Although diamonds have been mined from kimberlite pipes for more than a century, the precise origin of diamond has been a matter of debate. One of the key questions has been whether diamond is simply an accidental inclusion from deep in the mantle or whether diamond formation is associated spatially and temporally with kimberlite genesis — that is, are diamonds phenocrysts or xenocrysts in their host volcanic? A better knowledge of the origin of diamond is essential for both scientific and economic reasons, especially since the discovery of diamonds in lamproite at Argyle and Ellendale (WA) has confirmed that rocks which differ from the classical kimberlites of southern Africa may also carry diamonds at commercial grades (see BMR Research Newsletter 1, p. 10). The extraordinarily rich grade of the Argyle pipe has established Australia as a major producer of diamonds.

Recent research advances

Major advances in understanding diamond genesis in recent years have come from studies of primary (syngenetic or protogenic) mineral inclusions in diamond — i.e., minerals formed during or before diamond formation, and encapsulated in the diamond during growth. Perhaps the most important of these advances has been made by isotopic dating of syngenetic inclusions in diamonds by the U-Pb, Sm-Nd, and Rb-Sr methods. Until recently such determinations were precluded by the very small size (commonly 100 microns or less) and extremely low concentrations of REE and Rb in such inclusions. In pioneering research, Kramers (1979: Earth and Planetary Science Letters, 42, 58–70) obtained a model Pb age >2000 Ma for sulphide inclusions in diamonds from Cretaceous (90 Ma) kimberlites in southern Africa, and demonstrated a xenocrystal relationship between them. More recently, Richardson & others (1984: Nature, 310, 198–202) obtained model Sm–Nd and Rb–Sr ages of 3200–3300 Ma for subcalcic chrome pyrope inclusions of peridotitic paragenesis in diamonds from these kimberlites. In a second paper, Richardson (1986: Nature, 322, 623–626) described pyrope-almandine garnets and omphacitic clinopyroxene inclusions belonging to the eclogitic paragenesis from the Precambrian (1200 Ma) Premier kimberlite and Argyle lamproite, and documented Sm–Nd isotopic ages of 1150 and 1580 Ma respectively. These ages and the isotopic signatures differ considerably from those of the peridotitic inclusions analysed from the Cretaceous kimberlites, and appear to indicate a closer association of eclogitic diamonds and kimberlite and lamproite magmatism.

Another advance has come from studies of the mineral chemistry of syngenetic inclusions, and the application of experimentally calibrated geothermometers and geobarometers to these studies, thereby enabling estimates to be made of the pressures and temperatures of formation. Such estimates may then be compared with the established stability field of diamond and P–T

(continued on p.15)
Long-lived instability as a possible control of mineralisation in northeast Queensland

Epithermal-type and other mineral deposits associated with ignimbrite-dominated sequences similar to those developed during the late Palaeozoic in northeastern Queensland are likely to have been emplaced after major eruptive stages (e.g., Lipman, 1984: *Journal of Geophysical Research*, 89(B10), 8801–8841). One of the critical factors in maximising opportunities for mineralisation appears to be the occurrence of zones selectively dominated by steep faults with or without intrusions, of recurrent structural instability.

This article describes features indicative of such unstable margins of the Mount Mulligan area of northeastern Queensland (Fig. 19), and outlines the implications of these features for mineral deposit potential in this and other areas of northeastern Queensland. The research is part of a continent-wide exploration effort in eastern Australia, particularly focused on the evolution and its relevance to mineralisation in the region, and has been undertaken within a framework of regional mapping by GSQ.

### Setting

Apparently Lower Permian sequences of Feath•ered Volcanics comprising voluminous welded ignimbrites in the Nychum (Fig. 7) and Mount Mulligan areas of northeast Queensland have been interpreted as the result of tectonomagmatic evolution and its relevance to mineralisation in the region, and has been undertaken within a framework of regional mapping by GSQ.

Diamond genesis *(continued from back page)*

estimates obtained from diamondiferous peridotites and eclogites. These data, when combined with other data and with the model presented in this paper, indicate that the continental lithosphere beneath the Kaapvaal craton of southern Africa was stabilised to depths within the diamond field (150–200 km) in Archaean times.

Syngenetic mineral inclusions in diamonds are, therefore, able to provide important information on the nature, structure, and thermal history of the deep subcontinental lithosphere. Such information is obtained in diamond because of the extremely rare occurrence of inclusions even in mantle rocks, hence allowing the exploration of the mantle roots themselves, and the relationship with the surficial geology is, therefore, of importance to diamond exploration.

### Towards a model for the genesis of WA diamonds

Collaborative studies by scientists from BMR, CRA Exploration Pty Ltd, GSWA, and ANU over the past five years have centred on the Argyle and Ellenbrook diamond deposits, which are hosted in lamproite of contrasting ages (1200 and 20 Ma respectively) within Precambrian mobile belts surrounding the Kimberley Block. These studies (recently published as *GSWA Bulletin* 132) have shown that the lamproites and lamproite-hosted diamonds have many features in common with diamondiferous kimberlites from southern Africa, but that there are important differences. A major difference is that diamondiferous intrusions in Western Australia are located at or near the margin of the Kimberley Block (Fig. 20); these would be considered ‘off craton’ in relation to the southern Africa diamondiferous pipes.

Data from petrological and geochemical studies support a model whereby the Western Australian lamproites are derived from subcontinental partial melting within the diamond stability field of ancient, formerly refractory (i.e., chemically depleted in basaltic components, and possibly residual after early Precambrian tholeiitic basalt extraction) subcontinental lithosphere which has undergone long-term (>2000 Ma) enrichment in incompatible elements (K, Rb, Sr, Th, U, Nd, Zr, LREE, etc, high Rb/Sr, low Sm/Nd). This geochemically enriched lithosphere was reactivated in a series of Proterozoic-Mesozoic Mantle enrichment at about 2000 Ma correlates with a major crustal accretion event(s) now recognised in northern Australia.

The early development of enriched subcontinental lithosphere (250–150 km) beneath the Proterozoic mobile belts in Western Australia is similar to but apparently younger than that documented for the Archaean Kaapvaal craton. In addition, the chemical depletion in basaltic components in the Kimberley Block appears to be less extreme than that in the Kaapvaal craton, where diamonds are associated with garnet harzburgite and a relationship has been demonstrated between the diamond and garnet paragenesis composition. No such relationship has been found for the Australian deposits, where lherzolite appears to be the dominant rock type of the subcontinental lithosphere.

The apparent similarity of the P-T estimates for diamondiferous peridotites from both the Argyle pipe and southern Africa indicate either that the lithospheric roots beneath the mobile belts are overthickened (relative to the centre of the Kimberley Block), or, more likely, that early (1800 Ma) cratonisation of the mobile belts has resulted in craton-type (up to 200 km) lithosphere thickness over much of Proterozoic northern Australia. While the second interpretation is critical to the long-lived nature and potential for diamond, successful prospecting of such large areas requires better knowledge of the subcontinental lithosphere in order to delineate the more favourable regions.

An additional complication to the model outlined above (viz. that diamonds form in refractory lithospheric roots) is that diamond may have more than one origin. Further evidence to support a dual or multiple origin of diamonds has come from studies of the Argyle diamonds. In a study of the mineral inclusions and the carbon- isotope composition of the host diamond from Argyle we have recently found a relationship between diamond morphology, inclusion paragenesis, and C isotopic composition. Sharp-edged octahedral diamonds have eclogitic inclusions, and diamonds without such inclusions have 12C-depleted signature (Fig. 21). The sharp- edged octahedral diamonds have very similar morphology to diamonds found in peridotitic xenoliths from Argyle, suggesting that they are of eclogitic composition. The diamonds of eclogitic paragenesis clearly have a different origin, and may differ in age from their peridotitic counterparts; their 12C-depleted compositions, and the genesis of their inclusions, suggest that they may have formed from recycled crustal material.

The significant advances made in the past few years in understanding both diamond formation and the nature and thermal history of the subcontinental lithosphere demonstrate that diamonds have the potential to store unique information about the complex history of the mantle through geological time. This information when integrated with geophysical parameters, such as could be obtained by deep seismic profiling, will provide us with a much clearer understanding of both the nature and thermal history of the subcontinental lithosphere.

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