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US-Russian Civilian Research and Development Fund Project: An origin of microdiamonds in metamorphic rocks of the Kokchetav Massif, Northern Kazakhstan

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The Kokchetav Massif of northern Kazakhstan is a type-locality of occurrence of microdiamonds in ultrahigh-pressure metamorphic rocks. It records continental subduction and exhumation from depths greater than 120 km and provides unparalleled insights into mantle dynamics, global material recycling and the processes responsible for the genesis and destruction of continent. Through the support of a US Civilian Development and Research Fund, a group of Russian, US, Taiwanese and Kazakhstan geologists visited the reconstructed 800-m underground gallery to conduct field survey and sample collections. This gallery provides a useful geologic laboratory for international community to undertake similar geotectonic or different ecological and environmental studies.

Introduction

The discovery of coesite in Alpine and Caledonian metamorphic rocks of the continental crust in 1984 respectively by Chris Chopin and Dave Smith marks the recognition of a new and special type of ultrahigh pressure (UHP) metamorphism of crustal rocks. UHP metamorphism of continental crustal rocks took place at pressures exceeding 30 kbars during their subduction to mantle depths greater than about 100 km. Since this discovery, several other UHP terranes in continent collision orogens including the Dabie-Sulu terrane of central China and the Bohemian Massif of Germany with confirmed coesite occurrence have been recognized (for summary, see Ernst and Liou, 1999). Microdiamonds, with an average size of about 15 micrometers, along with coesite were discovered as inclusions in garnet, zircon and pyroxene of metamorphic rocks from the Kokchetav Massif, Northern Kazakhstan (Sobolev and Shatsky, 1990; Shatsky et al., 1995, 1999; Zhang et al., 1997).

Since then the study of UHP metamorphism has attracted a great deal of international attention. A special Task Group (III-6)

“Ultrahigh-Pressure Metamorphism and Geodynamics in Collision-Type Orogenic Belts” was established in 1993 by the Inter-Union Commission on the Lithosphere operating the International Lithosphere Program (ILP). A number of significant investigations have been performed in the framework of Task Group III-6 including the compilation of an Introductory book entitled *Ultrahigh Pressure Metamorphism* edited by Coleman and Wang (1995). A final task group report was summarized in a book edited by Ernst and Liou (2000). A new Task Group III-8 “Processes and Geodynamics in the Formation and Exhumation of Ultrahigh-Pressure Metamorphic Terranes” was established in 1999 to be continued to 2004. During the last decade, more than 20 new UHP terranes have been established (see Figure 1 from Liou and Zhang, 2002). Three members of this Task Group (N.V. Sobolev, V.S. Shatsky and J.G. Liou) are co-authors in this report.

On the origin of microdiamonds

Diamondiferous rocks contain microdiamonds with a distinctive range of crystal morphologies (Shatsky et al., 1998). Most diamonds

Figure 1 The location of the Kokchetav Massif in northern Kazakhstan.

Figure 2 Detailed geological map showing distribution of various diamond-bearing and diamond-barren metasedimentary rocks in the Kumdy-Kol area.

1–granite-gneiss,
2–biotite gneiss,
3–granite-gneiss and gneiss alternation,
4–fine-grained chlorite-tremolite quartzite,
5–migmatite,
6–garnet-bearing pelitic schist,
7–pyroxene-carbonate rock,
8–garnet pyroxenite,
9–eclogite and amphibolite,
10–dike of diorite porphyry,
11–a part of underground gallery reconstructed during summer 2002,
12–underground gallery constructed during 1981–1986.

Figure 3 Geological section of Kumdy-Kol deposit (modified from Goncharenko V. E., 1990, personal communication), scale 1:2,000.

1–Biotite gneisses, garnet-biotite gneisses,
2–muscovite and garnet muscovite gneisses,
3–muscovite-, garnet-muscovite, and kyanite-muscovite schists,
4–dolomitic marbles,
5–eclogites, amphibolites after eclogites,
6–chlorite-actinolite-quartz rocks,
7–garnet-pyroxene rocks,
8–dykes and veins of dioritic porphyrite,
9–granite, granite-gneiss,
10–migmatites,
11–"transition zone",
12–diamondiferous zone with biotite-, biotite-garnet graphite-bearing gneisses,
13–drill hole.

in garnet-clinopyroxene calc-silicate rocks and marbles have cuboid morphology. The greatest variety in diamond morphology within a single rock type is observed in biotite gneisses. In this rock type, the predominant crystal habit is the cubo-octahedron. Its cuboidal faces occur either as convex and concave surfaces with varying curvature. The ratio of cuboidal to octahedral surfaces shows a large range, even in a single specimen. Intergrowths and aggregates are quite

abundant. The surface of intergrowth is an octahedral face. Shatsky et al. (1995) observed an octahedron and a cuboid in a single intergrowth.

The fact that the diamonds in Kokchetav UHPM rocks are extremely fine-grained (<200 μm) suggests that the conditions in favour of diamond crystallization were prevailed during a "short" period of time only and/or diamonds were very fast captured by pri-

mary minerals, limiting their growth. In both cases a short period of UHP metamorphism and a superfast exhumation are required. Information about thermal regimes to which the diamonds were exposed, can be deduced from the nitrogen characteristics. All diamonds of the Kokchetav massif are of type Ib-Ia (De Corte et al., 1998). The preservation of singly-substituted nitrogen (diamond of Ib type) is in concert with short residence times and/or low aggregation temperatures. This feature suggests that the diamond-bearing rocks exhumed rather rapidly. De Corte et al. (1998) calculated aggregation temperatures for diamonds from garnet-clinopyroxene rocks assuming a residence time of 5 Ma.

Direct evidence was obtained for diamond crystallization from a silicate-carbonate melt (Palyanov et al., 2001, 2002). Based on these data it is suggested that diamond in the dolomite marble and pyroxene-carbonate rocks crystallized from a carbonate melt in equilibrium with a K-rich fluid (Shatsky et al., 2004). Morphologically,

the newly formed crystals of diamond differ from the natural crystals in the rocks of this type (Palyanov et al., 2001). The supersaturation of the fluid in carbon may be considered as a leading factor responsible for the morphology of the diamond crystals.

Description of the CRDF Project

The Kokchetav region of northern Kazakhstan (Figure 1), one of the largest suture zones in Eurasia, is well known for the widespread occurrences of diamond and coesite-bearing UHP metamorphic rocks related to the collision between the microcontinent and the Vendian-Ordovician island arc in northern Kazakhstan. The Kokchetav Massif is known as the type locality of diamondiferous metamorphic rocks. The Kumdy Kol microdiamond deposit (see Figure 2) represents only a small part of an area covering more than 200 km² large area in which diamondiferous rocks are distributed in the Kokchetav Massif. The proven microdiamonds reserve of this deposit is more than 3 billion carats with an average grade of about 20 carats per metric ton, and making it an absolutely unique phenomenon worldwide.

Many pioneering and significant petrologic and mineralogical studies of the Kokchetav Massif have been accomplished by Russian and Kazakhstan scientists prior to 1990 (see Katayama et al., 2002). Several international field trips have been conducted, including the one followed the 6th International Kimberlite Conference in 1995 and in the framework of International Eclogite Field Symposium in 1999. The Kokchetav Massif UHP metamorphic rocks have also attracted several international cooperative studies including the US-Russian project (1993-97), the Russian-Belgian-Kazakh project (1998-2001) and the Japan-US project (1998-2002). The latter group has recently had their research findings published in a jointed research book entitled "*The diamond-bearing Kokchetav Massif, Kazakhstan: Petrochemistry and tectonic evolution of an unique ultrahigh-pressure metamorphic terrane*" (Parkinson et al., 2002).

A new project entitled "Diamond Formation in Ultrahigh Pressure Metamorphic Rocks" was funded by the United States Civilian Research and Development Foundation (CRDF) for the Independent States of the Former Soviet Union for two years starting 2002. This project includes scientists from Novosibirsk of United Institute of Geology, Geophysics and Mineralogy, and Stanford University. Several Taiwan scientists were invited to participate in the project. This CRDF project (RG1-2387-NO-02) has two specific tasks: (1) to systematically map and collect samples in a 800 m long underground mining gallery; and (2) to characterize these samples using state-of-the-art facilities for microdiamond and to simulate the physical and chemical conditions for the genesis of microdiamond in the laboratory. The first task is significant because the gallery allows a systematic study of the sequence of UHP rocks from a cross section of a Kumdy Kol microdiamond deposit (Figure 3). Previous studies of microdiamonds are mainly from loose blocks in trenches and in waste deposits formed after unearthing the gallery from the digs. No useful information was practically available on the relationship of all these rock types.

Figure 4 Example of the occurrence of microdiamonds as inclusions in garnet of biotite gneiss. Phl – phlogopite.

Figure 5 Example of the occurrence of microdiamonds as inclusions in zircon which is included in carbonate (Car) of dolomitic marble. Phl – phlogopite.

Figure 6 Group photo of the CRSD project participants in front of the underground gallery taken during the summer fieldwork in 2002.

Figure 7 Example of an outcrop in the gallery showing steeply dipping and folded dolomitic marble.

The Kumdy-kol region is a flat farmland where blocks of eclogite, ultramafic rock, marble and gneiss were exposed. Microdiamond occurs only in gneiss and marble. The contact relations of these rocks were inferred from trenches and numerous shallow drillings. In order to obtain a more quantitative estimate of diamonds in this region, a project for the construction of a 800 m long underground mining gallery across the largest part of the Kumdy Kol microdiamond deposit was initiated in 1981 and completed in 1986. Reconnaissance structural and petrochemical studies of samples collected from the digging were done as this gallery provides the most important source of information on structures, contacts of various diamondiferous rocks and microdiamonds distribution. This gallery was reopened in the Summer, 1999 for participants of the 4th International Eclogite Field Symposium. With the support of the CRDF, the National Science Council of Taiwan and others, the gallery was reconstructed in 2002. Project participants were able to conduct systematic observations and sample collection in summer, 2002 (Figure 6). Diamondiferous rocks include dominant (about 85% in vol.) garnet-biotite paragneisses with a wide range of diamond grade between almost 0 and 100-200 carats per metric tons and subordinate carbonate-bearing garnet-pyroxene metasedimentary rocks and dolomitic marbles (about 15% in vol.) (see Figure 4 and 5 for examples of microdiamond inclusions in garnet and zircon). Exceptionally

high microdiamond grade of some carbonate rich pyroxene rocks exceeding 3000 carats per metric ton testifies to the importance of carbonate rich fluids in microdiamond formation.

Field examination of a whole cross section of the Kumdy-Kol microdiamond deposit was performed from September 5th through September 11th, 2002. We found that the gallery was well reconstructed and safe for working inside. Most of our efforts were to collect a variety of samples with precise locations marked by Kazakhstan colleagues during gallery reconstruction and to observe contacts and structural relations of the diamond-bearing and diamond-free UHP rocks.

The gallery entrance is located in the northern part of the Kumdy Kol deposit; the first 225 meters of gallery are paced with barren granite-gneisses and alternation of gneisses and granite-gneisses. Fine-grained quartzite layers intercalate with biotite gneisses. One of the gallery branches in south-western part of the gallery was specifically reconstructed for the purpose to examine a unique sequence of pyroxene-carbonate rocks including dolomitic marbles, about 30 meters thick. Some dolomitic marble layers exhibit well-developed foliation (see Figure 7). Migmatites occur and cross-cut the host gneisses and marbles. Several hundred samples were collected; polished thin sections were prepared in Novosibirsk. This is the first time that this extremely important type of diamondiferous metasedimentary rocks was accessed. Petrogenesis of both diamondiferous and diamond-barren rocks will be systematically investigated. Nanosize mineral inclusions in garnet, pyroxene and zircon and microstructures will be determined using the state-of-the-art equipments including Transmission Electron Microscope (TEM) and Ion microprobe. Zircons will be separated for both geochemical and geochronological studies. The U-Pb ages of zircons from migmatite which cut deposit in many places and especially at its southern end (see Figure) are especially important in reconstructing the whole exhumation history of diamondiferous rocks and formation of super-critical fluid associated with the genesis of diamond.

The integrated study of mineralogy, petrology and geochemistry of all rock types, collected systematically in the gallery and their relationships is within the framework of the project. Special attention will be paid to the detailed study of diamonds and other primary minerals using EMP, SEM, TEM, SIMS, FTIR and SHRIMP. The results will be published elsewhere including a special issue of Russian Geology and Geophysics, the scientific journal founded in 1960 in Novosibirsk, now printed and distributed by American Geophysical Union (www.agu.org/wps/rgg).

The reconstructed underground mining gallery has now become a useful geologic laboratory. We disseminate this information to the international community to draw its attention to the golden opportunity. If some scientists are interested in doing similar or different ecological and environmental studies, research actions should be taken now, as the gallery due to lack of maintenance is falling apart and would be unsafe for scientists to enter in the years to come.

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