Diamond prospectivity of Western Australia: a major synthesis and review

by

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Away from areas of thick cover, Western Australia hosts 696 000 km^2 of exclusively Archean rocks and 439 000 km^2 of Paleoproterozoic rocks. Pre-1.6 Ga rocks comprise about 45% of the onshore area of the State, constituting the West Australian Craton (WAC; incorporating the Yilgarn and Pilbara Cratons) and the western part of the North Australian Craton (NAC). Seismic tomography demonstrates that considerable remaining portions of the State are also underlain by thick mantle lithosphere (Kennett et al., 2013), hosting the conditions under which diamonds form. Most of the State is therefore prospective for diamonds and numerous diamondiferous lamproite and kimberlite fields are known. Emplacement of diamond-bearing rocks in Western Australia spans much of geological time, from the c. 1868 Ma Brockman Creek kimberlite in the Pilbara (White, 2000) to the c. 17 Ma Walgidee Hills lamproite, Noonkanbah field, West Kimberley (Phillips et al., 2012).

Australia produced approximately 11% of global rough diamond production by weight in 2015 (Kimberley Process Certification Scheme statistics), ranking it fourth in the world. All diamonds were derived from two mines, both in Western Australia. However, Western Australia's size, terrain, infrastructure, and climate mean that many areas still remain underexplored for diamonds. With the closure in 2015 of the Ellendale mine, which was responsible for a large proportion of the world's fancy yellow production, only one currently producing mine remains in Australia (at the AK1 olivine lamproite at Argyle, NAC). Hence a compelling case can be made for encouraging future diamond exploration in Western Australia. To that end, a thorough compilation of historical diamond exploration has been made (GSWA, 2018). The resulting data have subsequently been assessed in order to understand the effectiveness of prior exploration, draw attention to favourable, yet underexplored areas, and generate regional models of diamond prospectivity (Hutchison, 2018a).

Methodology

Continuous diamond exploration since the 1970s has resulted in numerous public and previously private datasets and 4200 statutory company reports citing diamond as a commodity of interest. These data have been used to construct the Diamond Exploration Database (DED; GSWA, 2018), which follows the structure described in Hutchison (2018b) and is based on similar structure previously applied to the Northern Territory (Hutchison, 2011). The focus has been on the primary method of exploration — that is, physical sampling. The DED incorporates the locations of over 88 000 diamond exploration samples, the overwhelming majority (~ 90%) having been tested for diamonds or other minerals indicating diamond potential. Associated with these samples are over 30 000 good-quality chemical analyses of mineral-separate grains. Furthermore, locations of 524 discrete in situ bodies with in-principal diamond potential (kimberlites, lamproites, ultramafic lamprophyres and carbonatites) have been compiled, of which 114 are confirmed to be diamondiferous. As a companion to the in situ occurrences, 127 determinations of emplacement age from 63 bodies have also been compiled with detailed geochronological information.

A two-fold approach to assessing diamond prospectivity has been followed. Mineral chemistry data are detailed in their coverage to the extent that statements can be made regarding the composition and thickness of the mantle lithosphere both regionally and underlying various specific locations with diamond potential. These data have been applied to four broad areas comprising the NAC, WAC, and off-craton in eastern and western parts of the State. Independently, mineral sampling data, including visual identification of diamond-prospective grains, have been detailed enough to allow prospectivity to be assessed with the State subdivided into 67 onshore tectonic units. The extent and results of sampling, in conjunction with the age of surface rocks relative to ages of diamond-prospective rocks, and of the underlying mantle structure, have been analysed to produce a prospectivity map. The methodology follows that of Hutchison (2012, 2013) for the Northern Territory (NT) and the resulting map presents a thirteen-level ranking of attractiveness for future diamond exploration.

Mineral sampling and mineral chemistry

Indicator distributions and sampling methodologies show that programs recovering >0.3 or 0.4 mm grains from high-energy trap sites are most successful. Diamond was present in 3.5% of the indicator mineral samples, and yellow and pink diamonds responsible for much of the revenue from Western Australia's diamond mines were also recovered from exploration samples. Diamond morphology is dominated by primary octahedral forms,

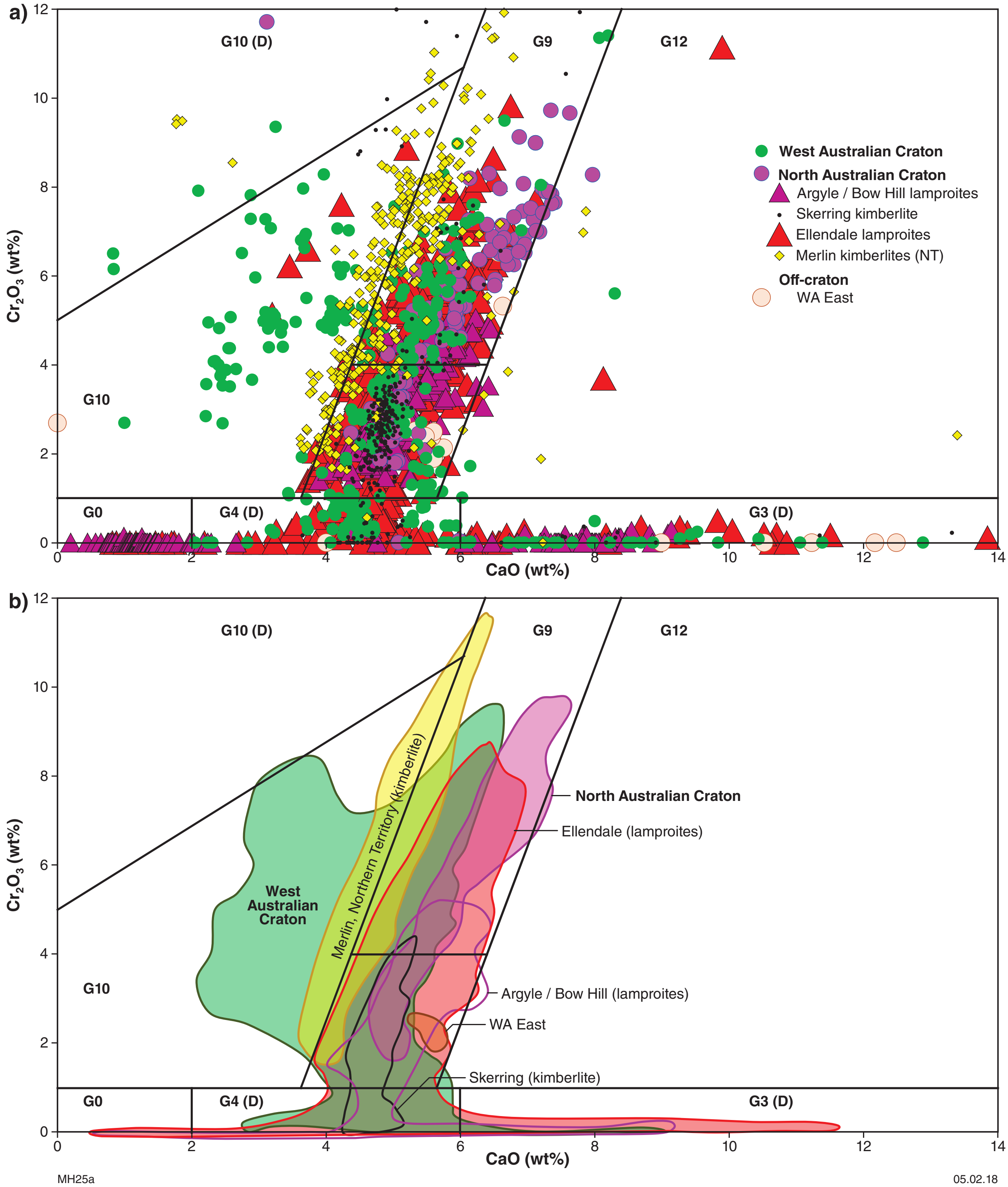

Figure 1. **Chemical composition of pyrope–almandine–grossular garnets in terms of CaO and Cr_2O_3: a) point data from all Western Australian and Northern Territory samples, with Argyle, Bow Hill and Skerring data from Ramsay (1992) and Merlin (Northern Territory) data from Reddicliffe (1999). Argyle, Bow Hill and Ellendale all contain abundant G0 composition garnets not considered to be mantle derived according to standard criteria (Grütter et al., 2004); b) simplified diagram showing representative compositional fields encompassing about 90% of analyses from each location: Argyle, Bow Hill, Ellendale and Skerring garnets – Ramsay (1992); Merlin garnets (Northern Territory) – Reddicliffe (1999). The lherzolite trends are increasingly Ca-depleted from the North Australian Craton of Western Australia (including Ellendale, Argyle and Bow River), through the West Australian Craton to the Merlin field (Northern Territory) samples. However, the West Australian Craton samples also show a much higher proportion of G10 (Grütter et al., 2004) garnets with an intermediate Ca-lherzolite trend**

but subsequent etching and resorption is also common. Recovered diamonds suggest that diamonds are more likely to have formed under Western Australia compared to the Northern Territory. However, in some places they are also more likely to have been damaged before reaching the surface.

Non-diamond indicators were identified by visual inspection in 28% of samples. The majority are spinels, capable of surviving Western Australia's harsh weathering environment. The Yilgarn and Pilbara Cratons and western parts of Western Australia (WA West) are particularly dominated by Al-free chromites, whereas (Mg,Fe,Ti)-bearing Al-chromites are abundant in the NAC and eastern areas of Western Australia (WA East). Increasing dominance of Al in chromites is interpreted as a sign of a shallower source than for mantle-derived Al-depleted Mg-chromites. Clinopyroxene indicators also largely show a mantle-derived garnet peridotite affinity. Kimberley Basin samples are more consistently eclogitic than other parts of the NAC. However, clinopyroxenes not classed as Cr-diopsides are associated with diamondiferous rocks in Western Australia, particularly at Argyle. For garnets, based on Grütter et al.'s (2004) methodology, the progression of garnet chemistry through G9 compositional space and into the G10 field from the NAC to the WAC (Fig. 1) suggests an incrementally increasing source depth for each of these areas. Garnet compositions, in a similar fashion to clinopyroxenes, show that despite diamond production being associated with the NAC, the WAC is particularly distinguished for its deep-mantle sourced indicators. Among ilmenites, 93% with indicator chemistry fall within the kimberlite field of Wyatt et al. (2004; Fig. 2). Samples from the Eastern Goldfields Superterrane are most kimberlitic. As with clinopyroxenes, Argyle-hosted ilmenites (Ramsay, 1992) would not be classed as indicators following the Wyatt et al. (2004) scheme, thus supporting a re-assessment of mineral chemistry exploration methodologies.

Further to regional observations, indicator mineral recovery, diamonds with un-attributed sources, and mineral chemistry anomalies also occasionally point to areas of local interest. Examples include the Hamersley Basin, the central Kimberley Basin, and the Big Spring area east of Ellendale, which has been the site of recent new lamproite discoveries.

Regional prospectivity ranking

Figure 3 shows the results of prospectivity ranking based on the 67 geological subdivisions of the State (Martin et al., 2016). Indicator mineral occurrences and in situ bodies with diamond potential largely occupy the north (NAC) and west (WAC) of the State. These areas correspond to thick mantle lithosphere (Kennett et al., 2013) establishing the conditions for diamond growth. Clusters in Figure 3 particularly correlate with areas of significant changes in mantle thickness reflecting structures favourable for diamond emplacement. Understanding deeply penetrating crustal and mantle structures using methods such as SEEBASE (Frogtech Geoscience, 2017) can be very useful for prioritizing exploration strategies.

The NAC, location of Western Australia's diamond mines, scores well in prospectivity ranking. However, partly because of under sampling combined with good indicator recovery, results point to parts of the WAC being more prospective. This corroborates the mineral chemistry study. The Hamersley Basin scores highest in prospectivity ranking. Equal second are the Eastern Goldfields Superterrane and Goodin Inlier, both located in the Yilgarn Craton. Regions ranked third are the WAC's Ashburton Basin, Biranup Zone, Bryah and Fortescue Basins, and Pilbara Craton; the Narryer Terrane, Marymia Inlier and the Youanmi Terrane of the Yilgarn Craton; and the Lamboo Province of the NAC. Areas with lowest scores, such as the Eucla Basin, lie farthest from craton margins and contain the youngest rocks.

Conclusions

Despite prolific diamond exploration, Western Australia is considerably underexplored and diminishing known reserves warrant a re-evaluation of diamond potential. Indicator mineral chemistries reflect mantle sources with respectable diamond tenor, consistent with diamond and visually determined indicator recovery, known diamondiferous source rocks, and mining in parts of the State. However, analysis of exploration data also draws attention to underexplored areas, particularly in the WAC. There are significant opportunities for diamond-affinity rocks being present near surface even within the large, underexplored sedimentary basins overlying thick mantle lithosphere evident through much of the State. Recent discoveries and the results of prospectivity analysis make a compelling case for renewed diamond exploration in Western Australia.

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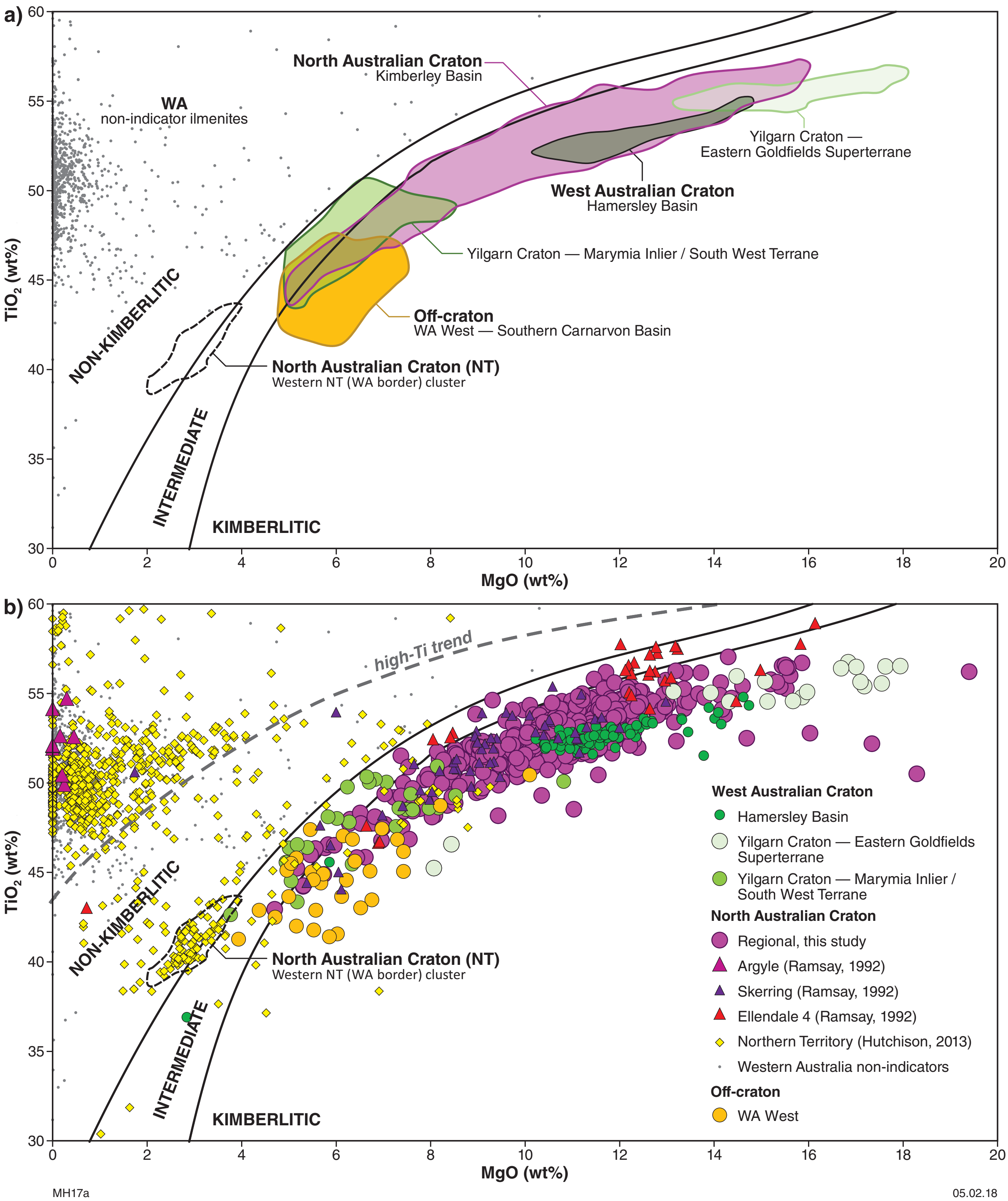

Figure 2. Chemical composition of ilmenites plotted as TiO_2 vs MgO: a) indicator-composition ilmenites are identified by fields encompassing 90% of data excluding outliers. Non-indicator composition ilmenites (Wyatt et al., 2004) are shown by grey dots. Among the Northern Territory ilmenites, a cluster of Northern Territory – Western Australia-border ilmenite compositions are labelled; b) all data points from the DED (GSWA, 2018) for Western Australia indicator ilmenites in the context of Northern Territory compositions (Hutchison, 2013) and locality-specific compositions from the NAC (Ramsay, 1992). Different regions show distinct compositional trends whereby kimberlite-derived samples (Skerring kimberlite pipe; Ramsay, 1992) generally fall more firmly within the kimberlite compositional field than lamproite samples (Ellendale 4 and Argyle; Ramsay, 1992). Lamproite-hosted Argyle ilmenites would not be classed as having indicator mineral compositions at all. Eastern Yilgarn samples are more kimberlitic than samples from the western WAC, just as western NAC samples are more kimberlitic than those in the Northern Territory (Hutchison, 2013)

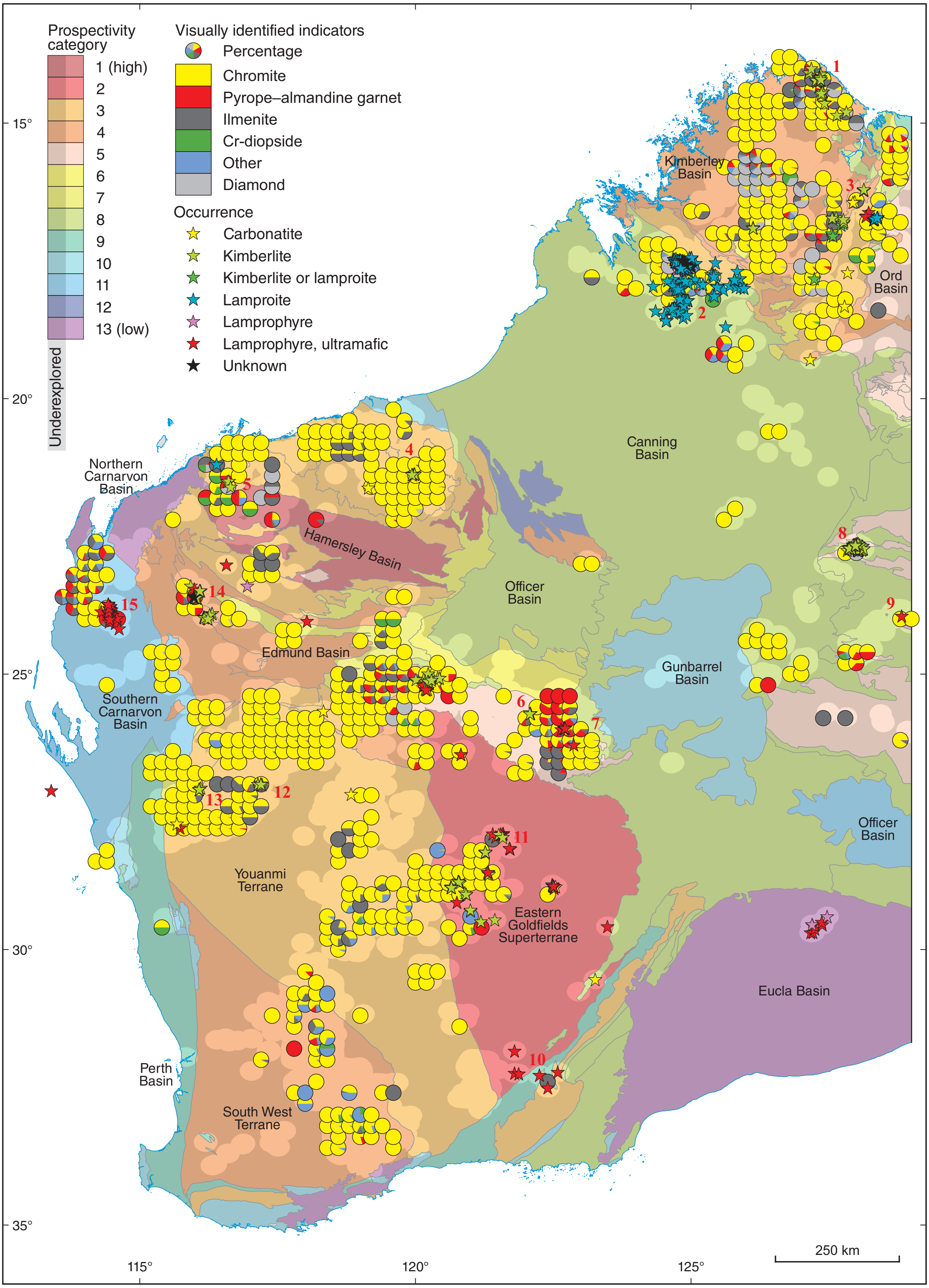
Prospectivity category
1 (high)
2
3
4
5
6
7
8
9
10
11
12
13 (low)
Underexplored
Visually identified indicators
Percentage
Chromite
Pyrope–almandine garnet
Ilmenite
Cr-diopside
Other
Diamond
Occurrence
Carbonatite
Kimberlite
Kimberlite or lamproite
Lamproite
Lamprophyre
Lamprophyre, ultramafic
Unknown
15°
20°
25°
30°
35°
115°
120°
125°
250 km
Kimberley Basin
Ord Basin
Canning Basin
Northern Carnarvon Basin
Hamersley Basin
Officer Basin
Edmund Basin
Gunbarrel Basin
Southern Carnarvon Basin
Youanmi Terrane
Eastern Goldfields Superterrane
Eucla Basin
Perth Basin
South West Terrane
1
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Figure 3. (opposite) Prospectivity map of Western Australia. Geological subdivisions are ranked for prospectivity (after Hutchison, 2018a) in the context of mantle structure, the age of surface rocks, the extent of sample coverage and recovery of visually determined indicators. A rank of 1 is the most prospective area and 13 is the least prospective. In situ bodies with diamond potential (tested or otherwise) are shown by stars colour coded according to the key. Notable localities numbered in red on the map are: 1 – Ashmore, 2 – Ellendale field, 3 – Argyle, 4 – Brockman Creek, 5 – Blacktop, 6 – Jewill, 7 – Bulljah Pool, 8 – Webb, 9 – JYP58, 10 – Norseman, 11 – Akbar, 12 – Cue, 13 – Mileura, 14 – Barlee, 15 – Wandagee. Sample site areas are indicated by shading such that unshaded areas lie within 20 km from an exploration sample location. Locations of recovered indicator minerals are shown within blocks of 0.2 degrees of longitude and latitude

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