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Discovery of Microdiamonds and Associated Minerals in the Makhtesh Ramon Canyon (Negev Desert, Israel)

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The Makhtesh Ramon erosional–tectonic depression (canyon), 40 km long and approximately 8 km wide, is situated in the Negev Desert (southern Israel), 65 km southwest of the Dead Sea. The canyon rim and center are located at an altitude of 800–1000 and 400–600 m, respectively. In terms of tectonics, this structure represents the southern margin of the Syrian-Sinai [1] block–fold belt. A comprehensive analysis of the available regional geophysical data revealed a collision-related origin of the belt [2]. Its formation terminated approximately 132 Ma ago, i.e., during the Levantine tectonic phase [3].The subsequent origination of the Levantine marginal volcanic suture [4] promoted the accumulation of postcollisional trap rocks (alkaline basaltic, alkaline gabbroic, and kimberlitic associations). The kimberlitic association, which was first discovered in western Syria, is represented in the study region by diatremes filled with kimberlite-type rocks containing eclogitic xenoliths [5]. Maximal magmatism in the region occurred approximately 120 Ma ago, which corresponds to the epoch of global tectonothermal activation (the Middle Cretaceous maximum in the development of upper mantle hot spots [7]).

In the Makhtesh Ramon area, this stage is reflected in central-type volcanoes composed of lava flows, eruptive breccia, and tuffs that suggest wide development of explosive volcanism in the Middle Cretaceous [8]. Vent facies of the central-type Mahale Khahatsmaut Depression contain peridotite xenoliths with spinel-bearing lherzolites [9]. The presence of such rocks indicates significant depths of explosive volcanism.

Magmatic rocks of the western Makhtesh Ramon Canyon are represented by picritic and olivine basalts and alkaline picrites. It should be noted that the development of these rocks does not rule out the presence of kimberlites in the study area.

Detailed analysis of the magnetic (including quantitative interpretation and 3D modeling) and gravity fields indicated the possibility of discovery of parental diamondiferous bodies in the Makhtesh Ramon area. The low heat flow (~35 mW/m^2) in southern Israel [11] is an additional indicator of diamond potential in the area.

The first diamond microcrystal discovered in the Negev Desert 30 km north of Makhtesh Ramon (Israel) in the Cretaceous/Paleogene boundary iridium layer was attributed to a meteorite fall. However, the habit, size, and characteristic impurities in the microcrystal suggest that it was washed out of diamondiferous bedrocks.

One should emphasize the historical fact mentioned by Gaius Plinius Secundis [12], the ancient Roman scientist and writer, suggesting that several types of diamonds were mined in the Mediterranean, including the Arabian (*Ad Arabicus*) and Cyprian (*Ad Cyprius*) varieties.

As a result of complex geological, geophysical, and geochemical investigations along with geomorphological reconstructions, the western part of the Makhtesh Ramon Canyon (10 × 10 km in area) was chosen as a most promising area with respect to the discovery of

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microdiamond. We sampled clastic rocks corresponding to both early and late epochs of secondary erosion represented by Mesozoic (Lower Cretaceous Arod conglomerates) and Cenozoic (Middle Quaternary–Recent alluvium) rocks, respectively. Samples from the near-surface layer (depth interval 20–80 cm) were concentrated and sent to Moscow, where they were thoroughly analyzed in laboratories of the Moscow State University and Moscow State Geological–Prospecting University [13].

Minerals of the diamondiferous association found in examined samples can be divided into two groups. The *first group* includes chrome-diopside, orange garnet, bright crimson pyrope, picroilmenite, chrome–spinel (Fig. 1), olivine, moissanite, perovskite, anatase, corundum, titanomagnetite, and tourmaline (including black species). It should be noted that this mineral list includes almost all major associated minerals of diamond. The total content of these minerals is very high (more than 15 000 grains in the examined 150 kg of concentrate).

The associated chrome-diopside is a proximal mineral. Orange garnet, bright crimson pyrope, and tourmaline are also indicators of the occurrence of diamondiferous associations in the study area. Corundum and moissanite are even better index minerals in this regard [14]. It should be noted that most of the associated mineral grains are not rounded or oxidized, suggesting the proximity of bedrock diamondiferous associations.

According to electron microscopy data [13], picroilmenite contains Co, Cr, Mg, and Ni, while pyrope encloses Cr, Mg, and Al. These data suggest the abyssal origin of the studied minerals and the presence of diamondiferous bedrocks in the region.

The *second group* includes hexagonal quartz, feldspars, pyroxenes (black, green, dark green, and greenish brown varieties), magnetite, hematite, ilmenite, galena, pyrite, limonite, mica, hydromica, chromite, leucoxene, zircon, rutile, secondary copper minerals (green and blue varieties), calcite, and others. The mentioned minerals combined with minerals of the first group also imply diamond potential of the study area.

The examination of rocks using fluoric and other acids revealed a number of gold and silver flakes accompanied by traces of La, Ce, Th, Nb, and Ta. According to [15], these elements are also indicators of the proximity of kimberlitic rocks.

The geophysical survey (scale 1: 1000 and larger) of the region included detailed magnetic exploration (surface observations combined with materials of a previous aeromagnetic survey) and measurements of magnetic susceptibility and natural electric field. We also carried out complex gradient physicochemical sampling of several significant indicators (S^{2+}, CO_3^{2-}, *Eh*, Pt, NO_3^-, Br^-, F^-, I^-, Cl^-, Ca^{2+}, B^+, ClO_4^-, pH, Hg^{2+}, Na^+, K^+, Cd^{2+}, Cu^{2+}, Pb^{2+}). Results of these investigations indicate a high probability of the discovery of kimberlite pipes at depths of 6–30 m. The geophysical data are consistent with the results of the biolocation frame (dowsing rod) investigation.

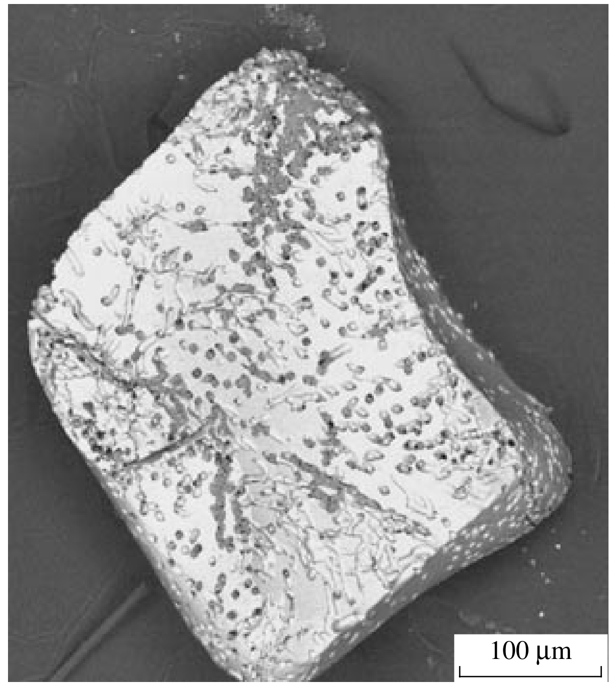

Fig. 1. SEM image of chrome-spinel from Lower Cretaceous Arod conglomerates (Makhtesh Ramon, Israel).

Recent investigations discovered blue clay (usually concentrated in the upper part of a kimberlite pipe) and yttrium phosphate [11], which usually associate with kimberlites [14].

After the visual and qualitative–quantitative analyses under the binocular microscope, the polymineral fractions were investigated using a Camscan-DV scanning electron microscope equipped with an energy-dispersive Link AN10000 microprobe.

The most significant result of these studies is a discovery of over 400 small diamond crystals and microcrystals. Most of them are characterized by cubic habit, while hexagonal species are less common. We detected two large crystals (fragments of a larger crystal) 1.45 (Fig. 2) and 1.37 mm in size. We have not completed all the necessary analyses, and the total number of diamond crystals is expected to increase.

Thus, the available geological, mineralogical, and geophysical data indicate that the Makhtesh Ramon area (southern Israel) is highly favorable for the discovery of a diamondiferous deposit [11, 13]. Judging from petrographic, geophysical, and geomorphological data, its bedrock sources are situated at shallow depths [11]. Unfortunately, further investigations of the Makhtesh Ramon area is hampered by the fact that this area is a state geological reserve, where any mining works are prohibited.

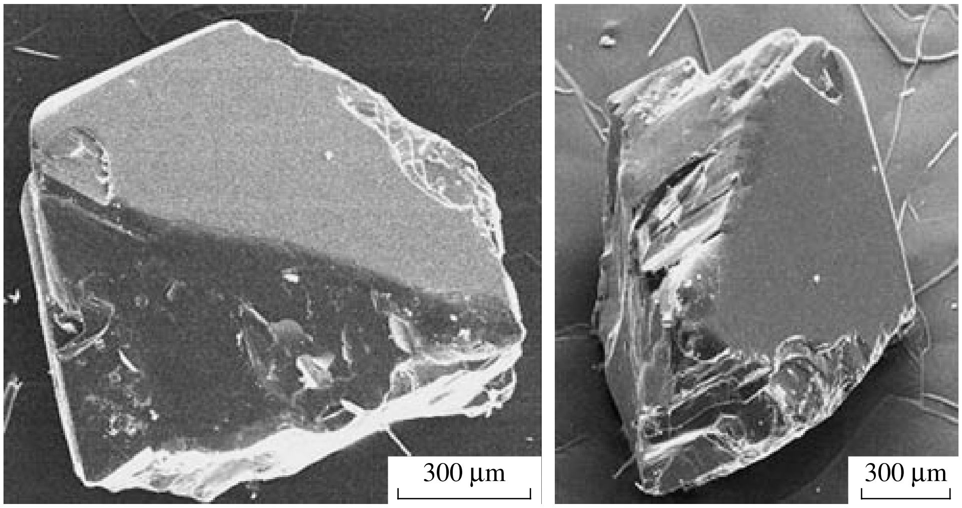

Fig. 2. SEM image of diamond 1.45 mm across (two views) found in Quaternary alluvial sediments of the Makhtesh Ramon area.

We believe that further complex mineralogical, geochemical, and geophysical studies, combined with mining works, will be rewarded with the discovery of diamondiferous bedrocks.

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