# OCCURRENCE AND STABILITY OF DIAMOND-BEARING ASSEMBLAGES IN ULTRAHIGH-PRESSURE METAMORPHIC ROCKS

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**Introduction:** Diamond and coesite as ultrahigh-P (UHP) minerals have long been recognized in kimberlite pipes (e.g., Mitchell, 1987) and meteorite craters (e.g., Chao et al., 1960). In deep cold subduction zone to mantle depths, supracrustal rocks and associated ultramafic/mafic slices were subjected to ultrahigh-P metamorphism at mantle pressures greater than ~25 kbar (~ 80-90 km). The resultant mineral assemblages depend, of course, on compositions of the protoliths. When bulk chemistry is appropriate, UHP metamorphism at such depths produce coesite, microdiamond, and other characteristic minerals (e.g., Chopin & Sobolev, 1995). Thus far, at least eight coesite-bearing terranes and four diamond-bearing UHP regions have been documented (for reviews, see Liou et al., 1994; Coleman & Wang, 1995).

**Occurrence:** Occurrence of microdiamonds in crustal gneisses in Kazakhstan has long been reported in the early 1970's (e.g., Rozen et al., 1972; 1973). However, its significance as UHP origin was not fully understood until microdiamond inclusions in zircons and garnets of the Kokchetav massif were documented by Sobolev and Shatsky (1990). Subsequently, microdiamonds were reported as inclusions in garnets from eclogite, garnet-pyroxenite and jadeitite in the Dabie Mountains of central China by Xu et al. (1992), in residues separated from Western Gneiss Region gneisses of Norway (Dobrzhinetskaya et al. 1993), and in garnet clinopyroxenite from the Beni Bousera massif (Pearson et al. 1989, 1993).

The Kokchetav diamond-bearing carbonates contain abundant dolomite (>70 vol%), garnet, diopside, and minor phlogopite; inclusions of diamond, dolomite ± graphite, biotite and clinopyroxene occur in garnet. Magnesite has also been reported; no coesite or coesite pseudomorph was found in the UHP marbles. Hence, diamond + diopside + dolomite + magnesite + garnet assemblage must have formed at P > 40 kbar and T >900-1000°C. The associated diamondiferous biotite garnet gneisses, on the other hand, contain coesite pseudomorph in garnet and coesite in zircon. Diamond has not been found in metabasaltic eclogites; inclusions of coesite pseudomorph were also identified.

Graphitized diamonds have been recently described in two garnet clinopyroxenite layers > 2 m thick from the Beni Bousera massif, north Morocco (Pearson et al., 1989, 1993). Some of these peridotites contain up to 15% graphite, several of the graphite octahedra contain faceted inclusions of garnet and clinopyroxene. Their occurrence constrains the depth of origin for pyroxenites to be in the diamond stability field (> 45 kbar and T of ~1100°C). Diamond apparently is stable with enstatite + diopside + olivine.

**Phase Relations:** In order to understand the paragenetic relations of diamond and its associated phases in carbonate, eclogite, and ultramafic rocks, $f_{O_2}$ - T - P stabilities of diamond, coesite, enstatite, forsterite, graphite, magnesite and dolomite in the system CaO-MgO-$SiO_2$-C-$O_2$-$H_2O$ were calculated. This was accomplished using non-ideal mixing of $CO_2$-$H_2O$ and the data set by Holland and Powell (1990). Isobaric $f_{O_2}$ - T relations at constant $X_{CO_2} = 0.1$ were calculated at P = 40, 50, 60, 70 and 80 kbar. At the UHP metamorphic regimes with geothermal gradient of 5 - 10 °C/km, diamond is restricted to P between 30 to 60 kbar. Diamond is stable at wide $f_{O_2}$ field at lower P (e.g., 40 kbar) whereas it is restricted to very reduced condition at high P (e.g., 60 kbar). An example of our calculated phase relations for this system at P = 50 kbar and $X_{CO_2} = 0.1$

| Diamond-bearing Assemblages | Divariant log $fO_2$-$T$ field high ← (log $fO_2/T$) → low | | | | | Bulk rock compositions* | | |
|---|---|---|---|---|---|---|---|---|
| | [6] | [7] | [8] | [9] | [10] | M | U | C |
| Co-Do-Ms-Dm | | | | | | | | + |
| Co-Di-Ms-Dm | | | | | | | | + |
| Di-Do-Ms-Dm | | | | | | | | + |
| Di-En-Ms-Dm | | | | | | | | + |
| Co-Di-En-Dm | | | | | | + | | |
| Di-En-Fo-Dm | | | | | | | + | |
| Di-Fo-Ms-Dm | | | | | | | | + |
| Di-Do-Fo-Dm | | | | | | | | + |
| Do-Fo-Ms-Dm | | | | | | | | + |
| $P$=40 kb | | | | | | | | |
| $P$=50 kb | | | | | | | | |
| $P$=60 kb | | | | | | | | |
| $P$=70 kb | | | | | | | | |
| $P$=80 kb | | | | | | | | |

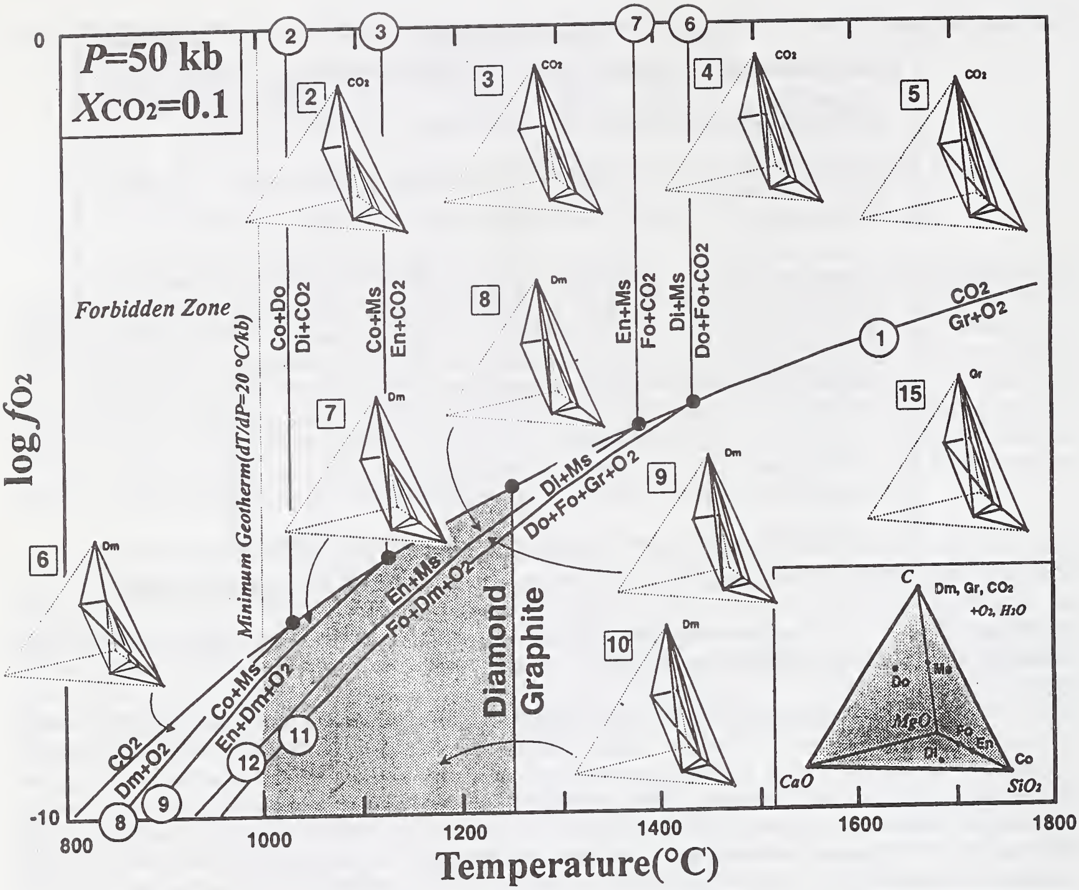
M: Mafic, U: Ultramafic, & C: Carbonate Composition in the model system

is shown in Fig. 1. Possible diamond-bearing assemblages for model mafic, ultramafic and carbonate rocks are listed in the above Table.

It is apparent that diamond is not common in mafic and ultramafic compositions which respectively have coesite + diopside + diamond + enstatite and diamond + forsterite + enstatite + diopside. Diamond-bearing assemblage in eclogites occurs at P > 60 kbar whereas that in garnet pyroxenite is stable at P > 70 kbar. The formation of diamond with coesite + diopside + enstatite in eclogitic rocks may be controlled by a reaction coesite + magnesite = enstatite + diamond + $O_2$; the formation of diamond with diopside + enstatite + forsterite in lherzolite may be controlled by a reaction enstatite + magnesite = forsterite + diamond + $O_2$. The former reaction occurs at slightly higher $f_{O2}$ conditions than the later reaction, consistent with previous suggestions (e.g., Luth, 1993).

On the other hand, diamond occurs in a variety of carbonate assemblages and is stable in a wide $f_{O2}$-T-P stability field; naturally, different diamond-bearing assemblage is stable in different condition. For example, diamond-coesite-dolomite-magnesite is restricted to P < 45 kbar and higher $f_{O2}$ conditions compared with wider stability field for diamond + dolomite + diopside + magnesite assemblage. Diamond + forsterite association occurs at much higher P in carbonate rocks.

**Discussion:** The calculated results shown in Fig. 1 should be considered to be preliminary as thermodynamic properties of these phases at UHP conditions are extrapolated and the calculated program may involve a large uncertainty. Moreover, introduction of other components and other phases, particularly for mafic compositions, will significantly modify the phase relations. Nevertheless, the calculated results summarized in Fig. 1 and Table 1 conclude the followings: (1) The observed diamond-bearing assemblage in the Kokchetav marble is stable at P > 50 kbar and does not contain coesite; (2) At the estimated P-T conditions for the Kokchetav UHP rocks, mafic eclogite may not have diamond-bearing assemblage; (3) The observed diamond-bearing ultramafic assemblages for the garnet pyroxenite from the Beni Bousera massif must have occurred at P> 60 kbar and low $f_{O2}$ conditions; and (4) the reported diamond inclusions in garnet of coesite-bearing eclogitic rocks from the Dabie UHP terrane of central China remain to be confirmed as their associated impure marbles lack of diamond-bearing assemblages and independent P estimates less than 60 kbar.





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