Diamond from the Dabie Shan Metamorphic Rocks and Its Implication for Tectonic Setting

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Diamond occurs in ultrahigh pressure metamorphic rocks from Dabie Shan, Anhui Province, eastern China. Diamond-bearing rocks include eclogite, garnet-pyroxenite, and jadeitite. Diamond occurs in a mineral assemblage with coesite and jadeite. The diamonds and diamondiferous rocks of Dabie Shan are interpreted to be the products of ultrahigh pressure metamorphism in the underthrust basement of the Yangtze continental plate during the early Mesozoic, at greater than 4.0 gigapascals and 900°C. This interpretation is based on the distribution of rock units, the stability field of diamond, and isotopic data indicating a crustal origin for the rocks. Most diamonds occur as euhedral inclusions in garnets and are 10 to 60 micrometers across, although some are up to 700 micrometers across.

Formation of diamond requires high pressures and temperatures; thus, its presence in crustal metamorphic rocks has important implications for tectonic models of metamorphism in that burial of crustal rocks to great depths is required. Diamond in crustal rocks had been found only in Koktachev Massif, northern Kazakhstan, Soviet Union (*1*). We have found a second occurrence of diamond of metamorphic origin, as shown by the presence of associated coesite and jadeite, in Dabie Shan, China. Dabie Shan forms the eastern part of Qingling orogen in central China, and is transected at the east end by Tan-Lu fault zone. Eclogite facies metamorphic rocks are distributed over an area of more than 1000 km^2 in Dabie Shan (Fig. 1). Rock types include eclogite; garnet-pyroxenite; and rare jadeitite bands, lenses, and nodules (with length from centimeters to hundreds of meters) intercalated with or enclosed within leucocratic gneisses and marbles. A few of the eclogite bands are intercalated with garnet-peridotite or enclosed in other ultramafic rocks. Diamonds are found as inclusions in garnets in these rocks.

More than 20 diamond crystals were found in polished thin sections. They all occur as inclusions in garnets. Most are 10 to 60 μm across, but some larger grains up to 240 μm were also found. Diamond crystals in thin section are typically euhedral octahedra (Fig. 2A), but a few are cubes (Fig. 2B) or dodecahedra. In addition, more than 20 diamond grains were extracted from rock samples for analysis. Most of these are cubes and octahedra (Fig. 2C), but a few are tetrahedra (Fig. 2D). These diamonds have diameters around 150 μm, although one is 700 μm. Features such as rouded (Fig. 2A), imbricated (Fig. 2C), and laminar or curved striated (Fig. 2, B and C) crystal faces are visible. Identification of diamond was made by optical microscopy at first, then by x-ray diffraction (Fig. 3A) and Raman spectroscopy (Fig. 3B) on a 0.1- to 0.3-mm-thick polished thin section. The slight deviation of the peak of the tested diamond in Fig. 3B (1310 to 1320 cm^{-1}) from that of a given free diamond crystal (1330 cm^{-1}) is believed to be due to the local pressure (*2*, *3*) supplied by the host garnet in thin section. Extracted diamond crystals were identified by x-ray diffraction with triaxial Gandolfi camera (designed by Zhang Hanqin). The principal peaks were observed at 2.06 Å (100), 1.26 Å (60), 1.075 Å (50), 0.892 Å (50), and 0.819 Å (60) (*4*) (numbers in parentheses indicate relative intensity of peaks).

The common mineral assemblage of eclogite is omphacite + garnet + kyanite + zoisite + phengite + rutile + titanite + zircon. Amphibole, coesite, jadeite, diamond, quartz, calcite, and graphite are also present, as are a few plagioclase grains in some samples. Garnet-pyroxenite is distinguished from eclogite by the presence of diopside instead of omphacite. Jadeitite occurs as lenticular bodies (~0.3 km^2) surrounded by jadeite-bearing gneiss near some of the eclogite bodies and is composed mainly of (50% or more) jadeite (with a composition of 85% $NaAlSi_2O_6$, Table 1) + quartz + garnet (Fig. 4A). Most jadeite grains are altered to symplectite composed of plagioclase and minor amphibole. Coesite or quartz pseudomorphs of coesite are common as inclusions in garnet in all the diamondiferous rocks (Fig. 4B). Rutile, zircon, titanite, graphite, and in some cases barroisite occur as inclusions in garnets as well. Most garnets from the diamondiferous rocks are almandine and grossular-rich (Table 1); a few may be knorringite (a garnet rich in Mg and Cr) (Fig. 3A), but this remains to be proved by compositional analyses. Omphacite in eclogite is characterized by moderate Al_2O_3 and Na_2O contents, and diopside in garnet-pyroxenite has low Al_2O_3 contents.

Three generations of mineral growth are

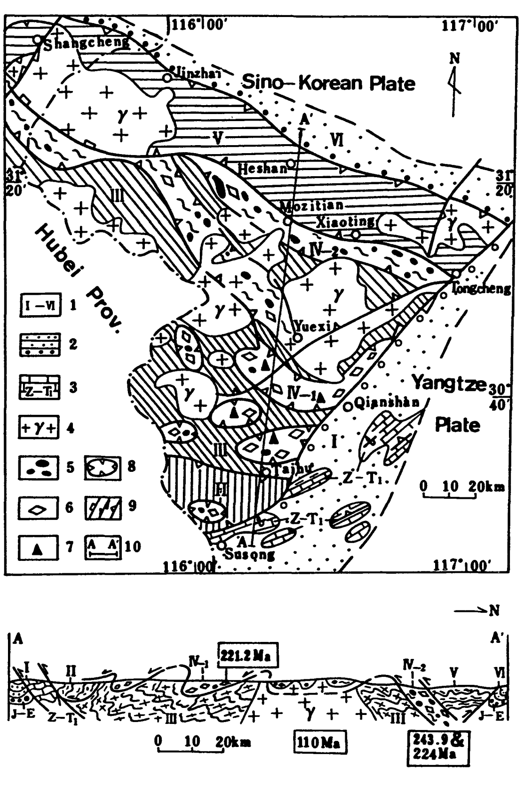

Fig. 1. Geologic sketch map and cross section of Dabie Shan. Symbols are: 1, Tectono-petrologic units (shown by roman numerals): I, Foreland belt including folded and thrust unmetamorphosed rocks of Sinian to early Triassic age, and Mesozoic molasse; II, rocks of greenschist facies of the underthrust cover; III, rocks of amphibolite facies of the underthrust basement of Yangtze continental plate; IV_{-1}, rocks of eclogite facies over the underthrust basement; IV_{-2}, root zone of the mélange; V, forearc flysch nappe of greenschist facies; VI, Mesozoic successor basin. 2, terrestrial sediments of middle Triassic to Tetiary age; 3, unmetamorphosed cover of Sinian to early Triassic age; 4, granite; 5, ultramafic rock body; 6, ultrahigh pressure metamorphic rock; 7, locality of diamond and diamondiferous rocks; 8, nappe; 9, faults; and 10, locality of cross section.

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evident in the rocks. The first is represented by crossite and barroisite inclusions, which formed during early greenschist-amphibolite facies metamorphism and were preserved as relics during subsequent metamorphism. The third generation is represented by mainly plagioclase, amphibole, biotite, quartz pseudomorph after coesite, and minor chlorite, graphite, and calcite. These phases are retrograded products that formed during amphibolite-greenschist facies metamorphism; they occur on crystals of the

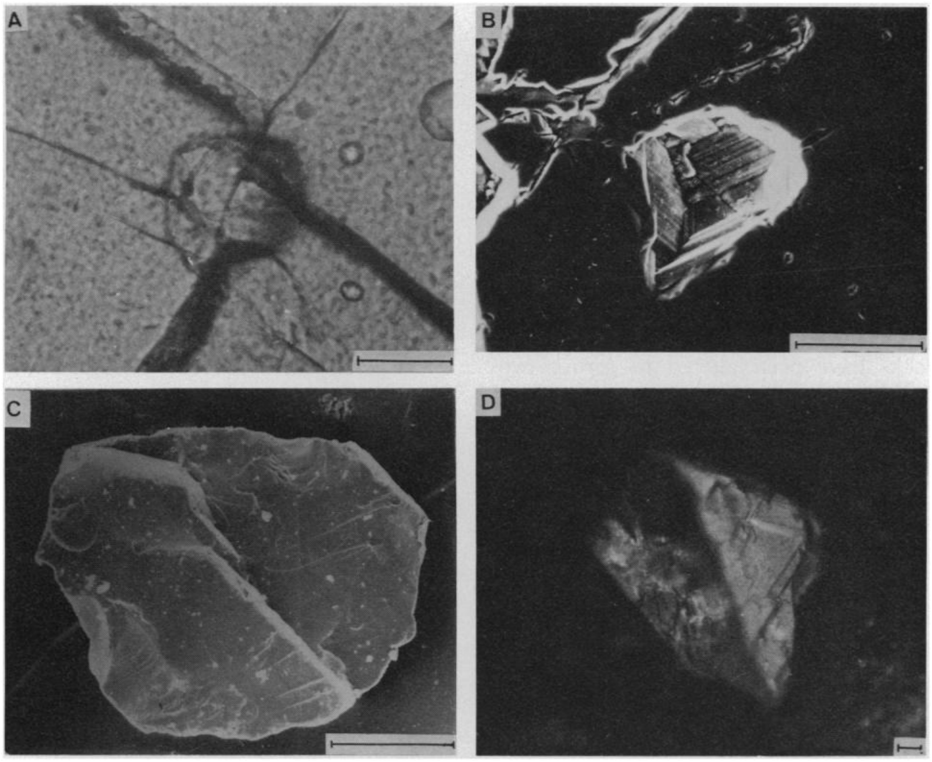

Fig. 2. Photos of diamond crystals. (**A**) Octahedral diamond inclusion in garnet in thin section, with rounded crystal faces. (**B**) Cubic diamond inclusion in garnet in thin section, with laminar growth on crystal faces. (**C**) Octahedral diamond crystal extracted from a rock sample of eclogite, with imbricated crystal face. (**D**) Tetrahedral diamond crystal extracted from a rock sample of garnet-pyroxenite, with curved striated crystal faces. The scale bar is 0.05 mm for all photographs.

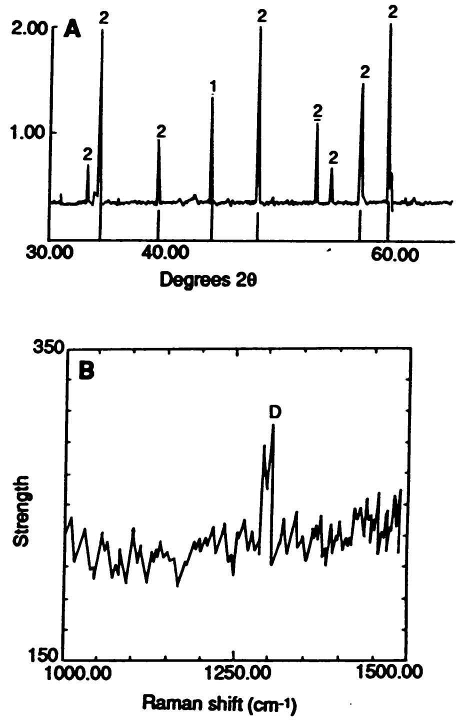

Fig. 3. (**A**) X-ray diffraction pattern of a diamond inclusion in garnet on a polished thin section. Vertical axis gives counts per second. (**B**) Raman microprobe spectrum from a diamond inclusion in garnet on a polished thin section; D is diamond peak.

Table 1. Mineral analyses (using Electron Microprobe JEOL 733) of representative samples from diamondiferous rocks from Dabie Shan; gt, garnet; omph, omphacite; cpx, diopside; amph, amphibole; bi, biotite; ph, phengite; parg, pargasite; jd, jadeite.

Component	Eclogite (233-1)		Garnet-pyroxenite (574-4)			Eclogite (574-3)			Jadeitite (547-4)	
	gt	omph*	gt*	cpx	amph†	gt*	bi†	ph†	parg†	jd*
SiO_2	37.49	55.01	36.51	55.98	39.95	37.36	34.35	45.96	40.36	58.05
TiO_2	0.09	0.10	0.05	0.01	0.15	0.09	2.24	0.39	0.18	
Al_2O_3	21.35	10.79	20.77	3.44	9.93	20.58	16.50	27.88	16.60	21.07
FeO	22.82	4.48	17.84	1.70	12.80	18.33	13.40	2.19	11.10	4.36
Mn	0.45	0.03	0.45		0.23	0.52	0.04		0.13	
MgO	3.11	8.53	4.68	15.41	13.33	4.34	14.65	3.66	11.15	0.76
CaO	13.71	13.46	17.26	22.95	12.40	16.70	0.01	0.02	10.75	1.68
Na_2O	0.04	6.32	0.01	2.24	1.98	0.01	0.11	0.15	3.29	12.66
K_2O				0.04	1.25		10.02	10.37		
Total	99.06	98.71	97.57	101.77	92.02	97.93	91.32	90.62	93.56	98.58
Oxygen	12	6	12	6	23	12	22	22	23	6
Si	2.970	1.983	2.908	1.845	6.361	2.961	5.360	6.486	6.140	2.023
Ti	0.006	0.002	0.003		0.018	0.005	0.236	0.041	0.021	
Al	1.994	0.459	1.950	0.134	1.862	1.924	3.035	4.637	2.980	0.864
Fe^{2+}	1.461	0.135	1.190	0.047	1.706	1.216	1.750	0.259	1.414	0.127
Mn	0.031	0.001	0.030		0.031	0.035	0.005		0.017	
Mg	0.367	0.458	0.556	0.726	3.160	0.513	3.410	0.770	2.532	0.040
Ca	1.162	0.521	1.475	0.810	2.120	1.420	0.002	0.003	1.756	0.063
Na	0.007	0.443	0.002	0.143	0.611	0.002	0.033	0.041	0.971	0.854
K				0.002	0.255		2.036	1.871		
Sum	7.998	4.002	8.114	3.743	16.124	8.076	15.894	14.477	15.831	3.971
Fe/(Fe + Mg)	79.9	22.8	68.2	5.8	35.1	70.3	33.9	25.2	35.8	76.1

*Some elements were not included in the microprobe analyses. †The low totals are due to the hydroxyl contents.

second generation. Most of the rest of the mineral assemblage are of the second generation, which is believed to be produced under an ultrahigh pressure metamorphism of eclogite facies.

Isotopic analyses (Sm-Nd) have been reported from eclogite garnet-pyroxenite and provide constraints on the age of metamorphism and origin of the rocks. Three analyses yielded formation ages of (i) 243.9 ± 0.2 million years ago (Ma) (whole rock, garnet, and diopside) and an initial ε_{Nd} of −3.4 (*5*), (ii) 224.0 ± 20 Ma (three garnets of different color from three samples of a garnet-pyroxenite) and an initial ε_{Nd} of −5.4 (*6*), and (iii) 221.20 ± 142 Ma (whole rock, garnet, and omphacite) and an initial ε_{Nd} of −17 (*7*). The negative ε_{Nd} values imply that these rocks represent metamorphosed continental crust (*8, 9*); the ages imply that the ultrahigh pressure metamorphism occurred during the early Mesozoic. In consideration of the few associated ultramafic rock bodies, we consider that the rocks are part of a tectonic mélange that has a pervasively sheared matrix. To the north, the mélange is dominated by ultramafic rock bodies, and a few eclogitic rocks have been altered to garnet two-pyroxene granulite by subsequent depressurization. To the north, the mélange lies structurally beneath a forearc flysch of greenschist facies, which overlaps a successor basin further to the north. The eclogitic terrane was thrust southward onto the basement of amphibolite-facies and cover of greenschist-facies rocks, which are now in fault contact with a foreland belt in the Yangtze continental plate (Fig. 1).

Coesite, a high-pressure polymorph of SiO_2, is stable above 25 kbar at metamorphic temperatures and is known from Alps (*10*) and Scandinavian Caledonides (*11*). Coesite from Dabie Shan was deduced to be produced at a depth over 90 km and temperature around 750°C, or at a pressure of 28 kbar (*12, 13*). The metamorphic conditions now must be revised to pressures greater than 40 kbar and 900°C by the presence of diamond in the mineral assemblage (*14*). The data mentioned above indicate that the tectonic process of the ultrahigh pressure metamorphic rocks of Dabie Shan records a record of subduction of continental material to a depth of more than 100 km and of its subsequent rapid uplift to the surface (Fig. 5). Thus, Dabie Shan is evidently a collision orogen between two continental plates, and the area occupied by the diamondiferous rocks likely corresponds to the underthrust basement of Yangtze plate.

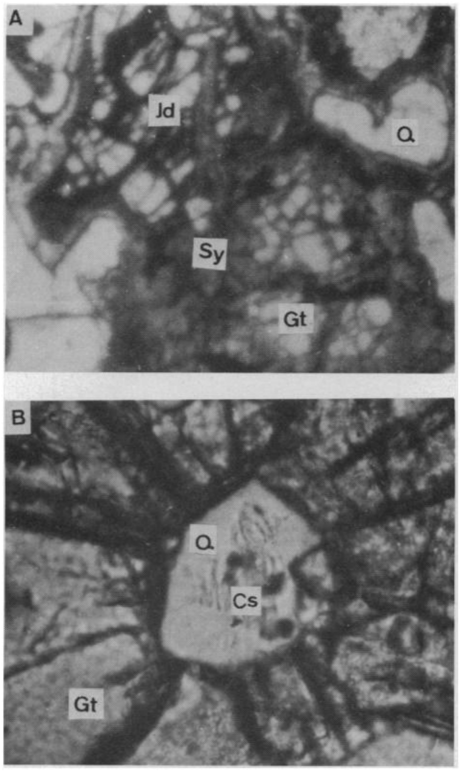

Fig. 4. Photos of jadeitite and coesite. (**A**) Jadeite (Jd) and its symplectite (Sy), and garnet (Gt) and quartz (Q) in jadeitite; single nicol. Width of image is 0.88 mm. (**B**) Coesite inclusion (Cs) and its quartz pseudomorph (Q) in garnet (Gt) with radial cracks, from eclogite, single nicol. Width of image is 0.09 mm.

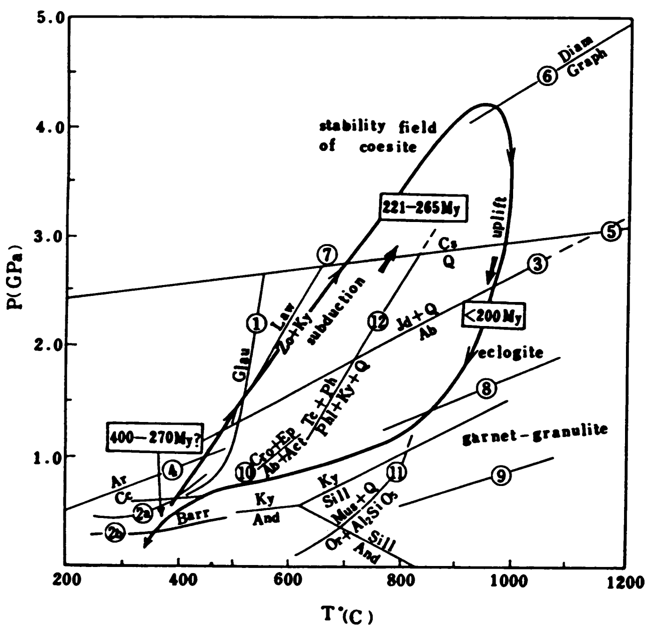

Fig. 5. A pressure-temperature-time path for the ultrahigh pressure metamorphic rocks of eclogite facies from Dabie Shan: 1, Stability field of glaucophane (*15*); 2a to 2b, stability field of barroisite (*16*); 3, transition between albite and jadeite + quartz (*17*); 4, transition between aragonite and calcite (*18*); 5, transition between coesite and quartz (*10*); 6, transition between diamond and graphite (*14*); 7, transition between lawsonite and zoisite + glaucophane (*19*); 8 to 9, garnet granulite field (*20*); 10, transition between crossite + epidote and acmite + albite + chlorite (*21*); 11, transition between muscovite + quartz and potassium feldspar + Al_2SiO_5 (*22*); 12, transition between talc + phengite + glaucophane + quartz (*23*).

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