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Diamonds and the Kokchetav Massif

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A geodynamical revolution in modern geosciences was initiated by Chopin (1984) and Smith (1984), who discovered metamorphic coesite in rocks of the Dora Maira Massif, Italy and the Western gneiss region, Norway, respectively. The term "UHP metamorphism" was born and such rocks which initially have been considered as products of an exotic process on a local scale, now completely changed our view of modern plate tectonics. Currently, more than 20 occurrences of UHP-metamorphic rocks worldwide document a process, that enables recrystallization of continental or oceanic lithosphere in mantle depths, documenting this process to be a rather a standard feature than of only local relevance. A further benchmark in the history of UHP rocks is related to the discovery of microdiamonds in the Kokchetav Massif, Kazakhstan by Sobolev and Shatsky (1990). Such diamonds, although often only tens of microns in size, provide an extremely valuable information on deep subduction processes.

A window into a completely new field of research was established by the discovery of microdiamonds in a very particular geological environment, in ophiolitic peridotite and chromitite. Such rocks occur, for instance, at Luobusa, Southern Tibet, China and the Urals, Russia; highly reduced minerals like alloys and Si-C and Fe-C-phases but also moissanite are important phases of the diamondiferous UHP mineral assemblage (e.g., Liou et al., 2014; Yang et al., 2014).

The contribution presented here gives an overview of the diamond-bearing UHP-metamorphic rocks from the Kokchetav Massif and summerizes the most important and far-reaching implications. The Kokchetv massif is part of an intracontinental orogenic belt between the former Laurasia and Gondwana; its structure is quite complex. It is part of one of the largest suture zones in Central Asia, the Central Asian Orogenic Belt, and represents a tectonic collage with fragments of continental crust, accretionary prism, and magmatic arc material. The HP and UHP rocks occur in two structurally different units, firstly the Vendian to Cambrian megamélange belt where the HP/UHP metamorphic blocks experienced different pressure conditions which correspond to 60-200 km depths and, secondly, the accretionary prism in which rocks were metamorphosed at depths of about 60 km (Dobretsov et al., 2006). The megamélange is subdivided into five terranes where microdiamond only occurs in the Barchi Kol and Kumdy Kol terranes; at Sulu-Tyube and Kulet coesite was found as an index UHP mineral but never diamond (e.g., Shatsky et al., 1998, Kaneko et al., 2000, Zhang et al., 2012). From the Enbek-Berlyk terrane which contains rare eclogite lenses within granitic gneiss and micaceaous schist, neither diamond nor coesite has been reported. At Kumdy Kol, an underground mining gallery was constructed that cuts diamondiferous rocks which include ~85 vol% gneisses and ~15 vol% calcsilicates. Rare garnet peridotite associated with diamondiferous paragneiss and eclogite are also known from Kumdy Kol. The Barchi Kol site that represents the second microdiamond locality comprises different types of Grt-pyroxene and calcsilicate rocks, eclogite, amphibolite, gneiss and migmatite. Importantly, up to date microdiamond was never observed in any of the Kokchetav eclogites.

A multitude of bulk rock geochemical analyses are available from the Kokchetav HP/UHP rocks. Most of the Kumdy Kol, Kulet, and Sulu-Tyube eclogites were interpreted to represent mafic compositions of the tholeiite series. Bt-Grt-Ky schists from Enbek-Berlyk, Bt schists from Sulu-Tube and Grt-Ms-Ky schists from Kumdy Kol contain abundant amounts of Al_2O_3 and were interpreted as former shales; mica schists higher in K_2O and SiO_2 presumably have arcosic protoliths (Shatsky et al.,1999). Other studies include Czo gneisses from Barchi Kol which represent former Ca-rich clays (Korsakov et al., 2002), and "whiteschists" which are suggested to be formed from basaltic protoliths by metasomatic processes, introducing Mg, K, Rb, Th, U and removing Ca, Na, Sr (Yui et al., 2010). Grt peridotite from Kumdy Kol as well as harzburgite from Enbek-Berlyk are depleted in Cr_2O_3 and enriched in TiO_2 and hence were related to the Fe–Ti type of peridotites. The protoliths of Kokchetav peridotites and pyroxenites probably represent metasomatized basalts, metamorphosed during subsequent subduction (Reverdatto and Selyatitskii, 2004; Yui et al., 2010). Shatsky et al. (1999) found trondhjemitic melts crosscutting eclogites and concluded partial melting to occur during the exhumation process within crustal levels.

Several $\delta^{18}O$-studies were carried out, first of all in order to

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resolve the controversy on crustal sedimentary versus mantle-derived magmatic protoliths. Eclogites were found to be isotopically heterogeneous and their protoliths were interpreted to have interacted with meteoritic water after their magmatic formation (Masago et al., 2003). δ^{18}O-studies on Grt peridotite, eclogite and "whiteschist" by Yui et al (2010) supported the model of seawater-rock interaction. Sobolev et al. (2011) performed in-situ δ^{18}O studies of a zoned garnet from a layered calcsilicate rock. Their results indicate a fluid-mediated oxygen isotope exchange during growth and confirm a sedimentary origin of the protolith. δ^{18}O zoning of garnet also suggested that the initial uplift rate must have been very rapid, since the measured profile could not have survived for more than 1 Ma at peak metamorphic temperatures of 1000°C.

PT-estimates yield peak metamorphic conditions of at least 43 kbar at temperatures of about 950-1000°C (see compilation by Schertl & Sobolev, 2013). Zircon separates show inherited Proterozoic cores and mantle with the peak of UHP metamorphism at about 537-530 Ma. Several Ar-Ar-ages on micas scatter around 529-528 Ma and 521-517 Ma and reflect different stages of the exhumation history (see compilation by Schertl & Sobolev, 2013). Migmatization occurred during exhumation at about 526-520 Ma. Microdiamonds which reach a grain size of 300 micrometers, contain highly potassic fluid inclusions as well as solid inclusions like carbonates, different silicates and metal sulphides (e.g., Dobrzhinetskaya et al., 2003; Hwang et al. 2005, 2006,), which favours the idea of a diamond formation from a C-O-H bearing fluid. Nitrogen isotope data and negative δ^{13}C values of Kokchetav diamonds indicate a metasedimentary origin (e.g., De Corte et al., 2000; Cartigny, 2005). Schertl et al. (2004, 2015) focused on cathodoluminescense (CL) microscopy of Kokchetav UHP minerals and were able to uncover important internal structures as, for instance, irregular net-like zoning of garnet, exsolution lamellae in carbonate and clinopyroxene, growth zoning of diamond, carbonates and potassium-bearing clinopyroxene. Many of such structures could easily have become overlooked without applying CL microscopy but provide important genetic information in deriving geological and tectonic interpretations. A number of unique mineralogical findings have been made. K-feldspar exsolutions in clinopyroxene (e.g., Shatsky et al., 1985) demonstrate that potassium can be incorporated into the clinopyroxene structure under upper mantle pressures. Other significant observations are coesite exsolutions in titanite (Ogasawara et al., 2002), quartz-rods in clinopyroxene (Katayama et al., 2000), the discovery of Maruyamaite, a potassium tourmaline (Shimizu & Ogasawara, 2011; Lussier et al., 2014), as well as other new minerals like kokchetavite, a hexagonal polymorph of K-feldspar and kumdykolite, an orthorhombic polymorph of albite (Hwang et al., 2004, 2009).

As a conclusion it is worth to point out that special attention has to be drawn to the huge impact of small-scale observations. Examples are (1) zircon which acts as a perfect container of UHP minerals as introduced in the 90th of the last century – those studies are of vital significance, especially if combined with REE-, fluid-inclusion and SHRIMP-studies of different growth zones, (2) zoning, mineral- and fluid-inclusion studies of metamorphic diamond and (3) petrological results which base on cathodoluminescence microscope studies of metamorphic minerals. Only through careful investigation and interpretation of these often sub-millimeter scale observations, it is possible to derive large scale orogenetic processes.

In essence, the Kokchetav UHP rocks kept busy geoscientists of various disciplines who were interested in the diverse properties and processes which occur under upper mantle conditions; they surely will keep us busy also for the next 25 years and even more. Thus far, about 400 papers have been published on various aspects of the Kokchetav UHP rocks. This discovery was a trigger for an intense search of further possible diamondiferous UHP terranes worldwide, successfully documented by numerous new findings. What will be the next revolution in geodynamics? Will it start with the finding of stishovite in metamorphic rocks? Time will tell.

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