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NORTHERN TERRITORY GEOLOGICAL SURVEY

Northern Territory diamond exploration database
Hutchison, MT

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Northern Territory diamond exploration database.

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Cover photograph credits: Main photograph: JA Hollis - Open pits at the Pal-Sac pipes, Merlin Kimberite Field; inset left: WR Taylor - Ground magnetometer surveying at Manners Creek Station, Georgina Basin; inset centre: WR Taylor - Stream sediment sampling at a limestone bar trap site, Georgina Basin; inset right: TH Reddicliffe - Merlin rough diamond.

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ABSTRACT

The Northern Territory Geological Survey (NTGS) Diamond Exploration Database incorporates the locations of over 75 000 diamond exploration samples, the overwhelming majority being samples taken for separation of diamonds and other minerals indicating diamond potential. Associated with these samples are over 14 500 chemical analyses of mineral separate grains acquired during the course of diamond exploration conducted in the Territory.

The database considerably expands upon its prior manifestation involving data acquired up to 2002, both in terms of numbers of records and data fields captured (NTGS 2005). Amongst the highlights of the updated database, data associated with the Merlin kimberlite field stands out. The Merlin field is the most significant field of primary diamond-bearing rocks within the Northern Territory. Although much of the Merlin data remain confidential, large quantities of publicly-available data have now been integrated into the current database. This dataset incorporates the range of data acquired from regional and local exploration to sample recovery from the kimberlites themselves. The Merlin data comprise over 1500 loam sample locations with accompanying diamond and other indicator mineral recovery data, and data from numerous regional and bulk stream sediments and large diameter drilling sites. Descriptions of representative diamonds are included, in addition to over 1600 mineral chemical analyses of indicator minerals. The expansion of the NTGS Diamond Exploration Database therefore provides valuable insights into successful exploration methodologies and a detailed picture of the most significant locality of Northern Territory diamondiferous rocks.

Detailed reconnaissance and mineral sampling data are now also publicly available for the second most prolific source of diamonds in the Northern Territory. The Timber Creek kimberlite pipes lie at the opposite, western edge of the Territory from the Merlin field and show a similar emplacement environment to the lamproite constituting Australia's largest diamond mine, Argyle. The Argyle pipe is located nearby to Timber Creek, being 250 km southwest across the border in Western Australia. A total of 17 387 macro-diamonds are reported to have been recovered from the TC-01 pipe and the updated database includes descriptions of some of these diamonds, in addition to the locations of bulk chemical and indicator mineral sampling, which has recovered a total of 11 636 chromites.

In addition to sampling within known kimberlite fields, considerable newly acquired and also previously unpublished exploration data have been incorporated into the database. This includes exploration conducted during the 2000s over some 15 000 km^2 predominantly in the southeast of the Northern Territory and previously uncaptured exploration data predominantly covering large areas of Arnhem Land. These data comprise over 5400 loam, stream sediment and *in situ* rock sample sites incorporating over 1250 major element mineral chemical analyses and 98 trace element analyses. The Arnhem Land data are of particular interest due to the reporting of prospective picro-ilmenite and garnet grains, and the recent discoveries of neighbouring Archaean inliers supporting an old, thick mantle lithosphere in the region.

Concurrent with the modernisation of the database, locations of immediate exploration interest are apparent in addition to considerable gaps in exploration coverage within areas of diamond potential. Notable very poorly-reconnoitered yet prospective areas include most of the Archaean inliers, the Aileron, Warumpi, Davenport and Warramunga provinces and the Tanami Region, and parts of the Pine Creek Orogen and McArthur Basin, particularly within Arnhem Land.

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INTRODUCTION

Australia is estimated to have produced approximately 12% of global rough diamond production by weight in 2010. All currently producing Australian mines are associated with Proterozoic mobile belts surrounding the Kimberley Block in Western Australia and diamondiferous kimberlites are also known from locations within the block itself. The Kimberley Block is understood to be underlain by Archaean lithospheric mantle (Graham *et al* 1999): old, cold and thick cratonic roots provide the most abundant source of diamonds exploited worldwide.

The Northern Territory hosts some 2200 km^2 of exposed Archaean rocks and over half a million km^2 of Palaeoproterozoic rocks comprising around 40% of the area of the Territory. Most notable due to their size are the Pine Creek Orogen (Worden *et al* 2008), McArthur Basin (Rawlings 1999) and Aileron Province (Scrimgeour 2003). Similarly to Western Australia, much of the Northern Territory's orogenic belts and sedimentary basins are also believed to be underlain by thick Archaean, lithospheric mantle (eg Hollis *et al* 2011) and Archaean inliers such as the Kukulak Gneiss in the Caramal Inlier, western Arnhem Land (Hollis *et al* 2009) continue to be discovered. Most exposed solid geology is sufficiently old so as to predate any diamondiferous intrusive rocks and diamondiferous kimberlites as young as 179 Ma are known from the Territory (Belousova *et al* 2001). Hence for much of the Northern Territory, only unconsolidated surficial deposits will act to obscure any exposures of primary diamond-bearing rocks. The Northern Territory hosted the only mined primary diamond deposit outside of Western Australia at Merlin until its closure in 2003 and this field is currently undergoing re-development. Merlin kimberlites are examples of diamond-bearing rocks penetrating a thick sedimentary succession (in this case the Neoproterozoic Bukalara Sandstone). They have a depth of origin of approximately 120 km [from calculations based on data in Reddicliffe (1999) following the methodology of Brey and Köhler (1990)] and this depth is well within the diamond stability field within thickened crystalline lithospheric mantle. In addition to Merlin, other diamond deposits are known; for example, the Timber Creek kimberlite pipes lie at the opposite, western edge of the Territory from the Merlin field. These are emplaced into Palaeo- to Mesoproterozoic limestones (Berryman *et al* 1999) in a similar setting to the Western Australian Argyle pipes (Jaques *et al* 1986).

Both theory and precedent therefore exist in support of future economic diamond discoveries in much of the Northern Territory.

The Northern Territory benefits from having experienced continuous diamond exploration since the early 1970s, generating in excess of 700 relevant company reports. Early work involved Stockdale (De Beers), CRAE (now Rio Tinto Exploration) and ADEJV (Ashton Mining Ltd., now also Rio Tinto Exploration) who undertook reconnaissance stream-sediment sampling across much of northern Australia. These early surveys and follow-up work revealed a swathe of microdiamonds extending across the North Australian Craton and hence much of the Northern Territory (Tyler 1987). It is this so-called 'North Australian micro-diamond anomaly' and associated kimberlite occurrences that have continued to drive exploration for diamonds within the Northern Territory.

A compilation of sample locations and diamond and indicator mineral recovery data up to 2002 (NTGS 2005) has been considerably expanded upon to bring diamond exploration up to date, incorporate newly released data on strategically important locations such as Timber Creek and the Merlin Field, and incorporate valuable data from sources other than statutory reports. A considerably larger number of 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 mineral phase sub-type 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, trace element mineral chemical data and full diamond descriptions complement the primary indicator mineral data. An interpretation of the data, incorporating discussion of successes and failures of historical exploration methods applied to the Territory and a prospectivity model, is provided by Hutchison (in press).

Terminologies

Mineral phases used in the course of diamond exploration are variously called 'diamond indicators', 'kimberlite indicators' and sometimes 'mantle indicators', and 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 diamond potential. Yet other phases, such as olivine 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 Territory diamond exploration has focused on indicator minerals (as it has done elsewhere, eg 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, 'Diamond Exploration Database' ('DED') is adopted.

Primary magmatic sources of diamonds have traditionally been thought to be restricted to kimberlites. However, 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. Diamonds occur as xenocrysts, in sometimes economic concentrations, in lamproites (eg the AK-1 pipe at Argyle; Jaques *et al* 1986) and ultramafic lamprophyres (such as aillikites; eg Hutchison and Frei 2009). 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' kimberlite, 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 required short 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 can be important, this is the accepted practice within the industry. Where it arises in the Diamond Exploration Database, the term 'kimberlite' is used without prejudice to interpretation 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 the Northern Territory, 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 of 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 non-diamond indicator minerals. An example of this is the field 'TotIndicat_exDiam' and where diamond is specifically excluded, this is drawn to the attention of the database user.

UNDERSTANDING THE DIGITAL INFORMATION PRODUCT (DIP)

Files constituting DIP 011 and accompanying this report have been assigned to the four principal folders described in **Table 1**.

Folders

\Data folder

MSExcel files are provided in Excel 2007 (.xlsx) format. 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 files. The data contained in these files are described in **Table 2**.

Files are constructed in such a fashion as to minimise repetition of data fields. Consequently for example, location coordinates are only provided in DED_BASICS.xlsx. However, all data files incorporate the same primary key in the SampleID column, where a unique numerical identity is applied to each sample (as distinct from sub-sample) and allows cross-referencing of data between files. GIS folders provide queries of the data matching some key concepts from the various data files, such as location, geological region and indicator mineral recovery.

An additional file entitled "DED_OCCURRENCES.xlsx" documents the locations and briefly describes kimberlites and similar rocks, and notable secondary concentrations of diamonds within the Northern Territory.

Each data file has a corresponding data dictionary file entitled "Data_Dictionary_*.xlsx", where * represents the name of the data file to which it refers. Data dictionaries describe the structure of each file, brief definitions and formatting rules

\Data	Contains MSExcel spreadsheets constituting the whole of the diamond exploration data in its original, captured form. Also 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. Also includes metadata for ancillary layers.
\ArcGIS	Contains the database data presented as ESRI ArcGIS format including thematic maps elucidating key aspects of the data.
\MapInfo	Contains the database data presented as MapInfo format (v9.5) including thematic maps elucidating key aspects of the data.
\Reports	Contains copies of company reports in .pdf or .tif format each containing the details of at least one positive macro-diamond recovery.

Table 1. Principal subdivision of files provided in this DIP.

DED_BASICS.xlsx	Contains basic information regarding individual exploration samples including location, data source, sample type and processing method.
DED_BULK_ANALYSES_Indicators.xlsx	Contains data regarding samples, and any sub-samples processed for indicator minerals, processing methodologies and the recovery results of such processing. Each entry corresponds to a unique entry (sample) within the file "DED_BASICS.xlsx".
DED_GRAIN_ANALYSES_Maj_Chem.xlsx	Contains major and minor element mineral chemical data acquired from individual mineral grains. Each entry corresponds to a unique entry (sample and sub-sample) within the file "DED_BULK_ANALYSES_Indicators.xlsx".
DED_GRAIN_ANALYSES_Trace_Chem.xlsx	Contains trace element mineral chemical data acquired for individual mineral grains. All trace element data have corresponding major element data and hence each entry corresponds to a unique entry (sample, sub-sample and grain) within the file "DED_GRAIN_ANALYSES_Maj_Chem.xlsx"
DED_GRAIN_ANALYSES_Diamond.xlsx	Contains descriptions of physical properties of individual diamond crysts. Each entry corresponds to a unique entry (sample and sub-sample) within the file "DED_BULK_ANALYSES_Indicators.xlsx".

Table 2. Primary data files.

applied to each field and any rules regarding mandatory population or controlled vocabularies for each field. These same rules apply to the GIS data files. Additional data dictionaries are included for the GIS layers as background datasets.

Finally, each data file and GIS layer has a corresponding metadata file in .rtf format entitled "Metadata_*.rtf, where * represents the name of the data file to which it refers. Metadata files were written to refer specifically to the MapInfo files, but they apply equally to equivalent MSExcel and ArcGIS files. Metadata files 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 report.

\ArcGIS folder

The ArcGIS folder contains the file 'DED.mxd'. This is the primary ArcMap document 'front-end' to the Database in ESRI ArcGIS format. The file opens as described in the _README.txt file in the root directory of the DIP and references various files contained in subfolders of the \ArcGIS 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 sub-directory structure within \ArcGIS is described in **Table 3**.

All contextual data are provided in its most up-to-date form. However, the background data provided represents a small portion of the geotechnical, geological, geophysical and geochemical data, incrementally updated and available online from the Northern Territory Geological Survey via the Spatial Territory Resource Information Kit for Exploration (STRIKE) website: http://apps.minerals.nt.gov.au/strike/.

The thematic GIS layers within the ArcGIS project are designed to be self-explanatory. They query the Diamond Exploration Database data in such a fashion as to draw attention to geographic areas exhibiting a variety of properties suggesting diamond potential. Thematic layers included are as described in **Table 4**.

Although some basic concepts, such as indicator recovery per kilogram, micro- and macro-diamond recovery and the relative proportions of specific mineral chemical classifications, are presented in map form, users of the DIP are encouraged to use the large amount and variety of data available to create queries consistent with their own particular requirements. It should be emphasised that considerable scope exists within the data to conduct sophisticated statistical treatments and quality control filtering of the data.

\ArcGIS\DED	Files constituting sub-sets of the DED data.
\ArcGIS\Topography	Files representing the geographic context of the DED data including coastline and Territory boundaries, principal roads and physiographic features such as drainage systems.
\ArcGIS\Geology	Files representing the geological context of the DED data including Geological Regions and Provinces, Regolith Geology (May *et al* 2011) and 1:1M-scale solid geology and structures.
\ArcGIS\Geophysics	Files representing key geophysical features of the Northern Territory, being combined radiometrics and gravity (hipass) and also including a digital terrain model (relief).

Table 3. Subdivision of ArcGIS files.

Layer	Notes
Occurrences	Indicates the location of kimberlites, lamprophyres and related rocks, particularly those with a known diamond association in addition to prominent secondary concentrations of diamonds
Sample sites	Represents the locations of sample sites coloured according to sample material
Micro diamonds	Indicates the locations of reported micro-diamonds with the symbol size reflecting their abundance in each sample
Macro diamonds	Indicates the locations of reported macro-diamonds with the symbol size reflecting their abundance in each sample
Diamond concentration	Represents diamond-bearing samples with symbol sizes proportional to total diamonds recovered per kg of sample
Indicator concentration	Represents non-diamond indicator-bearing samples with symbol sizes proportional to total indicators recovered per kg of sample
Visual indicators	Represents the occurrences of visually identified non-diamond indicator minerals as pie charts subdivided on the basis of phase with radius proportional to total number of grains reported
Chemical indicators - orthopyroxene	Represents the occurrences of chemically identified indicator orthopyroxenes as pie charts subdivided on the basis of classification
Chemical indicators - clinopyroxene	Represents the occurrences of chemically identified indicator clinopyroxenes as pie charts subdivided on the basis of classification
Chemical indicators - spinel	Represents the occurrences of chemically identified indicator spinels as pie charts subdivided on the basis of classification
Chemical indicators - ilmenite	Represents the occurrences of chemically identified indicator ilmenites as pie charts subdivided on the basis of classification
Chemical indicators - garnet	Represents the occurrences of chemically identified indicator garnets as pie charts subdivided on the basis of classification

Table 4. Thematic GIS layers elucidating various aspects of exploration data.

\MapInfo folder

The MapInfo folder contains the file 'DED.wor'. This is the primary MapInfo workspace container for the Database and accesses the individual MapInfo .tab format files. The file opens as described in the _README.txt file in the root directory of the DIP. It references various files contained in subfolders of the \MapInfo folder that provide the geological and geographical context of the data, in addition to aspects of the data itself presented as thematic and geographically referenced layers. Specific files equivalent to each of the MS Excel data files located within \Data are provided, having been generated following the rules described in the equivalent data dictionary.

The sub-directory structure within \MapInfo is described in **Table 5**.

All contextual data are provided in its most up-to-date form and 1:1M solid geology is only provided in MapInfo format. However, the background data provided represent a small portion of the geotechnical, geological, geophysical and geochemical data, incrementally updated and available on-line from the Northern Territory Geological Survey via **STRIKE**.

Queried Data

As for the ArcGIS project, the thematic layers within the MapInfo workspace are designed to be self-explanatory and query the Diamond Exploration Database in such a fashion as to draw attention to geographic areas exhibiting a variety of properties suggesting diamond potential. Running queries for thematic layers in MapInfo with such a large dataset requires significant computing time and hence all queries have been pre-run with associated .tab files generated. These .tab files can be found in the sub-folder \MapInfo\DED\Query_Data with descriptions of the queries given in '_README_QUERIES.txt'. Thematic layers included are the same as for the ArcMap document and are as described in **Table 4**.

Whilst some basic concepts such as indicator recovery per kg, micro- and macro-diamond recovery and the relative proportions of specific mineral chemical classifications are presented in map form, users of the DIP are encouraged to use the large amount and variety of data available to create queries consistent with their own particular requirements. It should be emphasised that considerable scope exists within the data to conduct sophisticated statistical treatments and quality control filtering of the data.

\Reports folder

The Diamond Exploration Database relies on 716 individual sources of data. Within this body of data, the company reports that describe samples from which diamond crystals have been recovered are alone represented by over 10 GB of data. Electronic copies of a sub-sample of important company reports that incorporate macro-diamonds (typically greater than 0.5 mm) are included in the \Reports folder. Reports are provided as either .pdf files or multi-page .tif files. Where tabulated data was also provided to the Northern Territory Geological Survey, these are incorporated in their original formats. The \Reports folder contains 61 sub-folders, each representing an individual company report and named according to the convention "CRyyyy-xxxx" where yyyy is the four-digit year of submission and xxxx is the four-digit consecutive report number. All reports and data are included unedited as originally submitted to NTGS.

Database structure

With the exception of the deposit occurrence file, DED_Occurrences', the individual files constituting the DED were created in a structured fashion that provides a consistent link between each file. **Figure 1** summarises the contents and describes the relative associations of each file. Each record within each file has its own numerical identifier 'ID', unique within each spreadsheet. Furthermore, each sample has an associated and unique numerical key, 'SampleID', which links through each file to entries within the principal file 'DED_BASICS'. As such, the Database files can readily be adopted into database software such as MS Access or Oracle, according to the structures in place for 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 metadata files located in the \Data folder in the DIP.

\MapInfo\DED	Files constituting sub-sets of the DED data. Queried sub-sets of the data for the generation of thematic layers are found in the sub-folder \MapInfo\DED\Query_Data.
\MapInfo\Topography	Files representing the geographic context of the DED data including coastline and Territory boundaries, principal roads and physiographic features such as drainage systems.
\MapInfo\Geology	Files representing the geological context of the DED data including Geological Regions and Provinces, 1:1M-scale Solid Geology and structures and Regolith Geology (May *et al* 2011).
\MapInfo\Geophysics	Files representing key geophysical features of the Northern Territory, being combined radiometrics and gravity (hipass) and also including a digital terrain model (relief).

Table 5. Subdivision of MapInfo files.

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 6**.

Within the 500 000-series, not all numbers are present. A small number of records have been removed, because they are subject to confidentiality, or refer to samples acquired from outside the borders of the NT within Queensland or Western Australia.

FIELD POPULATION RULES

General field population rules

In the course of structuring the Diamond Exploration Database, it became apparent that a significant number of types of information in common use by diamond explorers, for which much data is available for the Northern Territory, were not included in NTGS (2005). Examples are minimum sieve sizes, dense fraction concentrate weight, occurrences of non-traditional indicator phases, and mineral chemical quality control and classifications. The original sample location coordinates were often not recorded either, leading to additional uncertainties in correct sample locations. It was not possible within the

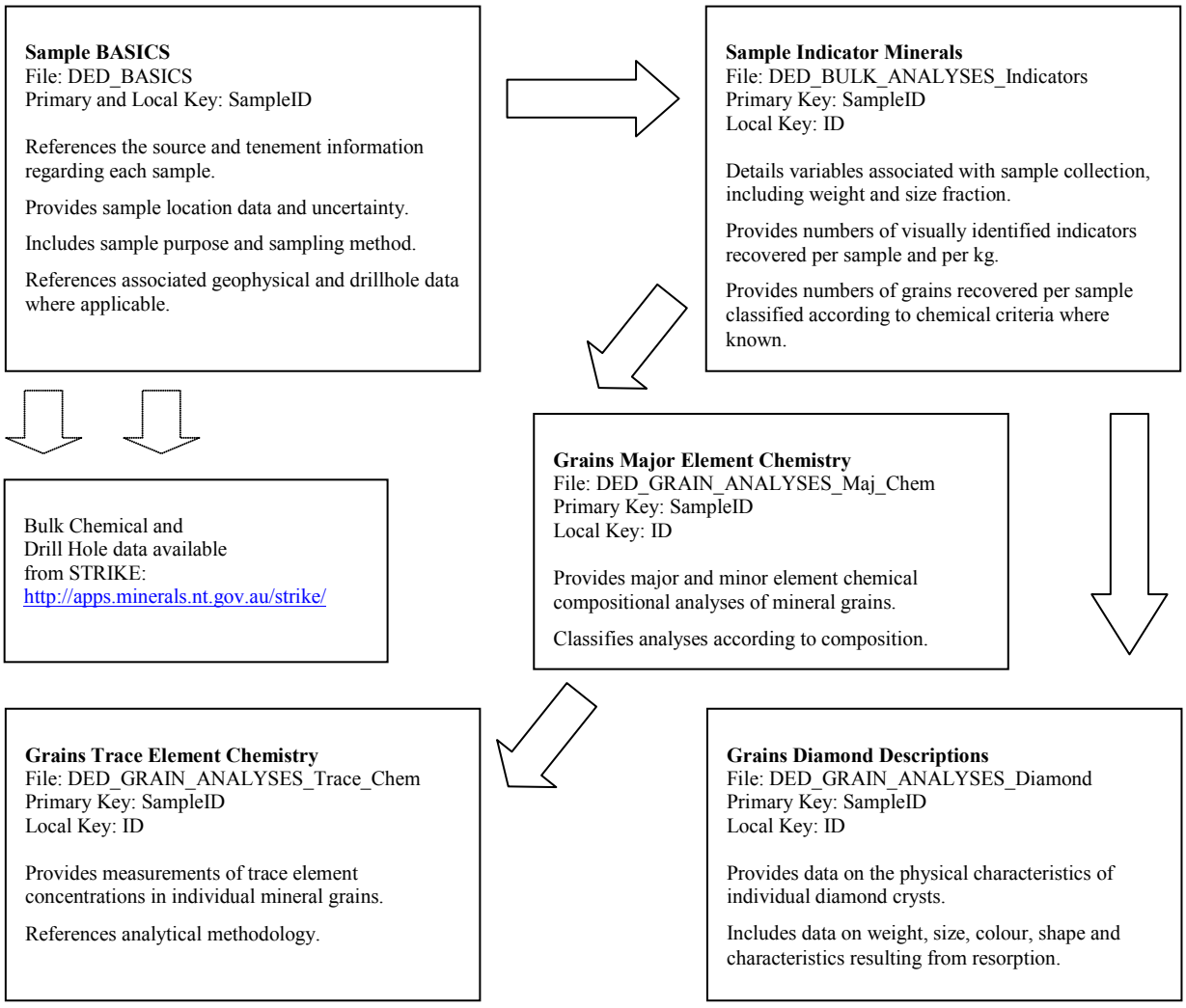

Figure 1. Diamond Exploration Database structure.

000001–009291	Company report sourced data from 2003 onwards and pre-2003 files not included in NTGS (2005) due to prior confidentiality or omission.
500000–560672	Data from NTGS (2005) minus data repeated in more detail elsewhere in the database.
560673–560975	Data constituting an unpublished portion of NTGS (2005) subsequently released from confidentiality.
600001–604363	Exploration data acquired by Elkedra Diamonds N.L. largely provided to the NTGS as a stand-alone database.
700001–702360	Data relating to the Merlin field sourced exclusively from the Masters thesis on the subject by Reddicliffe (1999).

Table 6. Assignment of SampleID records.

remit of the DED project to revisit all data sources in NTGS (2005) to incorporate additional data. Hence, in comparison with other records, the 500 000 series data remain incomplete. Users of the database are directed to the original company reports where a fuller picture of the acquired data may be available. In creating the database, focus was applied to the population of additional data fields for completely new records. As newly acquired records incorporate the large majority of exploration data pertaining to the principal primary-hosted diamond fields at Merlin and Timber Creek, and most of the oldest reports were in any case somewhat scant in the data they included, it is concluded that incomplete 500 000 series records impact only modestly on the completeness of the diamond exploration picture of the Northern Territory.

The 500 000-series data of NTGS (2005) has been amended to an extent to correct some errors which are mostly inconsistencies between data presented in company reports and their appearance in NTGS (2005). Such corrections have been carried out in a largely arbitrary fashion, although most concern reports that were revisited due to their references to diamond-positive samples. However given the large number of records and the minimal extent to which errors have been checked, it is likely that many remain uncorrected. Again, users of the database are referred to primary data sources in cases of uncertainty.

Blank fields have one of two possible meanings: either the data has not been assessed, or the particular field is not of relevance to the record in question. An example of the latter would be that the drillhole name field 'Drillhole' is left blank for samples that were not acquired from drillholes.

Where a blank field represents un-assessed data, such data may or may not be available in the original data source referred to. Such fields generally relate to 500 000-series data where the sources have not been re-checked.

Blank entries are not used in fields that are defined as being numerical. This is because MapInfo converts any blank entries into zeros, which is not appropriate for fields where it is critical to distinguish between the two meanings. 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. In numerical fields, what would normally be blank entries are represented by the number -333 to denote 'Not assessed'. Other negative integers are used in numerical fields as described in the following.

As distinct from blank (or -333) entries, the term 'Notreported' indicates that the data has been searched for in the associated data source but the information is not provided. Such an entry establishes that it would be unnecessary to refer to the original reference to investigate the presence of such data. Entries in numerical fields use the number -999 to denote '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 especially for numerical fields where blanks cannot be used. In text fields, the term 'Not-Applicable' is used. For numerical fields the number -111 is used to denote 'Not applicable'.

Entries in fields that are defined as numerical use the number -222 to denote 'Not calculable'. Not calculable 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'.

Although numerical codes are necessitated by MapInfo, it is emphasised that care should be applied to any calculations using numerical data. Numerical codes such as -222 should be filtered out of datasets before any calculations are applied. Excel spreadsheets provide the facility to incorporate text within otherwise numerical fields for ease of presentation and manipulation of the data. However, it should be noted that some Excel formulae that may be applied by the user do not adequately discriminate between text and zero values or blank cells. Data are presented without prejudice to the care that should be applied to all data manipulations.

Field-specific population rules

Basic data - DED_BASICS

Location data

Sample location information that can correctly lead an explorer to a sample site, either in person or through a GIS package is critical to the usefulness of the data associated with the sample. A number of factors influence the accuracy of location data. Many older company reports provide location data only as graphical representations on maps plotted to various scales. In such cases, sample locations have been captured by georeferencing and in some cases also rectifying maps. 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 to NTGS, positional information prior to the use of GPS technology was almost always achieved by cross-referencing topographic features with their representations on government published maps. Although NTGS (2005) reported the earliest use of hand-held GPS in the Territory as being in 1983, the technology does not appear to have been in common use until at least 1990. Whilst the Database provides an estimate of the uncertainty of location data through the 'LocAccuracy' field, where this is reported, users of the data should consider its age and any other relevant information in assessing the usefulness of positional data to their specific ends. Except in cases where precisely described and identifiable geographic features can be established, as a general rule of thumb, pre-1990 location data should not be expected to have an uncertainty 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 prior reference datum, AGD66. However at that time, there was considerable discussion concerning the need for Australia to adopt a geocentric datum using GRS80 rather than the Australian National Spheroid and the Northern Territory did not officially make the change

to AGD84. Another argument used in favour of ignoring the change was that the maximum difference between locations described by AGD84 and AGD66 within the Northern Territory is just 6 metres. Nationally, Australia adopted the Geocentric Datum of Australia in 1994 (GDA94). This datum is based on the GRS80 ellipsoid and for the purposes of geological locations, can be considered to be identical to WGS84; in fact locations at the Earth's surface differ by less than a millimetre between these two ellipsoids. Whilst latitudes and longitudes are based directly on the appropriate datum, typically the metric map system is used for geological work throughout Australia. MGA94 (Map Grid of Australia) is based on GDA94 and likewise Australia Map Grid AMG66 and AMG84 correspond to datums AGD66 and AGD84 respectively. Within the Northern Territory, Zones 52 and 53 apply, with the boundary between the two following the 132 degree line of longitude.

Irrespective of the official adoption of various projection systems, the various companies operating within the Northern Territory have had their own policies, or occasionally apparently random procedures for adopting a specific projection. For example, Tawana Resources NL were still using AMG66 for their Timber Creek project until at least 2004, Ashton Mining were using AMG66 in 2001 for their Lancewood project and Rio Tinto Exploration Ltd. were using AMG66 at Benda Bluff in 2000. In contrast, Rio Tinto were using AMG84 at Calvert Hills in 2003 but were using MGA94 at Walker Bay in 2006. Although the original format of data presentation has been captured amongst the new data acquired for the database update, all locations are also presented as their equivalent MGA94 coordinates, both angular and metric. Using a consistent projection system for the database is important for presenting an internally consistent picture of Northern Territory exploration; however, in addition to the number of projection methods used, company reports often present a considerable further problem. Namely, it is common (ca 42% of the time) for companies when using AMG not to specify AMG66 or AMG84. Following Northern Territory official policy, in these cases, AMG66 is assumed. The maximum error specific to the datum in this case should be 6 m. Some data is quoted simply as 'WGS84' in which case it is has been taken to be equivalent to GDA94 (based on GRS80) and should be subject to an insignificant error (GRS80 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). In some cases (ca 5% of update data captured) no projection system is referred to whatsoever. Where an educated guess of the correct projection can be made, this has been done; otherwise, for the remaining 28 records, it is assumed that pre-1994 data is AMG66 (subject to a 6 m uncertainty) and post-1994 data is 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 serious location uncertainties of up to 150 m, as noted in the Comment fields.

For all data further to that of NTGS (2005), location data as originally reported in conjunction with the original datum and projection used are provided in the database. The aim has been to reduce the possibility of conversion errors and provide more location data transparency, allowing an assessment of location uncertainty. Irrespective of original format, locations of all samples are presented as both latitude and longitude based on GDA94 and in metric format as MGA94. By providing the data in both formats, users of the database should be able to readily find location data suitable for their specific mapping requirements.

In addition to point data, the database structure provides for linear and polygonal location data as would arise from trenching or pitting, although no records of this nature are currently incorporated,. The 'Location_Type' field indicates the location type and the '2nd_*', '3rd_*' and '4th_*' fields allow for linear and polygonal coordinates to be presented (and re-calculated if necessary) only as MGA94.

Sample purpose

Although the majority of diamond exploration samples within the Territory were collected for the purpose of separation of indicator minerals (plus or minus diamond itself), a significant number of samples were collected with other intentions. The most common example has been for bulk chemical analyses. The 'Purpose' field provides the means to describe the intent of processing of the sample. Most data reported as 'Bulk-Chemistry' and its derivatives have the results of chemical testing provided in the referenced data source. The Diamond Exploration Database does not capture the chemical results of such sampling themselves because NTGS provides a separate geochemical database for this purpose. This database is available on the STRIKE web mapping system or in NTGS (2011).

Incorporation of bulk chemical data is an ongoing project and hence users of the Diamond Exploration Database who are unable to find bulk chemical data associated with samples of interest are directed to the original sources of the data.

Drillhole samples

The database refers to numerous samples taken from drillholes, as identified in the field 'CollMethod'. 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, NTGS provides a separate drillhole database providing more detailed technical and lithological information where known, available via STRIKE and NTGS (2011).

Composite samples

Due to sample size constraints, it is not uncommon for companies to process composite samples over considerable lengths of drill core. However, some companies have created composite samples incorporating material from a sometimes wide range

of geographical locations. Treatment of the data arising from such a sampling methodology presents particular problems. Population of the database has been carried out in order to achieve a consistency in the treatment of composite samples short of providing the lowest uncertainty in all cases. Problems arise in connection with assigning location data and as discussed in the following section, yet more striking problems arise in connection with mineral recovery data. For composite samples, an entry 'Composite_xx' is made in the Location_Type field, where 'xx' is an integer representing the number of samples in the composite. Where individual sample names are known, these are itemised in the Comment fields. In some cases, a central coordinate is reported and this is the coordinate given in the database. For example, sometimes 5-fold composite samples are reported as being 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 applied in achieving the reported coordinates.

Indicator recovery data - DED_BULK_ANALYSES_Indicators

SubSample field

During the course of exploration, most companies have elected to give separate sample numbers to samples destined for different purposes even if they are taken from the same location. For example, it is common for two separately labelled loam samples to be taken, one for bulk chemistry and the other for indicator mineral separation. There are other cases where samples have been subdivided after collection, either by mass splitting, or designating different size fractions for different types of analyses. In addition to the example given previously, it has been standard practice for some companies to assign the 0.1–0.25 or 0.3 mm size fraction for caustic fusion separation of diamond and the larger size fraction to non-diamond indicator mineral separation. To tackle these subdivisions of samples, in addition to the Sample field, the Indicators data file introduces a SubSample field. Rather than being assigned by the company concerned, the SubSample field has usually been assigned entries during the population of the database based on a description of the subsample processing method and where known, a processing batch number usually assigned by the processing laboratory. All sub-sample labels are retained in identical forms throughout all subsequent data files, as described in **Figure 1,** to allow precise cross-referencing between data files.

Sample weights and composite samples

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 where volume has instead been reported. In such cases, an estimate of sample weight is made and details of the assumptions made are described in the Comment fields.

Composite samples, as described in the previous section, have had to be considered with particular care in populating fields in the Indicators file. Specific variables relating to composite sample components are rarely reported and hence the usual assumption made is that each composite component is of the same weight. Hence, entries in the SampleWt, SampleVol, ConcentrateWt represent the total quoted value divided either by the number of samples or in relative proportion based on component weight. Similarly, one might expect the fields relating to number of indicators recovered to always be populated by integers, however for composite samples, values are assigned based on the number of components to the sample or else in a proportion based on component weight. For example a composite sample from which 125 spinels were recovered, and where it is known that the central sample weighed 25 kg and the four satellite sample components weighed 10 kg, would return four records reporting 19.23 spinels and one record reporting 48.08 spinels. Although it is not satisfactory to have to report fractions of an indicator mineral, it is considered to be a better and more conservative 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.

Arguably, calculation of the number of indicators per gram of heavy mineral concentrate may be a better reflection of proximity to source than indicators per kg of total sample. However, the significant variability of size fraction, processing method and picking protocols introduces too many variables to be able to satisfactorily remove their influence. In some cases, it is reported that only a proportion of the recovered concentrate was picked from and where this is the case, the full concentrate weight has been reported with notes included in the Comments fields. Consideration of such comments provides an important quality control on any calculations made regarding concentrate weight. Furthermore, aside from the 500 000-series records, particular care has been applied to populating the sieve size ranges for each sample with the ranges from which indicator grains were picked. It is common, for example, for a sample to be sieved at -2 mm in the field, whereas concentrates and indicators were only generated from the -1 mm fraction. This latter value is the one which, in this case, would be entered into the MeshUpperObs field.

Micro-, macro-diamond definition

In conjunction with the number of micro- and macro-diamonds recovered, a field allowing definition of the micro-macro subdivision, 'MacroDefn', is provided. This is because there is neither a single Australian, nor an international standard for

the definition of a macro-diamond. The closest to a standard would perhaps be that all three axial dimensions are greater than 0.5 mm, but this requires that each stone is physically measured. Despite numerous company reports reporting micro- or macro-diamond recovery, almost none reports the definition they use. Where such information is given, examples include 'one dimension greater than 0.5 mm', 'captured on the 0.5 mm sieve', or simply '0.5 mm'. In contrast, Lee *et al* (1997) reported Merlin micro-diamonds within the size range 0.1 to 0.8 mm. Ashton Mining, in the earlier years of exploration in Australia often quoted a 0.4 mm cut-off, which in reality related to whether or not a stone would pass through a US 40 mesh sieve (425 µm square mesh). Such a mesh could readily pass a 0.6 x 0.4 x 0.4 mm diamond, which would subsequently be classed as a micro-diamond. Certainly, for populations of diamonds that fall far from the definition boundary, the details of the definition are academic. However a threshold of 0.5 mm falls comfortably within the upper range of sizes which one may expect from an exploration sample within several km from a primary diamond source. Hence in reality, a definition is important. Given that a definition is almost never provided and that there is no rigorous research to support the oft-quoted contention that micro-diamonds are easily transported by wind whereas macro-diamonds are not, it is recommended that the Tot_Diamond or Diam_perkg fields are of more practical use than the micro and macro subdivisions.

Diamond recovery result

A diamond results field 'DiamResult' is included that indicates whether a sample is barren or positive, because the database includes some rare records in the Indicators file where there are no numbers provided for diamond recovery for diamond-positive samples. Such records arise 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 is reported as carats per ton and therefore a value for number of diamonds cannot be obtained. Hence, in filtering the Database for diamond-positive samples, the 'DiamResult' field should be used rather than querying 'Tot_Diamond' > 0.

Visually-identified indicator counts – non-diamond

In the database, as a general rule, the fields 'Chromite', 'Garnet', 'PicroIlm', 'ChromeDiop' and 'OtherIndicat' are all populated by indicator counts as determined by visual inspection. Because chromite is generally the only indicator mineral which has a chance of surviving any significant distance from source in Australia (Towie *et al* 1994, Reddicliffe 1999), laboratories apply considerable care to using visual criteria to discriminate kimberlite-sourced ('indicator') chromite from other types. Hence, it is notable that separate 'UnresChromite' and 'NK_Chromite' visual identification fields are included in the database.

Other minerals

In addition to true kimberlites, lamproites and lamprophyres are amongst the target primary sources for diamonds within the NT. This is particularly true by analogy with diamondiferous rocks in Western Australia (eg Jaques *et al* 1986). These rocks often contain different mineralogies to kimberlites. However to a large extent, the indicator mineral protocols applied in the NT have been taken off the shelf from successful methodologies applied in southern Africa and more recently, in the Canadian Arctic (eg Fipke *et al* 1995). The Canadian Arctic presents in some cases quite a different mineralogical environment with its emphasis on true kimberlite and a completely different weathering environment to the Territory. It is for this reason that it has been deemed important in populating the Diamond Exploration Database, to more broadly capture exploration data than simply the classical indicator mineral data. A previously cited example is the capture of samples processed for bulk chemistry. Other examples are the 'OtherMin1', 'OtherMin2' and 'OtherMin3' fields within the Indicators data file. These fields allow for the capture of other minerals recorded as being present in heavy mineral concentrates in post-NTGS (2005) records. Some minerals such as zircon and tourmaline have been identified as being important in exploration for lamproite (Fipke 1994) and are recorded in numerous database entries.

Chemically-derived indicator mineral counts

Chemically derived indicator mineral counts fields reflect the number of distinct mineral grains per sample (and sub-sample) having indicator mineral chemistries (ie, analyses with a 'YES' in the 'Indicator' field in file DED_GRAIN_ANALYSES_Maj_Chem). Indicator mineral counts incorporate parts of composite grains and exclude repeat analyses. It is notable that only mantle-derived garnets falling into the G3 and G4 fields are counted in the GT_G3 and GT_G4 fields in the Indicators file DED_BULK_ANALYSES_Indicators.

Although the chemically defined mineral classifications fields, such as 'SP_CID', 'SP_Gt_Per' provide high-value data, the number of grains chosen for chemical analysis is arbitrary and usually gives no reflection of the abundance of a particular indicator within a sample. Therefore unlike a field such as 'Indicat_perkg', which is a useful prospectivity variable, a calculation of, for example, number of CID spinels per kg of sample is largely meaningless. Hence it is important that the visually-identified indicator fields, such as 'Chromite' give a true reflection of the presence of indicators within a sample. However, when populating mineral chemical fields with data, it became clear that 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 be due to a phase appearing as part of a composite grain during chemical analysis; however in other cases, this arose from shortcomings in the data capture or

initial data reporting. In order to ensure that a record with indicator chemistry shows up as a positive when filtering on the basis of visual indicator picks, all records that returned a zero in the relevant indicator field were populated with the numeral given in the chemically identified field. Due to the number of affected records, where the number of grains chemically identified exceeded those visually identified, no alteration to the data has been made.

Major and minor element data – DED_GRAIN_ANALYSES_Maj_Chem

The file DED_GRAIN_ANALYSES_Maj_Chem provides individual mineral chemical analyses for discrete mineral phases. Entries are as reported except for data with over four decimal places which are truncated. It is arguable that there are very few cases where analytical precision is as good as four decimal places. Users of the database are therefore encouraged to consider likely analytical precision particularly when using such analyses. Each record provides a single analysis, although where averaged analyses are reported, provision exists in the Comments fields to draw attention to this fact.

Analysis names

The 'Grain' field has been populated using the grain identification reported, amended with various suffixes. Repeat analyses have been identified where two or more closely similar analyses were reported with identical grain identifications. In such cases, a suffix is applied to the 'Grain' name to draw attention to repeat analyses and these repeats are not included in the counts of chemically-defined indicators, as reported in the file DED_BULK_ANALYSES_Indicators. Repeat analysis suffixes also apply to grains where a core and rim have been measured. Attention is drawn to these cases in the Comments field and care should be taken not to calculate averages from such core / rim repeat analyses. Analyses on different phases comprising composite grains are distinct from repeat analyses. Although indicators are picked visually as distinct grains, during the course of mineral chemical analyses, composite grains are occasionally found and the different components analysed. Such grains are annotated in the 'Grain' field with suffixes such as '_Polyphase_1' with a further 'Repeat' suffix added where necessary. Examples of composite grains are garnet with clinopyroxene or ilmenite with chromite. Where composite grains are identified, each distinct mineral phase is used to populate the chemically-derived indicator counts reported in DED_BULK_ANALYSES_Indicators.

Composite samples

Where it is not known from which component of the composite sample a particular grain is derived, the grain is assigned to the first sample component and hence is also assigned its SampleID number. The DED_BULK_ANALYSES_Indicators file takes account of mineral counts assigned for each component of the composite, both visually and chemically, and hence the added complexity of reproducing the same chemical analyses numerous times is not warranted.

Analysis quality

An initial quality control has been applied to the data. Each analysis has been assessed for quality and assigned a 'YES' or 'NO' entry in the 'Valid_Analysis' field. Generally speaking, analyses with totals greater than 102 wt% or less than 96 wt% are considered unacceptable. For wave dispersive spectrometry data (WDS), these are generous limits; however, they have been chosen to also capture acceptable energy dispersive (EDS) analyses. In cases within this total weight range, where specific analyses give particularly poor stoichiometry, they have also been deemed invalid. Furthermore, analyses with totals under 96 wt% may be considered acceptable depending on the phase analysed. Acceptable lower thresholds are described in the metadata and **Table 7**.

For some poor analyses (where the Valid_Analysis field is populated with 'NO'), there is enough chemical data to support a reasonable determination of the phase identity. In such cases, a mineral name is provided; otherwise the mineral is described as 'Unknown'. However as mineral classification requires high-quality data, mineral classifications are not given for poor analyses. In such cases, the Mineral_Class field is populated with the term 'Poor-Analysis'.

Phase	Lower Threshold	Phase	Lower Threshold
Default	96%	Haematite¥	87%
Phlogopite*	90%	Magnetite†	90%
Pseudobrookite	93%§	Chlorite	87%
Picroilmenite#	94%	Carbonate, perovskite	Variable
Spinel¢	95%	Other exotic OH-minerals	Variable

* :- After Mitchell (1986); # :- where Fe_2O_3 is not quoted, otherwise 96%; ¢ :- Spinels other than magnetite where FeO > 20 wt% and Fe_2O_3 is not quoted, otherwise 96%; § :- Pseudobrookite analyses would typically show good stoichiometry or total under 97 wt% as distinct from ilmenite; ¥ :- Haematite analyses without Fe_2O_3 data should lie within the range 87–90 wt% total; and, † :- Magnetite analyses without Fe_2O_3 data should lie within the range 90–93 wt% total.

Table 7. Acceptable analysis total thresholds based on mineral phase.

Mineral identification

The mineral phase identity and classifications fields, 'Mineral' and 'Mineral_Class', derive from the major and minor element analyses and have been used to populate the chemically-derived mineral counts fields for records in the file DED_BULK_ANALYSES_Indicators. The method and laboratory for each analysis are presented in 'Probe_Lab' and 'Probe_Method' fields. Mineral names and classifications (where data quality allows) have been assigned based on major and minor element chemistry presented in the DED_GRAIN_ANALYSES_Maj_Chem file only. The particular significance of this statement is that some data appearing in the trace element analyses records may be of relevance to mineral terminology, such as spinels with reported Zn concentrations; however, trace element data has not been used for phase identification.

The 'Mineral' field identifies the mineral phase and applies a simple subdivision of relevance particularly aimed at discriminating likely crustal- and mantle-derived grains. The 'Mineral_Class' field however provides a further subdivision using one of a number of mineral classification schemes in common use in diamond exploration. Numerous such classifications schemes are used in exploration. However for the DED, one scheme has been chosen for each mineral type either due to its strong reliance on Australian data or prominence in being particularly well accepted internationally.

In assigning a 'Mineral_Class' term, 'Mineral' subdivisions have been applied or ignored where relevant. Hence for instance, all ilmenites (regardless of whether they are termed, for example, 'Ilmenite-picro') have been considered equally when applying a Mineral_Class term, as the classification scheme used takes account of the 'picro-' or non-picro-' quality of the data. However for spinels, only chromites (with the exception of Al-chromite) and Mg,Cr,Al-spinel have been subdivided, other spinels being classified 'SP-crustal'.

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

'Mineral' field

Amphibole, feldspar and mica subdivisions follow established criteria. Definitions of other 'Mineral' subdivisions are described in **Table 8**.

'Mineral' field – Ilmenite

The definition of picro-ilmenite as containing >5 wt% MgO is commonly accepted (Mitchell 1986, Kerr *et al* 2000, Wyatt *et al* 2004), but is empirical and appears to be largely arbitrary (B Wyatt, *pers comm* 2010). Many kimberlites have ilmenite with less than 5% MgO (including Kirkland Lake and Iron Mountain; D Schulze, Univ. Toronto, *pers comm* 2010), as well as substantial ferric iron. Hence, there is an argument supporting a more generous, 3 wt% cut-off. However, as all ilmenite analyses have an indicator classification applied to them in Mineral_Class, the details of the cut-off applied to the picro-ilmenite subdivision are largely academic.

'Mineral' field – Pseudobrookite

Cr-absent ferropseudobrookite and pseudobrookite (*sensu stricto*: $Fe^{3+}{}_2TiO_5$) are interpreted to be oxidation products of common ilmenite. Further weathering, as is common in tropical environments such as that over much of the Northern Territory, 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 picro-ilmenite. Many ferropseudobrookites recovered in Northern Territory samples have octahedral habits, interpreted to be pseudomorphs after Cr-spinel (WR Taylor, Elkedra Diamonds NL, *pers comm* 2010). Consequently, it is considered to be an indicator mineral and occurrences of Pseudobrookite-Cr are counted in the 'OtherIndicat' field of DED_BULK_ANALYSES_Indicators.

'Mineral' field – Spinel

The spinel subdivisions follow a modified version of Ramsay (1992), developed by WR Taylor and reported in Denny (1998), which is based on a large dataset of Australian crustal- and mantle-derived spinels. Ramsay (1992), in his very comprehensive assessment of mostly Australian mantle indicator minerals, concluded that spinel compositions more satisfactorily discriminate diamond potential from non-diamond potential sources than garnet classification. He observed 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 occurring between garnet peridotite- or diamond-associated spinels (Cr# [defined as 100xCr/(Cr+Al) cations] >55) and spinel or plagioclase peridotites. Diamond-associated harzburgitic spinels were seen to show Cr# >75.

Taylor (WR Taylor, *pers comm* 2010) has modified the Al_2O_3 cut-off to a more generous 40 and 45% on the basis that the 35 wt% (Ramsay 1992) threshold was modelled on specific, well characterised 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 $Fe^{3+}/\sum Fe$ of 0.4, which captures FMQ buffer grains in addition to more oxidised phases as would be typical of high-pressure phenocrysts. In contrast, Taylor (WR Taylor, *pers comm* 2010) used a more restrictive minimum Cr# value of 60, as otherwise, numerous basaltic and layered-intrusion origin Cr-spinels would flood the dataset.

Amongst 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 serpentinisation, but this is rare compared to greenschist-facies Zn overprints. In some areas of the North Australian Craton, it is common to find populations of indicator grains with Zn overprints, where 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, *pers comm* 2010).

'Mineral_Class' field – Garnet

Garnet classification follows the methodology of Grütter *et al* (2004) described in **Table 9**. The classification scheme has been applied to all garnets for which mineral chemistry has been acquired, the large majority of which were identified visually as being indicators. The Grütter *et al* (2004) D-classification relies on an accurate measurement of MnO (where MnO <0.36 wt% for the lower Cr, G10 analyses) and Na_2O (where Na_2O >0.07 wt% for G3, G4 and G5) and as such would

Mineral subdivision	Criteria	Mineral subdivision	Criteria
Orthopyroxene-Al	Al_2O_3 > 1 wt%	Ilmenite-altered	FeO_{total} > 53 wt%
Diopside-Cr	Cr_2O_3 > 1 wt%	Ilmenite-picro	MgO > 5 wt%
Rutile-Fe	FeO_{total} > 15 wt%	Pseudobrookite-Cr	Cr_2O_3 > 0.2 wt%
Rutile-Nb	Nb_2O_5 > 10 wt%		

Subdivision	Phase	Criteria
SP-MC**	Mg-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$<0.4, Mg#≥40, TiO_2<1, ZnO<1
SP-ZMC*	Zn,Mg-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$<0.4, Mg#≥40, TiO_2<1, ZnO≥1
SP-CH*,#	Chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$<0.4, Mg#<40, TiO_2<1, ZnO<1
SP-ZCH*	Zn-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$<0.4, Mg#<40, TiO_2<1, ZnO≥1
SP-TCH**	Ti-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$<0.4, Mg#<40, TiO_2≥1, ZnO<1
SP-ZTCH*	Zn,Ti-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$<0.4, Mg#<40, TiO_2≥1, ZnO≥1
SP-FTCH*	Fe,Ti-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$≥0.4, Mg#<40, TiO_2≥1
SP-TMC**	Ti,Mg-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$<0.4, Mg#≥40, TiO_2≥1
SP-FTMC*	Fe,Ti,Mg-chromite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$≥0.4, Mg#≥40, TiO_2≥1
SP-MAC*	Mg,Al-chromite	Cr# <60, Cr# ≥20, Cr_2O_3≥15, $Fe^{3+}/\sum Fe$<0.4, Mg#≥40, TiO_2<1
SP-TMAC*	Ti,Mg-Al-chromite	Cr# <60, Cr# ≥20, Cr_2O_3≥15, $Fe^{3+}/\sum Fe$<0.4, Mg#≥40, TiO_2≥1
SP-AC	Al-chromite	Cr# <60, Cr# ≥20, Cr_2O_3≥15, $Fe^{3+}/\sum Fe$<0.4, Mg#<40, TiO_2<1
SP-TAC*	Ti,Al-chromite	Cr# <60, Cr# ≥20, Cr_2O_3≥15, $Fe^{3+}/\sum Fe$<0.4, Mg#<40, TiO_2≥1
SP-FMAC*	Fe,Mg,Al-chromite	Cr# <60, Cr# ≥20, Cr_2O_3≥15, $Fe^{3+}/\sum Fe$>0.4, Mg#≥40, TiO_2<1
SP-TFMAC*	Ti,Fe,Mg,Al-chromite	Cr# <60, Cr# ≥20, Cr_2O_3≥15, $Fe^{3+}/\sum Fe$>0.4, Mg#≥40, TiO_2≥1
SP-MCAS†	Mg,Cr,Al-spinel	Cr# <20, Cr# ≥8, $Fe^{3+}/\sum Fe$<0.4, Mg#≥40, TiO_2<1
SP-TMCAS*	Ti,Mg,Cr,Al-spinel	Cr# <20, Cr# ≥8, $Fe^{3+}/\sum Fe$<0.4, Mg#≥40, TiO_2≥1
SP-AS	Al-spinel	Cr# <8, Al_2O_3≥45, $Fe^{3+}/\sum Fe$<0.4, Mg#≥30, TiO_2<1
SP-TMFAS*	Ti,Mg,Fe,Al-spinel	Cr# <8, Al_2O_3≥40, $Fe^{3+}/\sum Fe$≥0.4, Mg#≥30, TiO_2≥1
SP-HER	Hercynite	Cr# <8, Al_2O_3≥45, $Fe^{3+}/\sum Fe$<0.4, Mg#<30, TiO_2<1, ZnO≤15
SP-GHN*	Gahnite	Cr# <8, Al_2O_3≥45, $Fe^{3+}/\sum Fe$<0.4, Mg#<30, TiO_2<1, ZnO>15
SP-CMGT	Cr-magnetite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$>0.4, Mg#≤30, TiO_2<1
SP-TCMGT	Ti,Cr-magnetite	Cr# ≥60, Cr_2O_3>8, $Fe^{3+}/\sum Fe$≥0.4, Mg#≤30, TiO_2≥1
SP-MCMGT	Mg,Cr-magnetite	Cr# ≥60, Cr_2O_3>8, Cr_2O_3<40, $Fe^{3+}/\sum Fe$>0.4, Mg#>30, TiO_2<1
SP-FMC*	Fe,Mg-chromite	Cr# ≥60, Cr_2O_3≥40, $Fe^{3+}/\sum Fe$≥0.4, Mg#>30, TiO_2<1
SP-MGT	Magnetite	Cr_2O_3<8, $Fe^{3+}/\sum Fe$≥0.4, Mg#≤30, TiO_2<5
SP-TMGT	Ti-magnetite	Cr_2O_3<8, $Fe^{3+}/\sum Fe$≥0.4, Mg#≤30, TiO_2≥5
SP-MTMGT	Mg,Ti-magnetite	Cr_2O_3<8, $Fe^{3+}/\sum Fe$≥0.4, Mg#>30, TiO_2≥5
SP-ULV	Ulvöspinel	Cr_2O_3<8, $Fe^{3+}/\sum Fe$<0.4, Mg#≤30, TiO_2≥15
SP-MULV	Mg-ulvöspinel	Cr_2O_3<8, $Fe^{3+}/\sum Fe$<0.4, Mg#>30, TiO_2≥15

* Possible indicator mineral :- ; ** :- High priority indicator mineral; Spinel subdivisions follow the methodology of Taylor, W.R., modified from Ramsay (1992) and as reported in Denny (1998) and; # :- CH refers to $FeCr_2O_4$ in the strict sense i.e. Cr-spinels with dominant $FeCr_2O_4$ end member composition; † :- Mg,Cr,Al-spinel is usually a crustal phase and has been interpreted as such for numerous Northern Territory examples, however the EMU-1 kimberlite pipe hosted such a grain (SampleID 560666) hence MCAS grains have been considered for further classification; all variables are expressed as wt% with the exception of: $Fe^{3+}/\sum Fe$:- based on charge-balanced cation calculations of stoichiometric analyses where $\sum Fe$ represents Fe^{2+} + Fe^{3+}; Cr# :- 100 x $Cr/(Cr + Al)_{cations}$ and Mg# :- 100 x $Mg/(Mg+Fe^{2+})_{cations}$

Table 8. Chemical criteria for the subdivision of Mineral terms.

typically require measurement by EPMA analysis. The possibility of 'D' designation is not considered for analyses in the database acquired by EDS or SEM techniques. Even for good analyses 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 cut-off for potentially diamond-associated eclogites, garnets from graphitic eclogites can range from 0.03 to 0.20 wt% Na_2O with three-quarters of graphite-association analyses quoted having >0.07 wt% Na_2O. Hence, the eclogitic D-classification where applied cannot be used as an exclusive criteria. Furthermore, garnets classified as G3 or G4 and with 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, *pers comm* 2011). 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 DED_BULK_ANALYSES_Indicators. Text is also added in the Comments fields indicating the crustal assignment criteria.

Garnets classified as eclogitic G3, G4 and harzburgitic G10 (and particularly those with a D-suffix) are regarded as being particularly indicative of an association with diamond. However, much of the Grütter *et al* (2004) classification scheme is empirical, with boundaries between fields based on the capture of something of the order of 80–90% of grains with particular characteristics. Consequently for example, G9 garnets should not necessarily be considered un-prospective for diamonds and numerous examples of diamondiferous kimberlites and lamprophyres contain garnet populations dominated by G9 rather than G10 garnets (eg Hutchison and Frei 2009). It is notable that the G9/G10 split of Merlin kimberlite-sourced garnets, as reported by Reddicliffe (1999), is close to even. Of grain analyses reported, G9s constitute 47% of those falling into either the G9 or G10 fields.

'Mineral_Class' field – Orthopyroxene

Orthopyroxene classification follows the methodologies of Ramsay (1992) and Ramsay and Tompkins (1994), based on Al_2O_3, SiO_2, MgO and FeO content. Grains with compositions falling in the diamond lherzolite (ODL), diamond harzburgite (ODH), on-craton diamond peridotite (OGP) and garnet peridotite and on-craton megacrysts (OGM) fields are considered to be indicators. Spinel-lherzolite (OSP) and eclogite/pyroxenite (OEC) association compositions and 'Undefined' compositions (where MgO/(MgO+FeO) wt% <0.7) are not considered indicators.

'Mineral_Class' field – Clinopyroxene

Clinopyroxene classification follows the methodologies of Ramsay (1992) and Ramsay and Tompkins (1994) based on Cr_2O_3 and Al_2O_3 content. Clinopyroxene from garnet peridotite (CGP) and eclogitic, megacrystic and cognate clinopyroxene (CPP) are considered to be indicators favourable for a diamond association. Spinel peridotite association (CPS) composition grains are not considered to be indicators.

'Mineral_Class' field – Ilmenite

Ilmenite classification follows the methodology of Wyatt *et al* (2004), where ilmenites are subdivided into kimberlitic, non-kimberlitic and intermediary associations, based on TiO_2 and MgO compositions. The Ilm-Kim/Ilm-Inter subdivision of Wyatt *et al*'s (2004) is quoted in their text and their Ilm-Inter/Ilm-N-Kim boundary, shown graphically, is interpreted to lie at:

$$TiO_2 \text{ wt\%} = 25.4062 + 6.1433 \times \text{MgO wt\%} - 0.4187 \times (\text{MgO wt\%})^2 + 0.0106 \times (\text{MgO wt\%})^3$$

Wyatt *et al* (2004) stressed that boundary lines quoted whilst describing a best-fit for ilmenites from their own database 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, where users of the database are cautioned that an Indicator designation may be over-optimistic in some cases. It should also be noted that although the quoted boundaries

Classification	Explanation	Classification	Explanation
G0	Unclassified	G5D*	Pyroxenitic, websteritic and eclogitic (diamond-facies) - with higher Fe than moderate- to low-Cr G9 garnets
G1	Low-Cr megacrysts	G9	Lherzolitic
G3#	Eclogitic	G10	Harzburgitic
G3D*	Eclogitic (diamond-facies)	G10D*	Harzburgitic (diamond-facies)
G4#	Pyroxenitic, websteritic and eclogitic - with Cr lower than G9 garnets and overlapping with low-Ca eclogitic garnets	G11	High-Ti peridotitic
G4D*	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		

* :- D-classification relies on accurate measurement of MnO and Na_2O and as such would typically require measurement by EPMA analysis. The possibility of 'D' designation is not considered for analyses in the Database acquired by EDS or SEM techniques; # :- Some garnets classified as G3 or G4 are crustal-derived and are therefore not considered to be indicators.

Table 9. Description of Mineral_Class names for garnets.

constrain compositions associated with kimberlites quite well, some non-kimberlite sources of ilmenites such as melnoites, alnöites and basanites have significant proportions of their populations falling into the Ilm-Kim field. Hence, the classification scheme captures kimberlitic ilmenites, but does not preclude ilmenites from some other sources.

'Mineral_Class' field – Spinels
For mantle-derived chromites (ie excluding Al-chromite, 'SP-AC'), grains are classified according to the methodology of Grütter and Apter (1998). Their modified chromite in diamond "SP-CID" boundary is defined by:

TiO_2 <0.6 wt%;
Cr_2O_3 <68.2–3.5 x TiO_2;
Cr_2O_3 >62 wt%
10.4 wt% <MgO <16.5 wt%; and
$Fe_2O_{3calculated}$ <6 wt%.

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

For TiO_2 <1.0 wt% then Cr_2O_3 <68.2–3.5 x TiO_2, or
where TiO_2 >1.0 wt% then Cr_2O_3 <66.0–3.5 x TiO_2

Grütter and Apter (1998) demonstrated that numerous barren kimberlites contain chromites whose compositions overlap the CID field, which is often used by explorers as a proxy for diamond-associated rocks. Hence, caution should be applied in using CID-classified analyses as indicating a definitive association with diamond.

'Indicator' field

As the principal concern of the DED_GRAIN_ANALYSES_Maj_Chem is to provide indicator mineral data, the field 'Indicator' has been included. Criteria for designation of analyses as indicators or non-indicators are described in **Table 10** and take account of 'Mineral' and 'Mineral_Class' designations.

It should be cautioned that, particularly as some mineral classification schemes apply an empirical approach to an indicator designation (such as Grütter *et al* 2004), it would be unwise to preclude all non-indicators from further consideration. Furthermore, the chemical criteria used for identifying a grain as an indicator or not evolve with time. Hence, users of the database are advised to consider the assumptions of current schemes and the possibility of new or alternative mineral classification methods that may alter the indicator designation of the data.

Included amongst major element data are a number or 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 Comments fields. Particularly for spinels, the most common indicator mineral in the NT, discrimination amongst 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 the Northern Territory.

Trace element data - DED_GRAIN_ANALYSES_Trace_Chem

Trace element data provided are largely self-explanatory. It is notable that all elemental concentrations are presented as ppm with the exception of iridium and ruthenium data, which are presented as ppb. All data provided in the first release of the database and current to February 2011 are of trace element compositions of spinel grains, as determined by laser-inductively

Phase	Indicator		Indicator
Poor Analyses*	NO	Ilmenite - ILM-N-Kim	NO
Amphibole, staurolite, sphene, quartz, haematite, feldspar, rutile, corundum, chlorite, columbite, pyroxenoids	NO	Ilmenite - ILM-Inter and ILM-Kim	YES
Garnet - G0 and crustal G3 and G4	NO	Pseudobrookite	NO
Garnet - all other garnet classifications included	YES	Pseudobrookite-Cr	YES
Spinel - ulvöspinels, magnetites, hercynite, Al-spinel and Al-chromite end-members and unclassified	NO	Mica - Phlogopite and Tetraferriphlogopite	YES
Spinel - all other spinel classifications included	YES	Mica - all other mica classifications included	NO
Olivine#	YES	Monticellite	YES
Orthopyroxene - OPX-OGM and OPX-OGP, OPX-ODH, OPX-ODL	YES	Clinopyroxene - CPX-CGP and CPX-CPP	YES
Orthopyroxene - OPX-OEC, OPX-OSP, OPX-Undefined	NO	Clinopyroxene - CPX-CLS	NO

* :- i.e. records where the Valid_Analysis field is 'NO'; # :- Olivines are not abundant enough nor typically of high enough analysis quality to discriminate hence all grains are designated as indicators

Table 10. Criteria for designation of analyses as Indicators.

coupled mass spectrometry (laser-ICPMS or LA-ICPMS). Provision is given in the 'Mineral', 'Mineral_Class' and 'Trace_Method' fields to describe data acquired by other methods and on other phases.

Mineral phase identity and classifications for each grain are identical to those assigned to the same grain in the file 'DED_GRAIN_ANALYSES_Maj_Chem'. Where required, major and minor element data can be assigned to trace element data by matching the unique combinations of 'Sample', 'SubSample' and 'Grain' fields present in both files.

Diamond description data - DED_GRAIN_ANALYSES_Diamond

The diamond description file reflects the range of physical criteria reported to NTGS during the course of exploration. Some companies simply report carat weight, or else diamond size either by direct measurement of various axes or by discrimination based on sieve size. Other companies have provided fuller descriptions incorporating colour, shape and surface, and internal features. Fields have been designed to subdivide descriptions into features reflecting colour, 'DiamColour', shape as produced by growth and resorption, 'DiamCrystal', as distinct from discrete surface features, 'DiamSurf', and the effects of brittle deformation, 'DiamCleavage'. Reported data have been rearranged where appropriate to fit these fields. Hence, data can be reasonably easily filtered to provide a reflection of the extent to which diamond crystals have been compromised within their magmatic transport media or during emplacement, and the length of time they may have resided in sediments rather than their primary hosts.

Although some attempt has been made to introduce consistency in the descriptions of various criteria, entries largely reflect the actual terms reported. Care should therefore be applied in drawing comparisons of, say, crystal shape between samples, as explorers may not have used internally or externally consistent criteria for reaching their descriptions.

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