin 132, 268p.

Kennett, BLN, Fichtner, A, Fishwick, S and Yoshizawa, K 2013, Australian Seismological Reference Model (AuSREM): mantle component: Geophysical Journal International, v. 192, p. 871–887.

Kerr, DE, Kjarsgaard, IM and Smith, D 2000, Chemical characteristics of kimberlite indicator minerals from the Drybones Bay area (NTS 85I/4), Northwest Territories: Geological Survey of Canada, Open File Report, v. 3942, 29p.

Lee, DC, Milledge, HJ, Reddicliffe, TH, Scott Smith, BH, Taylor, WR and Ward, LM 1997, The Merlin kimberlites, Northern Territory, Australia: Russian Geology and Geophysics, v. 38, p. 82–96.

Martin, DMcB, Hocking, RM, Riganti, A and Tyler, IM 2016, 1:10 000 000 tectonic units of Western Australia: Geological Survey of Western Australia, digital data layer.

Mitchell, M 1999, Annual Report on Exploration Licence E45/1422: Company report to the Department of Mines and Petroleum, A59462, 120p.

Mitchell, RH, 1986, Kimberlites: mineralogy, geochemistry, and petrology, Plenum Press, New York, USA, 442p.

Mitchell, RH 1995, Kimberlites, orangeites, and related rocks, Plenum Press, New York, USA, 410p.

Muggeridge, MT 1989, The efficiency of fluvial trap sites in concentrating kimberlite indicator minerals: an experimental sampling survey: Geological Society of Australia, Special Publication, v. 14, p. 1154–1168.

Muggeridge, MT 1995, Pathfinder sampling techniques for locating primary sources of diamond: recovery of indicator minerals, diamonds and geochemical signatures: Journal of Geochemical Exploration, v. 53, p. 183–204.

Phillips, D, Clarke, W and Jaques, AL 2012, New 40Ar/39Ar ages for the West Kimberley lamproites and implications for Australian plate geodynamics, *in* Extended abstracts 10th International Kimberlite Conference: 10th International Kimberlite Conference 2012, Bangalore, India, p. 104.

Ramsay, RR 1992, Geochemistry of diamond indicator minerals: The University of Western Australia, Perth, Western Australia, PhD thesis (unpublished).

Ramsay, RR and Tompkins LA 1994, The geology, heavy mineral concentrate mineralogy, and diamond prospectivity of the Boa Eperança and Cana Verde Pipes, Corrego D'Anta, Minas Gerais, Brazil, *in* Diamonds: characterization, genesis and exploration *edited by* HOA Meyer and OH Leonardos: Companhia de Pesquisa de Recursos Minerais, CPRM Special Publication, v. 1B Jan/94, p. 329–345.

Reddicliffe, TH 1999, Merlin Kimberlite Field Batten Province, Northern Territory: The University of Western Australia, Perth, Western Australia, MSc thesis (unpublished).

Singh, B and Cornelius, M 2006, Geochemistry and mineralogy of the regolith profile over the Aries kimberlite pipe, Western Australia: Geochemistry: Exploration, Environment, Analysis, v. 6, p. 311–323.

Smith, CB, Atkinson, WJ and Tyler, EWJ 1990, Diamond exploration in Western Australia, Northern Territory and South Australia, *in* Geological aspects of the discovery of some important mineral deposits in Australia *edited by* KR Glasson and JH Rattigan: Australasian Institute of Mining and Metallurgy, Monograph, v. 17, p. 429–453.

Towie, NJ, Bush, MD, Manning, ER, Marx, MR and Ramsay, RR 1994, The Aries diamondiferous kimberlite pipe Central Kimberley Block, Western Australia, *in* Diamonds: characterization, genesis and exploration *edited by* HOA Meyer and OH Leonardos: Companhia de Pesquisa de Recursos Minerais, CPRM Special Publication, v. 1B Jan/94, p. 319–328.

Tyler, EWJ 1987, Australia's new diamond search, *in* Transactions of the 4th Circum-Pacific Energy and Mineral Resources Conference, Singapore 1986 *edited by* M K Horn: American Association of Petroleum Geologists; 4th Circum-Pacific Energy and Mineral Resources Conference 1986, Singapore, p. 597–608.

Tyler, IM, Hocking, RM and Haines, PW 2012, Geological evolution of the Kimberley region of Western Australia: Episodes, v. 35, p. 298–306.

Wyatt, BA, Baumgartner, M, Anckar, E and Grütter, H 2004, Compositional classification of "kimberlitic" and "non-kimberlitic" ilmenite: Lithos, v. 77, p. 819–840.

Wyche, S, Kirkland, CL, Riganti, A, Pawley, MJ, Belousova, E and Wingate, TD 2012, Isotopic constraints on stratigraphy in the central and eastern Yilgarn Craton, Western Australia: Australian Journal of Earth Sciences, v. 59, p. 657–670.

RECORD 2017/16

DATA METHODOLOGIES APPLIED IN THE WESTERN AUSTRALIAN DIAMOND EXPLORATION PACKAGE

Hutchison

This Record is published in digital format (PDF) and is available as a free download from the DMIRS website at <www.dmp.wa.gov.au/GSWApublications>.

Further details of geological products produced by the Geological Survey of Western Australia can be obtained by contacting:

Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Phone: +61 8 9222 3459 Fax: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications