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TYPE IIA DIAMONDS AND THEIR ENHANCED ECONOMIC SIGNIFICANCE

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INTRODUCTION

In the period since the first International Kimberlite Conference was held in southern Africa in 1973 a great deal of information has been gathered by researchers world-wide relevant to diamond formation. It is now widely accepted that most natural diamonds have formed at depth below the earth's surface, in the diamond stability field, by fluid interaction with peridotitic, websteritic and eclogitic rocks and their high pressure analogues in the asthenosphere (majorite) and associated with ultra high pressure minerals in the lower mantle (ferro-periclase, perovskite, inter alia) (see Harte 2010, tables 2, 3). Diamond formation has occurred at various depths ranging from approximately 140 km below the earth's surface in cool thick lithospheric craton roots and extending through the asthenosphere into the lower mantle. Whilst the majority of natural diamonds are lithospheric there are deposits where a high proportion of the diamond population is from greater depths (e.g. Monastery Mine, Jagersfontein Mine, RSA, Juina, Sao Luiz alluvials, Brazil). Furthermore each diamondiferous magmatic source has transported diamonds to the earth's surface from more than one depth and may have diamonds that have formed in the same location in more than one process (e.g. fibrous coated diamonds). These events can have occurred over a major portion of earth evolution, with diamond ages ranging from the Archaean to shortly before the sampling event that transported them to the surface. It is therefore commonly the case that diamonds from diverse origins can be found at individual locations and some of these are relatively readily recognized visually. Amongst them are Type II diamonds, classified as being diamonds with no detectable nitrogen using FTIR methods (<5ppm). Type I diamonds are defined as diamonds with detectable nitrogen and are sub-divided according to whether or not the nitrogen is single substitutional, or accommodated in lattice vacancies as paired or four nitrogen atoms. The focus of interest in this abstract are the Type II diamonds, and the discussion largely centers around Type I and Type II as though the two categories are mutually exclusive. That is not in reality the case. It is quite common for the lithospheric Type I diamonds to have growth zones without nitrogen (Harte et al 1999) and similarly with largely nitrogen free Type II diamonds there can be zones of diamond with detectable nitrogen (Hutchison et al 1999). It is unclear what is controlling the nitrogen content in both cases. However these overlapping situations do not dominate the current discussion of either Type I or Type II crystals. It does raise the possibility that there could be more than one paragenesis for Type II diamonds and that the large resorbed nitrogen free stones that are the subject of this abstract are simply one of several populations. This population is visually recognizable on the basis of shape, colour and surface texture with more than 90% certainty. (Bowen et al, 2009).

ABUNDANCE

Diamonds containing nitrogen (Type I) are estimated to have an abundance of 98% dominating natural diamond populations world-wide (Tappert and Tappert 2011). Clues to the origins and age of these diamonds can be obtained from the nitrogen content, distribution and particularly degree of aggregation. The latter characteristic in conjunction with other observations such as the geochemical (including isotopic) compositions of diamond inclusions supports strongly the ancient origins of the majority of Type I crystals, particularly gemstone diamonds.

Type II diamonds on the other hand comprise only 1% to 2% of the world's diamonds and the lack of detectable nitrogen means that less has been deduced about their origins.

SIZE

Type I diamonds may reach considerable size. A good example is the Kimberley Octahedron, a yellow diamond showing some resorption, which at 616 carats is the largest octahedron ever found, and currently the 14th largest gem diamond ever recovered. It was found at the Dutoitspan Mine in 1971 and is now on display at the Mine Museum in Kimberley, RSA. However the largest diamonds ever found are dominated by Type II crystals, in contrast to the low global abundance of Type II diamonds.

The largest single crystal gem diamond ever found is the Cullinan diamonds from the Premier (now Cullinan) found in 1905 and weighing 3,107 carats. The Cullinan has all the visual characteristics of a Type IIa diamond as do numerous other well publicized recoveries from this locality such as the Premier Rose (354 cts), the Centenary Diamond (599 cts) and most recently a 508 carat stone found in 2009. The Cullinan Mine is also noted for the occasional finds of rare blue Type IIb diamonds which contain boron and are semi-conductors as well as prized gemstones. Historically the long since (1971) defunct Jagersfontein Mine was also a noted and regular producer of visually recognizable Type II diamonds of which the Excelsior (995 cts) and the Jubilee (651 cts) are the most famous. Williams (1932) records that despite being a low grade ore body, Jagersfontein produced 54 diamonds larger than 200 carats in the period 1884 – 1930 including 6 over 500 carats.

The size dominance of Type II diamonds is well demonstrated at Letseng la Terai in N. Lesotho by the fact that Type II diamonds >10.8 ct constitute 38% (in carat terms) of the diamonds in the main pipe and 69% in the satellite pipe (Bowen et al 2007, Moore 2009). Chinn (2008) estimated that Type II diamonds constituted 25% by weight of the diamonds in the AK-6 pipe in Botswana.

CRYSTAL FORM

Type I gem diamonds range in crystal form from primary octahedra and cubes, which may have fibrous coats, to resorbed rounded dodecahedra and tetrahexahedra. Occasional broken stones often have inclusions. Twinned diamonds are sub-ordinate in abundance, as usually are polycrystalline aggregates, though these are common at some locations (e.g. Orapa).

Type II gem diamonds in contrast are highly resorbed crystals, never octahedra, often with fresh cleavage breaks and irregular form which appears to be the result of extensive resorption and susceptibility to cleavage. Only occasionally, where a crystal has a re-entrant feature that has been protected from the resorbtion episode (the host kimberlite?) can octahedral growth features be seen in a limited window.

COLOUR

The relevant facts about colour with respect to Type IIa diamonds are that because they have no nitrogen and are particularly pure carbon, they frequently receive the very best colour grading for jewellery purposes (D on the GIA scale: essentially completely colourless). The common exceptions to this occur when Type IIa diamonds are subjected to stress during their residence in the earths interior when they readily deform by virtue of developing slip planes and become brown or occasionally pink. Type IIa diamonds never become yellow. Type IIb diamonds are blue due to the presence of boron or brown or grey when deformed and also are never yellow. Type I diamonds in comparison may be visually colourless, but seldom are D colour and frequently are brown or yellow. In Ib diamonds the nitrogen is incorporated in the diamond lattice and the diamond acquires a distinctive canary yellow colour. Since substitutional nitrogen readily migrates under mantle storage conditions very few natural diamonds are Ib variety (~0.1%). Predominantly Type I diamonds are classified as IaA and IaB or mixtures of both. IaA diamonds have paired nitrogen in lattice vacancies and IaB diamonds have four nitrogens in lattice vacancies. Neither arrangements has a colour implication. Yellow colour is imported by the presence of N3 centers, and may be common (e.g. at Finsch Mine, RSA and Ellendale, WA).

SURFACE FEATURES: A BRIEF COMPARISON

Type II diamonds, particularly the larger crystals, have been produced by a resorbtion process that proceeds very evenly over the entire outer surface removing all primary crystal faces and by-passing the dodecahedral and tetrahexahedral face development often seen in Type I diamonds. Trigons are rare, as are hexagonal pits, hillocks, and other corrosion sculptures seen commonly on Type I diamonds. Deformation lines etched on the surfaces of brown Type II diamonds and associated with plastic deformation are, however, common, reflecting the particular susceptibility of Type II diamonds to this process in comparison to nitrogen bearing diamonds. Related to this property is the propensity for Type II diamonds to cleave relatively easily, with the result that breakage surfaces are more common than in Type I diamonds.

VALUE

Whilst large gem quality diamonds have always been prized for their value, that appreciation has been accentuated in recent years. This is best illustrated by prices paid for large Type II diamonds in the past 5 years.

At the Cullinan Mine in 2009 a 508 carat diamond realized US35.3 million. In 2010 a Type IIb diamond was sold for over US$1 million per carat.

At Letseng la Terai published data shows over 85% of the mine revenue is derived by Gem Diamonds from the sale of diamonds larger than 5 carats, predominantly Type IIa (Bowen et al 2007). Monthly sales values per carat have reached >$3,000/ct, with the best diamonds sold for more than US$50,000/carat. In 2006 the Lesotho Promise (603 cts) was sold for US$12.4 million and more recently the Lesotho Legacy realized US$10 million. Such returns have made it economically viable to operate an open-cast mining operation in difficult mountain terrain with recovered grades of under 2 carats of diamonds per 100 tonnes of kimberlite. At present market prices 1 carat of D colour Type II diamonds / 100 tonnes of ore can be a viable mining operation.

ECONOMIC IMPLICATIONS

The presence of D-colour large Type II diamonds in a deposit can be a mine-maker in that the presence of one 20+ carat diamond in 50,000 tonnes of host rock can convert to revenue in excess of US$20 / tonne of rock mined, which in some cases is close to mine operating cash flow costs. Consequently in the evaluation stage of a diamond deposit it would be advantageous to be able to predict the presence, size and abundance of Type II crystals. At present the only way to do that is to take a very large bulk sample such as is currently under way at the Mothae Kimberlite in N Lesotho by Lucara Diamonds.

DISTRIBUTION OF TYPE II DIAMONDS

The distribution of Type II diamonds is poorly recorded. The well known localities where they proliferate are or were Cullinan, Letseng la Terai and Jagersfontein all in southern Africa. However there are references in the literature to Type II occurrences in several Lesotho kimberlites, in particular at Mothae and Kolo, in South Africa (Koffiefontein, Bellsbank), Botswana (AK6, Jwaneng, Orapa), West Africa, India and South America. The recently recovered Spirit of Ekati from the Ekati Mine in the NWT, Canada and the Star of Sierra Leone have the visual appearance of a Type II diamond. So these important diamonds have a wide global footprint.

DISCUSSION

Considering that the presence or absence of Type II diamonds can be a critical factor when assessing or mining a diamond deposit, their origins are poorly studied and not clearly understood. Carbon isotope studies on Type II diamonds from the Cullinan Mine (Milledge et al 1983) suggest an origin from an eclogitic source of subducted ancient sea floor, but in a different event to that of the lithospheric, eclogitic Type I diamonds from the same diatreme (Moore 2009). At Letseng la Terai McDade and Harris (1999) identified six small Type IIa diamonds as having a lithospheric peridotitic mantle source based on combinations of olivine, orthopyroxene, garnet and chromite inclusions in the diamonds plus one example of ferro-periclase of possibly ultra-deep origin (e.g. Harte 2009). Type IIa brown diamond with ferro-periclase as an inclusion has also been identified from KanKan in Guinea (Tappert & Tappert 2011 p118). Ferro-periclase has been noted as a common mineral inclusion in diamonds from the Sao Luiz/Juina deposit where Type II diamonds are very abundant (Harte et al 1999). Moore (2009) in contrast argues for Type II diamond formation in evolved lithospheric low temperature pegmatitic megacrysts magmas closely associated with the kimberlite event itself, followed by the crystallization of framesite and fibrous cubic diamonds. These various scenarios leave all options open as far as the processes that produce Type II diamonds are concerned. They could be ultra-deep, lithospheric, peridotitic, eclogitic, ancient and related to major tectonic events or young and related to the ultra basic host magma that transports them from the mantle.

Given the lack of definitive evidence, some speculative comments can be justified.

Firstly the large Type II gemstones are without exception highly resorbed crystals with no significant remnant original surfaces surviving despite the large size and exceptional purity of the crystals. As with all diamonds, some if not all of this resorption has taken place after plastic deformation where the latter has occurred. The magnitude of the resorption is exceptional, perhaps due to early liberation from the host rock in which the diamonds actually formed, and the consequent longer than average subjection to the resorbtion effects of the host magma en route to surface. At Letseng la Terai and Mothae less than 1% of all the diamonds are octahedral, so that the Type II resorbtion is only distinguishable by being more extreme than the dominant rounded dodecahedral form of the Type I diamonds from the same locality However elsewhere (e.g. Ekati) a high proportion of the run-of-mine production is octahedral, yet the Spirit of Ekati is anhedral. Cullinan Mine and AK6 in Botswana both also have diamonds with a wide variety of crystal forms ranging from octahedra to stronger resorbed forms. Yet the Type II crystals are uniformly irregular and anhedral.

Type II diamonds define a size distribution that is distinctive from the run-of-mine size distribution. This suggests a separate origin for the Type II diamonds. However a connection with the megacryst magma appears very unlikely. Only as the magma cools does it approach the diamond stability field P/T regime, at which stage the precipitating minerals are phlogopite, zircon, ilmenite, a clinopyroxene and possibly a carbonate. None of these minerals, nor any other megacrysts components have ever reported as inclusions in any diamonds. The further linkage (Moore 2009) with framesites, fibrous cubes and some eclogitic components are speculative and have no logical connection with Type II diamonds.

World-wide although numerous lithospheric eclogite xenoliths and some peridotites have been discovered to have diamonds, none of them have been Type II populations and so it would seem that whilst Type II diamonds have some tenuous connections established with both eclogite and peridotite, they may not be of lithospheric origin, but may be derived from a process associated with megalith development at the upper mantle / lower mantle boundary region and the uppermost lower mantle as proposed for some diamonds from a range of localities by Harte 2010.

CONCLUDING REMARKS

Given that they constitute <2% of the world's diamonds, Type II crystals are over-represented in the world's largest known gem diamonds. Their distinctive appearance, great purity and lack of association with lithospheric source rocks leaves open the possibility that they are sub-lithospheric in origin. Since no xenoliths have been reported to survive to the earth's surface from such depths (600km – 800km), the most likely source of additional information on the diamonds origins is through diamond inclusions.

Whilst Type II diamonds constitute only a minor proportion of natural diamonds world-wide their importance is greatly enhanced by the exceptional value of undeformed large Type II crystals. In exploration a better understanding of their origins and geographic distribution would be useful, whilst in mining size distribution is a major concern if the largest crystals are to survive in the mining and recovery processes.

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