

MAKHTESH RAMON: A UNIQUE NATURAL-RESOURCE COMPLEX OF STRATEGIC, MULTI-COMPONENT MINERAL RAW MATERIALS IN SOUTHERN ISRAEL

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Summary. An integrated analysis of regional geological and geophysical factors led to selecting the Makhtesh Ramon area (northern Negev, Israel) to search for diamondiferous associations. The most important regional factor is the Middle Cretaceous maximum in upper-mantle hot-spot development, which appears prominently in this area. Analysis of magnetic (paleomagnetic), self-potential, and ion-selective data unambiguously indicates the presence of some bodies possibly having kimberlite (lamproite) origin occurring at small depths (8-50 m) in the western Makhtesh Ramon. Repeated erosion in the area removed most of the sedimentary associations and significantly simplified mineral sampling and rock collection for geochemical and petrological analyses. Comprehensive mineralogical analyses enabled the detection of the following minerals-satellites of diamond associations: chrome-diopside, orange garnet, bright-crimson pyrope, picroilmenite, moissanite, corundum, black spinel, olivine, anatase, and tourmaline (including black samples). These minerals are not rolled or oxidized, providing additional evidence of their association with the indigenous rocks. Data from electron microscopy show that the grains of (1) picroilmenite and (2) pyrope contain, respectively: (1) cobalt, chrome, magnesium, and nickel and (2) chrome, magnesium, and aluminum. This indicates that both picroilmenite and pyrope have a hyper-abysal origin, which also indicates the possible occurrence of diamondiferous pipes. Secondary-importance satellite minerals include feldspars, pyroxenes, magnetite, hematite, ilmenite, galena, pyrite, limonite, mica, chromite, leucosene, zircon, rutile, etc. These minerals (compared with the first group) also indicate diamond-bearing mineralization in the studied area. Small gold and silver plates, along with considerable traces of La, Ce, Th, Nb, and Ta (Rare earth elements), may also be associated with the nearest kimberlite rock occurrence. The total number of recognized microdiamonds exceeds 300; five diamonds (> 1 mm) were identified (the largest crystals are 1.2 and 1.35 mm). Thus, based on a set of geological-geophysical factors and the identification of the mentioned minerals, we estimate that the Makhtesh Ramon area is promising for discovering diamondiferous rocks (kimberlite or lamproite pipes) as well as diamond crystals in loose deposits. The discovered silver-, gold-, and REE-bearing signatures may be important on their own.

Keywords: hot spot, diamonds, satellite minerals, gold, REE, geophysical signatures

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Introduction

Three tectono-erosional cirques, termed “makhteshim” in Hebrew (sing. “makhtesh”), lie the anticlinal ridges in southern Israel (northern Negev): Makhtesh Ramon (largest), Makhtesh Gadol (intermediate), and Makhtesh Qatan (small). The makhteshim form closed valleys surrounded by steep cliffs 200-400 m high, with outlets carved into the steep southeastern flanks of some of the largest asymmetric folds (Zilberman, 2000).

The Makhtesh Ramon erosional-tectonic depression (canyon), 40 km long and about 8 km wide, lies 65 km southwest of the Dead Sea (Fig. 1).

Its formation ended approximately 132 Ma ago, during the Levantine tectonic phase (Katz, Eppelbaum, 1998; Eppelbaum, Katz, 2015). The subsequent origination of the Levantine marginal volcanic suture (Eppelbaum, Katz, 2012) promoted the accumulation of post-collisional trap rocks (alkaline basaltic, alkaline gabbroic, and kimberlitic associations).

Vent facies of the central-type Mahale Khatmaut depression contain peridotite xenoliths with spinel-bearing lherzolites (Stein et al., 1993). 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, basanites, mantle xenoliths, melilites, and alkaline picrites (Shimshilashvili, Yudalevich, 2005; Vapnik, 2005; Eppelbaum et al., 2006; Samoilov, Vapnik, 2007; Sharygin et al., 2011). Itamar (1988) described polymetallic mineralization in Makhtesh Ramon.

Based on integrated geological, geophysical, and geochemical investigations, along with geomorphological reconstructions, we selected western part of the Makhtesh Ramon Canyon (Fig. 1) as the most promising area for discovering microdiamonds. We sampled clastic rocks from 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 by conventional tools in the geological base in Mizpe Ramon town and afterward were thoroughly analyzed mainly in the laboratories of

the Moscow State University and Moscow State Geological-Prospecting University (Eppelbaum et al., 2002, 2003, 2006; Samykina et al., 2005; Surkov et al., 2008).

Brief Geological Background

Over 200 basaltic and trachytic dikes intruded the sedimentary rocks in the Makhtesh Ramon area (Bayer, Reches, 1991). Most dikes are arranged in a complex (radial) system, and a smaller number of dikes create two systems of NW-SE and NE-SW trends. The dikes are accompanied by many sills of similar composition. The smaller folds tend to form second-order structures superimposed on the larger folds and flexures (Garfunkel, 1993). The known magmatic outcrops at Makhtesh Ramon, Har Arif, and Qrief en Naqa belong to two different magmatic phases, pre- and post-dating a sub-Cretaceous unconformity (Garfunkel, Katz, 1967; Starinsky et al., 1980; Lang, Steinitz, 1985; Baer et al., 1995; Gvirtzman et al., 1994).

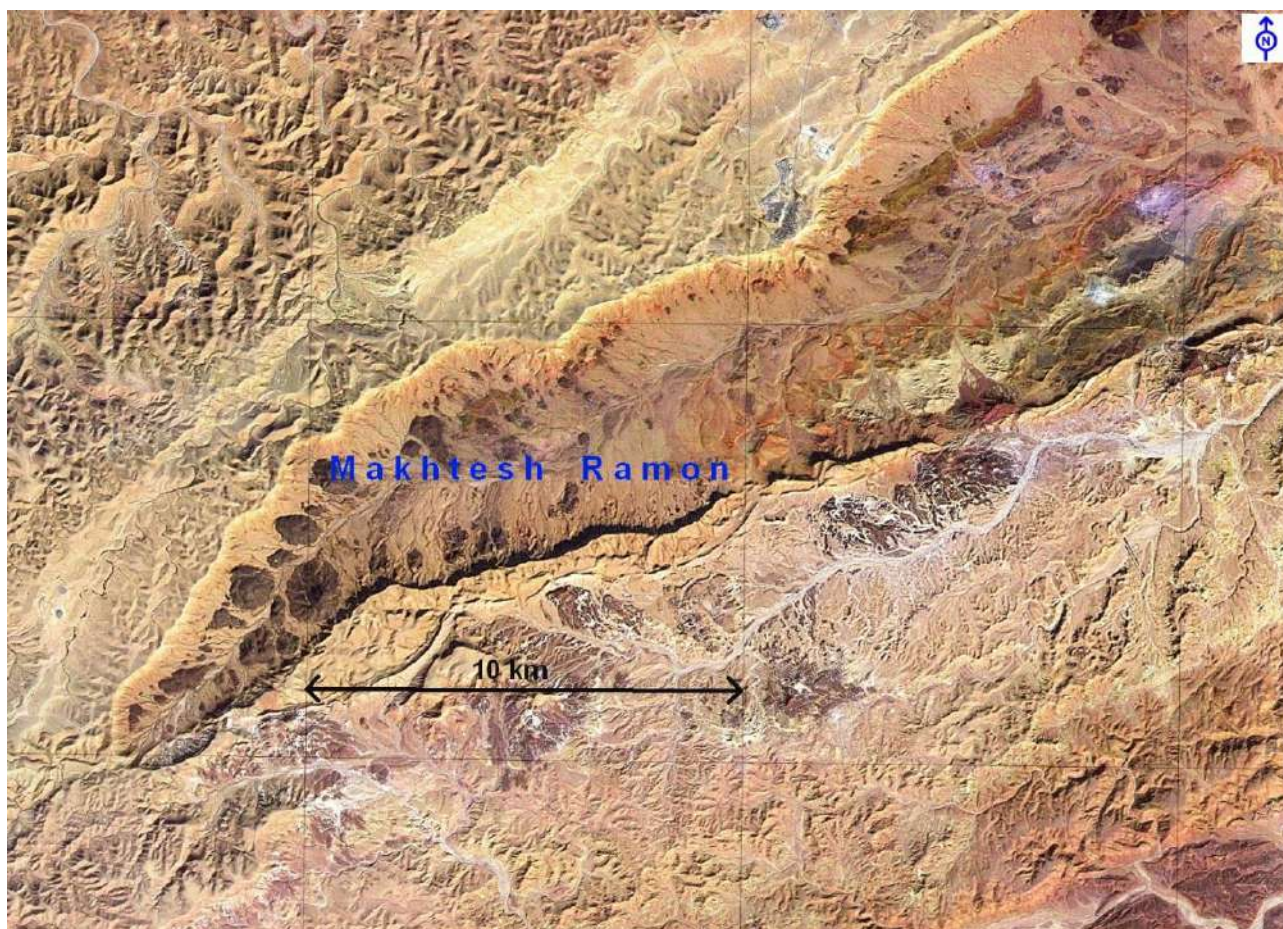


Fig. 1. Makhtesh Ramon (southern Israel): Fragment of “The Holy Land Satellite DataBase Project” (the imagery was made from data obtained from NASA’s Landsat 5 satellite with French SPOT satellite)

Maximal magmatism in the region occurred about 120 Ma ago, corresponding to the epoch of global tectono-thermal activation. Larson (1995) termed this epoch the Middle Cretaceous maximum in the development of upper mantle hot spots and associated it with the high development of diamond-bearing kimberlites during the Mid-Cretaceous. In the Makhtesh Ramon area, this stage is reflected in central-type volcanoes composed of lava flows, eruptive breccia, and tuffs, suggesting widespread explosive volcanism in the Middle Cretaceous (Lang, Steinitz, 1989; Segev et al., 2005).

Chang and Lee (2011) presented a tectonic map with three large mantle plumes in the Near and Middle East, and one of the plumes completely covers the makhteshim family location.

Ben-Avraham et al. (2002) and later Eppelbaum and Katz (2015) have recognized Ab-

delaziz, Negev, Aleppo, Anaximander, Antilebanon, Cyprus, Eratosthenes, Galilee-Lebanon, Heletz, Judea-Samaria, Levant Basin, Palmyrides, and Pleshet terranes in the Easternmost Mediterranean (Fig. 2). It should be noted that Makhteshim occurs at the boundary between the Sinai and Negev terranes, i.e., in the tectonically weakened zone (see Fig. 2).

The geological map of the Makhtesh Ramon area (after Sneh et al., 1998) (Fig. 3) shows a complex, mosaic distribution of sedimentary rocks and magmatic and metamorphic associations. The stratigraphic sequence along the Ramon lineament ranges from the Middle Triassic to the Middle and Late Eocene (Bentor et al., 1965; Benjamini, 1979; Sneh et al., 1998). At the same time, Early Cretaceous igneous rocks play the most significant role.

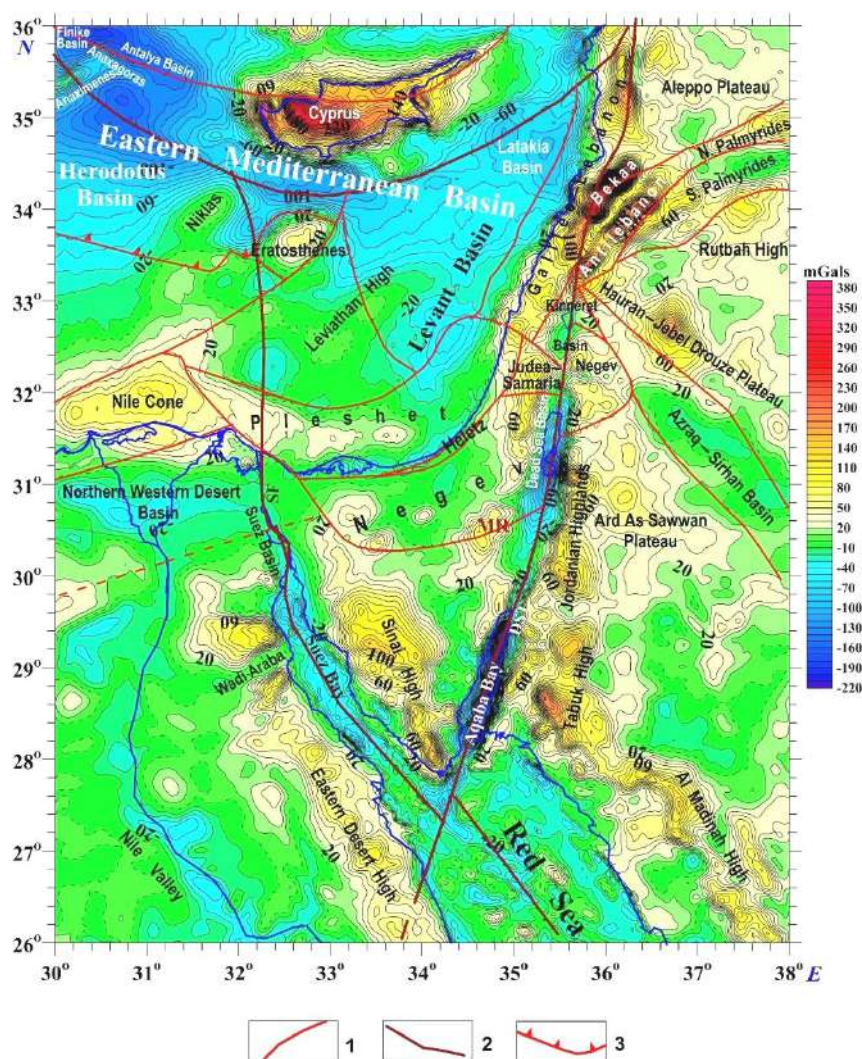


Fig. 2. Areal map of the region under study (supplemented after Eppelbaum et al. (2023)). Satellite-derived gravity map of the study area with the main tectonic features (isoline density is 10 mGals). (1) Intraplate faults, (2) interplate faults, (3) the southern boundary of the Mediterranean accretionary belt. DST, Dead Sea Transform; SF, Sinai Fault. MR, Makhtesh Ramon

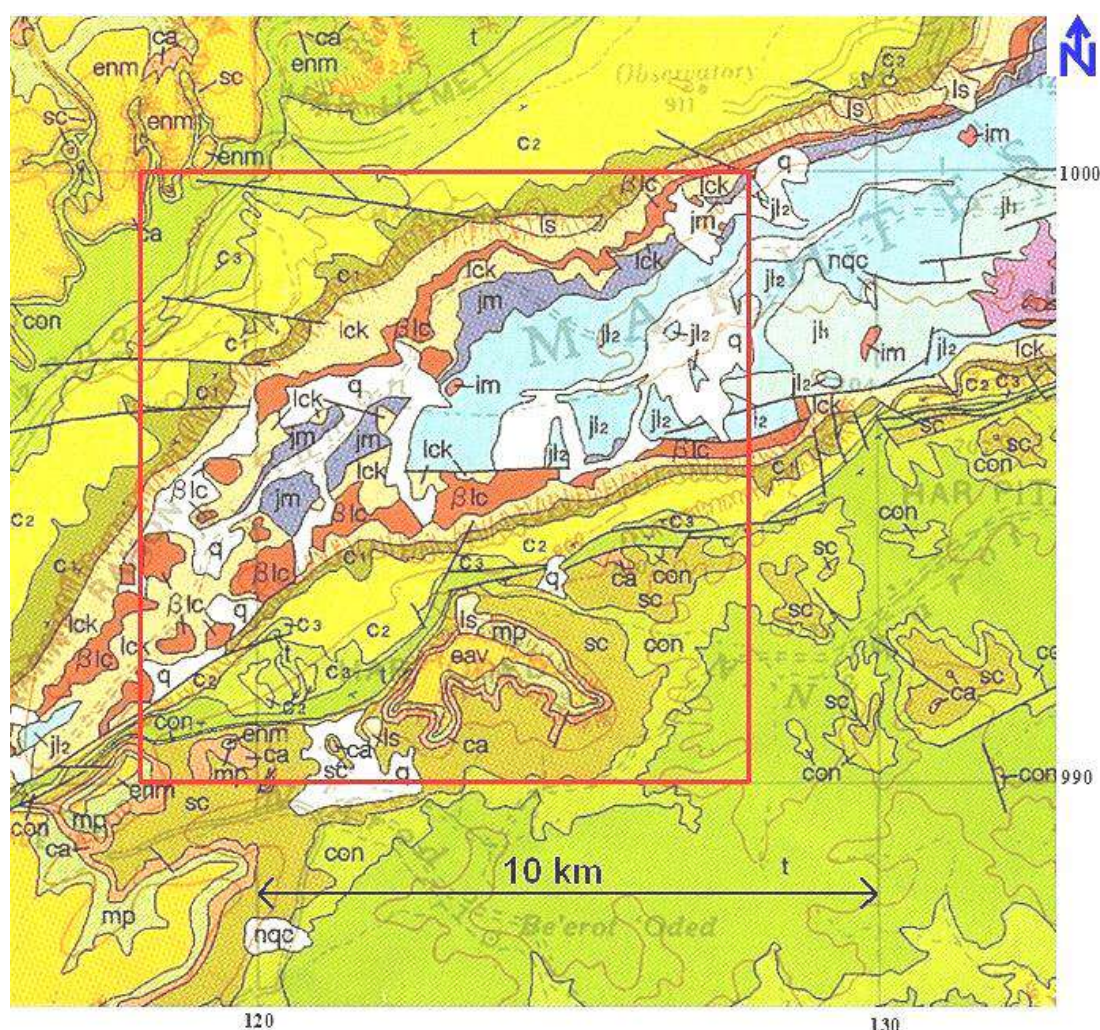


Fig. 3. Geological map of the Makhtesh Ramon area. Fragment of the geological map of Israel. Scale: 1: 200,000, Sheet No. 3 (Sneh et al., 1998). The red square indicates the study area

The volcanic sequence in the western Makhtesh Ramon area overlies 55 m of Aptian sediments (Gvirtzman et al., 1996) and reaches its maximal thickness of ~200 m there (Garfunkel, Katz, 1967). At Ma'ale Ramon, the volcanics are 37 m thick and disappear in the easternmost part of Makhtesh Ramon (Hall et al., 2005).

Mt. Arod (diameter of 1500-2000 m, height of about 180 m), located in the western Makhtesh Ramon, is an important tectonic element of the area. It is an Early Cretaceous volcano, re-exposed by erosion during the incision of Makhtesh Ramon. Mt. Arod is composed of basanitic-nephelinitic rocks, with a lava lake at its center. The mountain (hill) is surrounded by tuffs and lava flows and intruded by subvolcanic stocks and dikes, and a diatreme (Eyal et al., 1996). Interestingly, diatremes (volcanic pipes formed by a gaseous explosion) are frequently associated with kimberlite magmatism.

Avni (2001a) describes the tectonic evolution of the Makhtesh Ramon area in seven stages.

1. In the beginning (110 million years ago), this area had rivers and lakes, which developed near a shallow sea. Sandstone rocks (Hatira Formation) were deposited in this continental environment (Lower Cretaceous).

2. A shallow sea with a dense population of life forms flooded the area 90-100 million years ago. The Cenomanian and Turonian rocks cover the top of the Ramon anticline.

3. The rocks folded and formed an anticline (80 million years ago) along the length of the Ramon fault, an ancient underground geological fault that was "awakened" by tectonic movements. A deeper sea later flooded the area, where friable limestone formed (Senonian Formation). The conglomerate rock on top of the limestone, at the base of the anticline, formed under continental conditions, indicating

that the anticline peak protruded like a continental island above the rest of the anticline, which was still underwater. Because the top of the anticline was worn away, there is no conglomerate rock on the peak.

4. The Ramon anticline continued to rise (60-70 million years ago) along the line of the Ramon fault, with strata of chalk and flint (Senonian formation) and chalk with some clay and phosphates (Maastrichtian formation). Strong erosion washed sands and conglomerates away from the top of the anticline, and they were deposited around the anticline.

5. During the Eocene era (40-50 million years ago), the whole area flooded, including the Ramon anticline and the primary makhtesh. Geologists identified the limestone deposited in this sea in the western part of the Ramon anticline and on the Avdat plateau.

6. The sea level dropped, and the Ramon anticline continued to rise (30 million years ago). The peak of the Ramon anticline was largely eroded, exposing a large sandstone core that precipitated during the early stages of the Makhtesh Ramon formation.

7. The rivers have been developing and creating Makhtesh Ramon (20 million years ago – present). The fact that the Ramon Ridge now stands more than 1,000 meters above sea level is evidence of a marked rise in the ridge. As the ridge rose, it tilted slightly northeast (towards the Arava) as the deep Dead Sea Transform valley developed. The large height difference and the ridge's tilt led to vigorous erosion and undermined the soft sandstone strata, which were carried from the Ramon Ridge to the Arava. Erosion of the ridge's inner parts created Makhtesh Ramon as we observe it today.

Regional Geophysical Data Analysis

It is assumed that events of regional kimberlite magmatism are associated with some parameters of Earth's crust and lithosphere, including some of their physical properties and the presence of linear deformations on the mantle surface and in the Earth's crust (Milashev, 1974; Kaminsky et al., 1995; Mitchell, 1995; Morgan, 1995; Kutinov, Chistova, 2016).

The low heat flow ($\sim 35 \text{ mW/m}^2$) in southern Israel is a positive indicator of potential diamond deposits in the area (Eppelbaum et al.,

2006). Commercial diamond deposits have been found exclusively in regions with heat flow less than 40 mW/m^2 (Kaminsky et al., 1995; Morgan, 1995; Kutinov, Chistova, 2016).

The comparatively deep Moho discontinuity in the Makhtesh Ramon area (38 km) (Fig. 4) (Eppelbaum, Pilchin, 2006) is also a positive signature (Morgan, 1995; Cherepanova et al., 2013; Kutinov, Chistova, 2016).

Another significant geophysical indicator is the large depth of the Curie Point isotherm (Morgan, 1995; Condie, 2001). The calculated Curie Point isotherm for the Makhteshim area location is about 39 km (Eppelbaum, Pilchin, 2006) (Fig. 5), which is also an auspicious indicator (cooling lithosphere).

Finally, the last positive regional geophysical indicator is the relatively shallow depth of the crystalline basement (Morgan, 1995; Nixon, 1995). In the Makhtesh Ramon area, the depth of the crystalline basement, according to Rybakov, Segev (2004), is 3.3-3.5 km.

Taken together, these two indicators suggest that a thick crystalline basement is also favorable. It can also be considered a positive signature (Morgan, 1995; Cherepanova et al., 2013). In the study area, the crystalline basement exceeds 30 km in thickness.

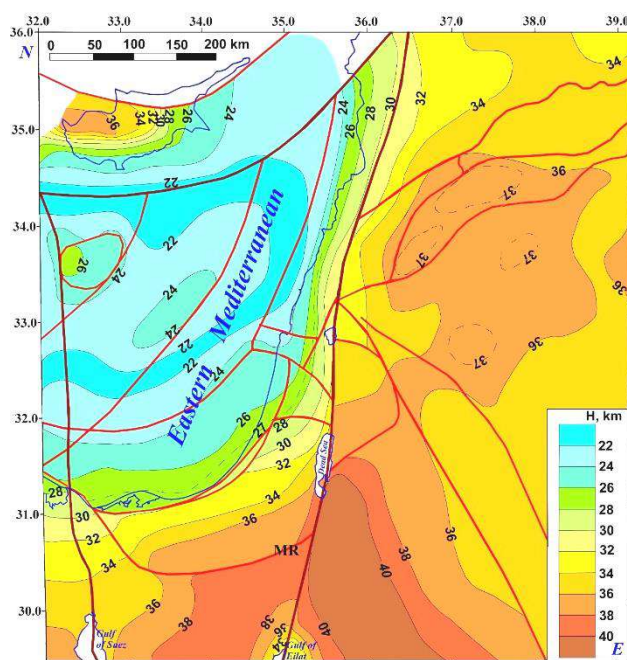


Fig. 4. Map of Moho discontinuity of the Easternmost Mediterranean (after Eppelbaum, Pilchin, 2006, with small modifications). MR, Makhtesh Ramon

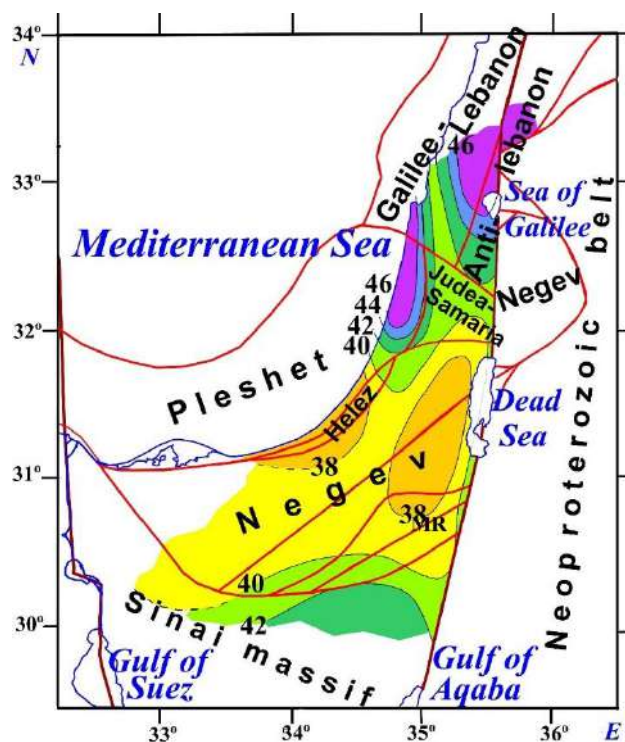


Fig. 5. Curie map of Israel (supplemented after Eppelbaum, Pilchin, 2006). MR, Makhtesh Ramon

Many authors (e.g., Green, Gueguen, 1974; Mitchell, 1986; Griffin, 2008) note a possible major role for mantle diapirism in transporting kimberlite material from depth to the Earth's surface. From this perspective, the greatest magnetic anomaly in Israel, 'Hebron' (~110 km NNE of the Makhtesh Ramon), was interpreted as a mantle diapir (Eppelbaum et al., 2005). This indicates that mantle material is rising in this region.

Figure 6A shows an airborne magnetic map of western Makhtesh Ramon overlaid on a simplified geological map (after Gvirtzman, Weinberger, 1994) and two interpreting magnetic profiles. Results of magnetic field modeling (semi-automatic software developed at the Moscow State University was applied) along profile II – II are presented in Fig. 6B. It should be noted that the airborne magnetic observations (considering the altitude and spacing of the aeromagnetic survey) reflect only large anomalous bodies (at least two buried targets have expressed quasi-kimberlite structure).

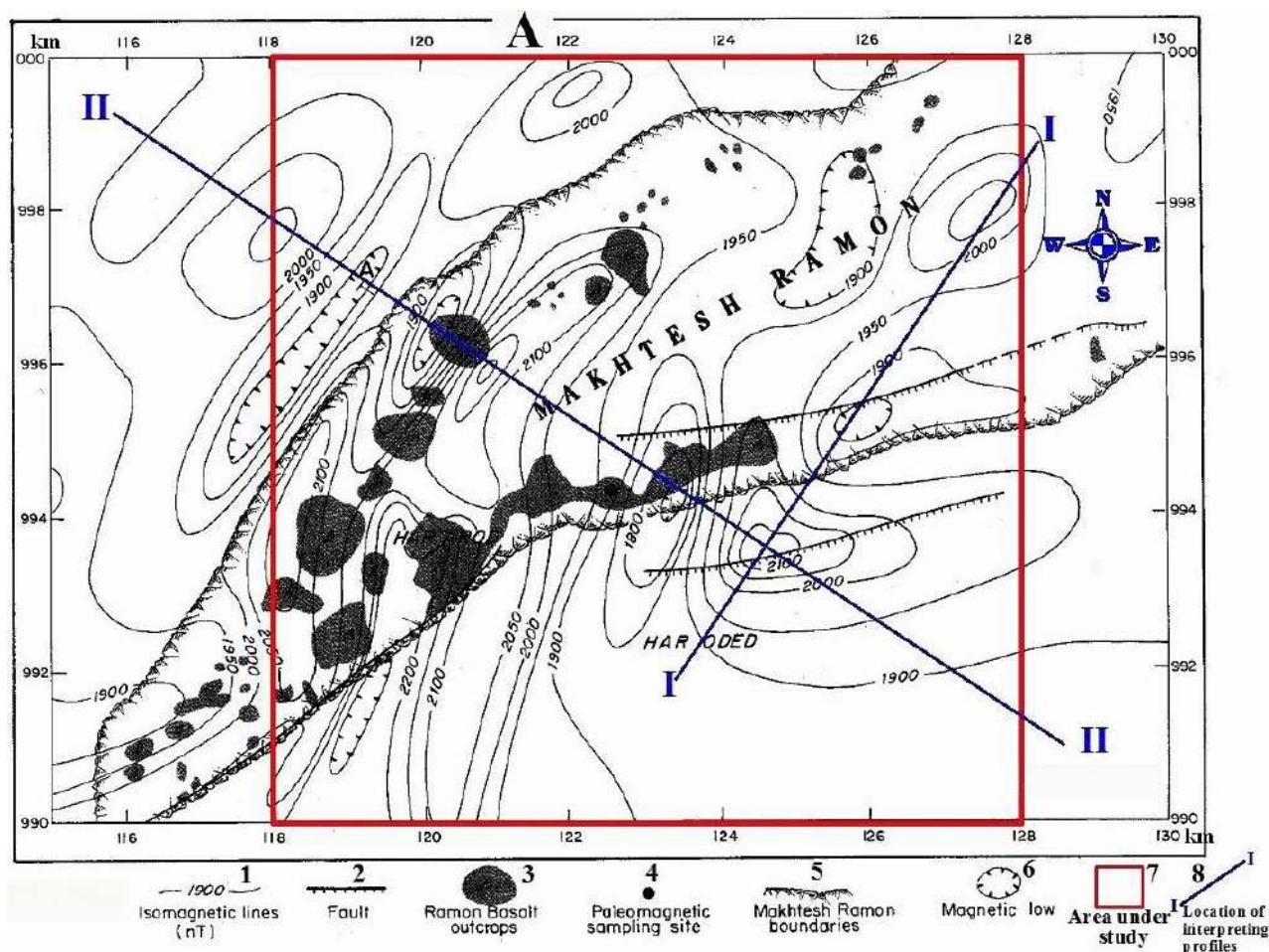


Fig. 6A. The aeromagnetic map (flight altitude: 1000 m, spacing: 2000 m, IGRF removed) of western Makhtesh Ramon overlaid on a geological map (after Gvirtzman, Weinberger, 1994), with the locations of two interpreted profile

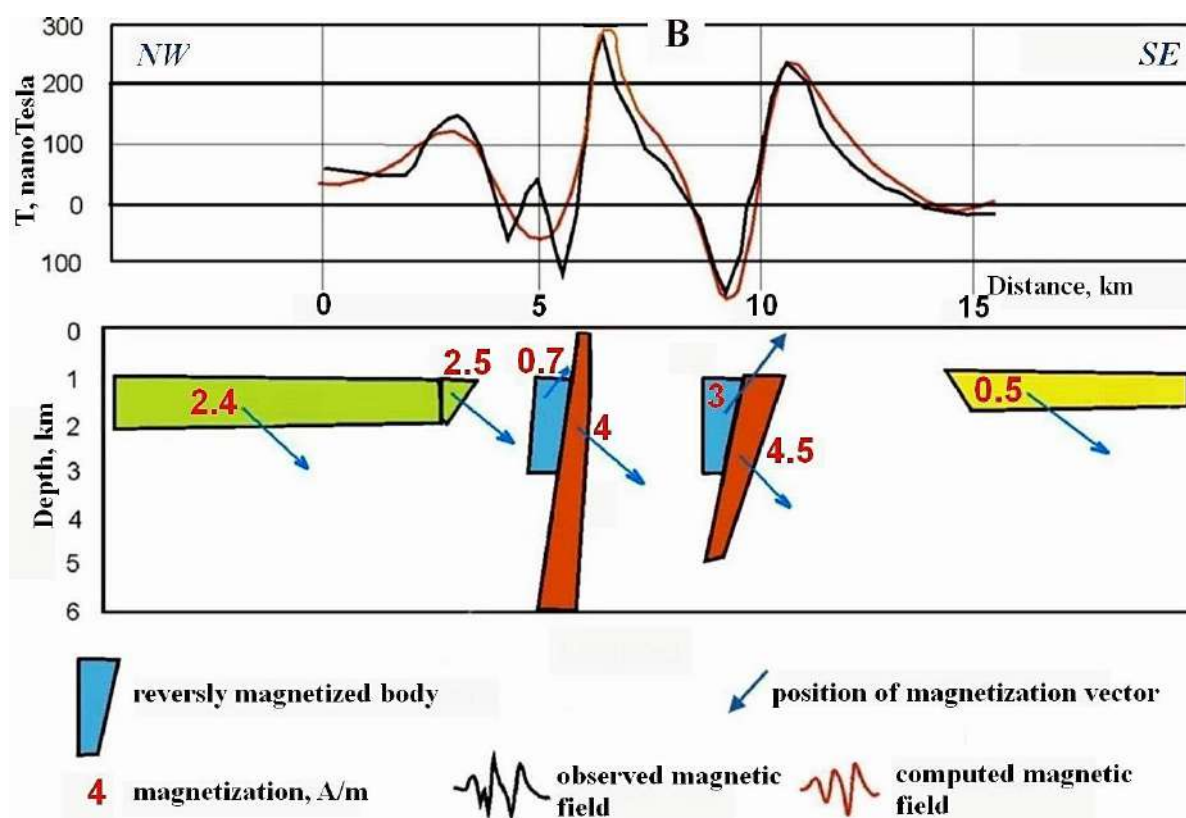


Fig. 6B. Results of magnetic field modeling along profile II – II in Makhtesh-Ramon (location of this profile is shown in Fig. 6A) (after Eppelbaum et al., 2002, with modifications)

Concerning the confinement of the kimberlite magmatism to zones of regional linear deformations. Several investigators (e.g., Ben-David, Mazor, 1988; Zilberman, 1991; Ben-David et al., 2002) have suggested that the makhteshim structures were developed during the Middle to Late Cenozoic in response to the formation of the Dead Sea Transform Zone (see Fig. 2).

Detailed Geophysical Data Analysis

Magnetic data analysis

The magnetic pattern of the Makhtesh Ramon area is very complex (Folkman, Yuval, 1976; Gvirtzman et al., 1994) because magnetized rocks at different depths (tephrites, basanites, olivine basalts, quartz syenites) contribute diverse effects to the observed field.

Detailed analysis of the magnetic data (including the quantitative interpretation and 3D modeling; developed methodologies for complex physical-geological conditions are described in detail in Khesin et al. (1996) and Eppelbaum, Khesin (2012)) indicates the presence of near-surface occurrence (from eight to fifty meters) bodies having the form of thin beds and 'inverse carrot' (Eppelbaum et al., 2003; 2006).

The observed magnetic map of area 'I' is unclear because a strong regional background masks local anomalies. Fig. 7 shows the results of applying the gradient operator to the total magnetic field data in area 'I'. Even a simple visual analysis of this map indicates a series of ring structures at low depths.

Figure 8 shows an interesting example of magnetic data re-interpretation. Initial geological-geophysical data analysis (Baer et al., 1989) proposed that this anomaly originated from a buried sill (Fig. 8). However, re-interpretation of this anomaly (Eppelbaum et al., 2006) allowed us to conclude that a kimberlite pipe (classical kimberlite pipe model presented in Haggerty (1995)) is the most suitable model.

Gvirtzman et al. (1994) analyzed sizable magnetic anomalies in the Makhtesh Ramon area and south of it. The authors associated the examined anomalies with large magmatic bodies of Late Jurassic–Early Cretaceous age and apparently basaltic consistency. Interestingly, models of disturbing bodies developed using 2.5D magnetic field modeling (Gvirtzman et al., 1994) often resemble the classic models of large kimberlite pipes (Haggerty, 1995; Mitchell, 1995).

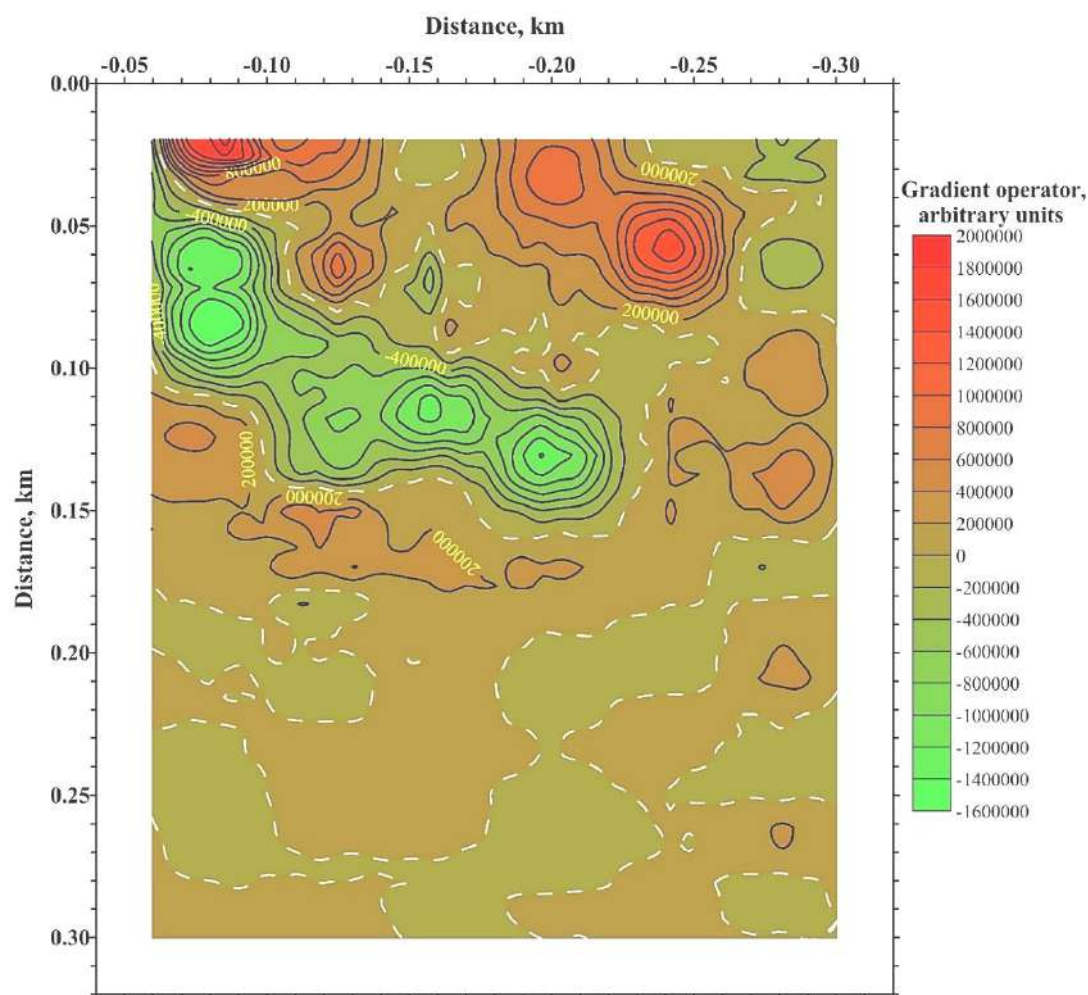


Fig. 7. Results of the total magnetic field processing by the gradient operator in area 'I'

Paleomagnetic map compilation

Paleomagnetic data are sometimes important because they can provide results that other geological and geophysical methods may not (Eppelbaum, 2015). For compiling the first paleomagnetic map of Makhtesh Ramon, the available paleomagnetic, radiometric, and geological data were examined (e.g., Garfunkel, Derin, 1988; Lang, Steinitz, 1989; Baer, Reches, 1991; Baer, 1993; Eyal et al., 1996; Gvirtzman et al., 1996; Segev, 2000; Segev et al., 2005). The oldest preaccretional dikes (Omolon paleomagnetic zone) trend south-north, and the dikes of the accretional stage (upper part of Gissar paleomagnetic zone) trend east-west (Fig. 9A). The eastern margins of preaccretional and accretional dike complexes and other magmatic bodies are older than the western margins. The eastern Omolon zone is 165.7 Ma; the western margin is 151.4 Ma. Within the Gissar zone, ages change from east to west from 142.5 Ma to 126.8 Ma. Various volcanic bodies of the

postaccretional stage (Jalal paleomagnetic zone) are discordant relative to dike orientations in the Omolon and Gissar zones. Most magmatic bodies of the Jalal zone trend from WSW to ENE (Fig. 9A). Paleomagnetic analysis carried out by Gvirtzman et al. (1996) in the SWW part of the Jalal zone (this paleomagnetic zone is characterized by predominant direct polarity) indicates that all magmatic sample determinations show direct polarity except for the Mt. Arod area, where both direct (younger flows) and inverse (older flows) polarities were registered. The Gissar paleomagnetic zone is characterized by numerous approximately equivalent alternations of direct and reverse polarities (this must be considered in the qualitative and quantitative examination of magnetic anomalies). Figure 9B shows the geodynamic rotation of the Makhtesh Ramon block (subterranean) in the Middle Mesozoic. This rotation was primarily counterclockwise, driven by a deep, giant rotating mantle structure (e.g., Eppelbaum et al., 2021, 2025).

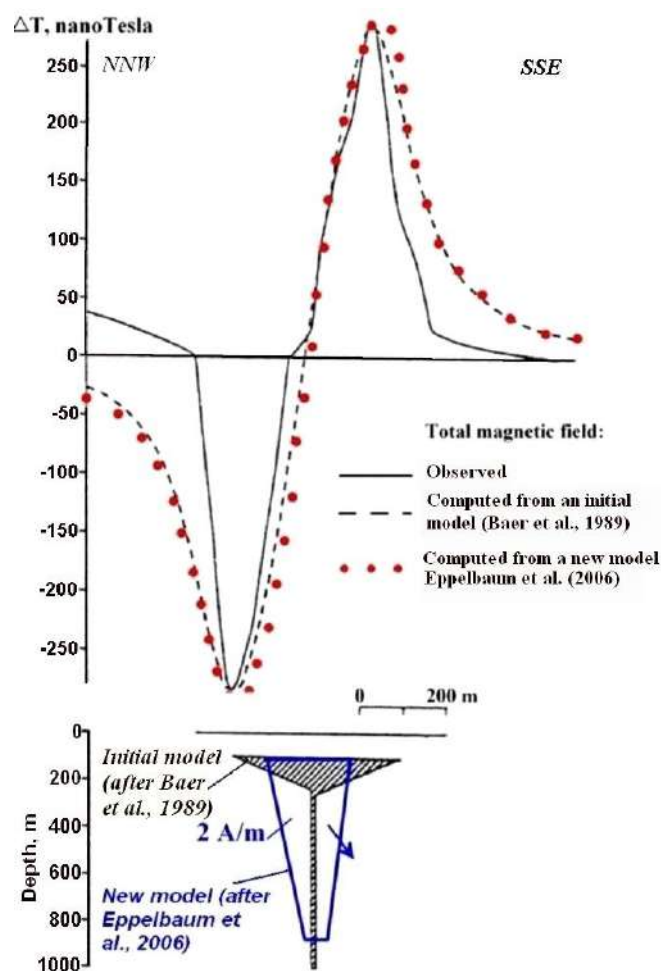


Fig. 8. Results of magnetic data interpretation in the eastern part of the Makhtesh Ramon area (initial data after Baer et al., 1989; revised model – after Eppelbaum et al., 2006)

Self-potential data examination

In the developed self-potential map of area I (Fig. 10), an anomalous zone is contoured (white dashed line), which agrees well with the magnetic susceptibility map examination (Eppelbaum et al., 2003). Quantitative interpretation of the self-potential anomalies performed using advanced methods developed in magnetic prospecting (Eppelbaum et al., 2004; Eppelbaum, 2021) allowed us to estimate a depth of the upper edge of the buried target: $\approx 25\text{--}30$ m.

Application of ion-selective electrodes

An ion-selective electrode method (e.g., Nowak, 2010) is based on applying a set of calibrated ion-selective electrodes (Cl^- , Br^- , I^- , Na^+ , K^+ , NH_4^+ , NO_3^- , NO_2^- , Ag^+ , S^{2-} , Cu^{2+} , Cd^{2+} , Pb^{2+} , Hg^{2+} , Ca^{2+} , Ba^{2+} (SO_4^{2-} , ClO_4^- , ReO_4^- , F^- , AuCl_4^- , CNS^- , $\text{Ca}^{2+}+\text{Mg}^{2+}$, Ph, Ph_{int} , Eh) for

studying soil mixtures (loose deposits) “in situ” or under laboratory conditions. Among these electrodes, we selected parameters associated with kimberlite pipes. We present only Na^+ and Ba^{2+} maps (Figs. 11 and 12, respectively), but other ion-selective electrodes also gave positive results.

Kimberlite rocks, or products of their destruction, contain higher Na^+ contents (Ahrens et al., 1975; Mitchell, 1986, 1995), which may also serve as a search indicator. Measurements using Na^+ electrodes show a direct correlation between ion concentration and the registered potential. The developed Na^+ map (Fig. 11) enabled delineation of a fault-oriented SW–NE across the points 0/150, 50/375, 100/325, 150/300, 200/275, and 300/225. The fault is traced in almost all developed ion-selective maps. The proposed kimberlite pipe location is contoured by elevated Na^+ contents.

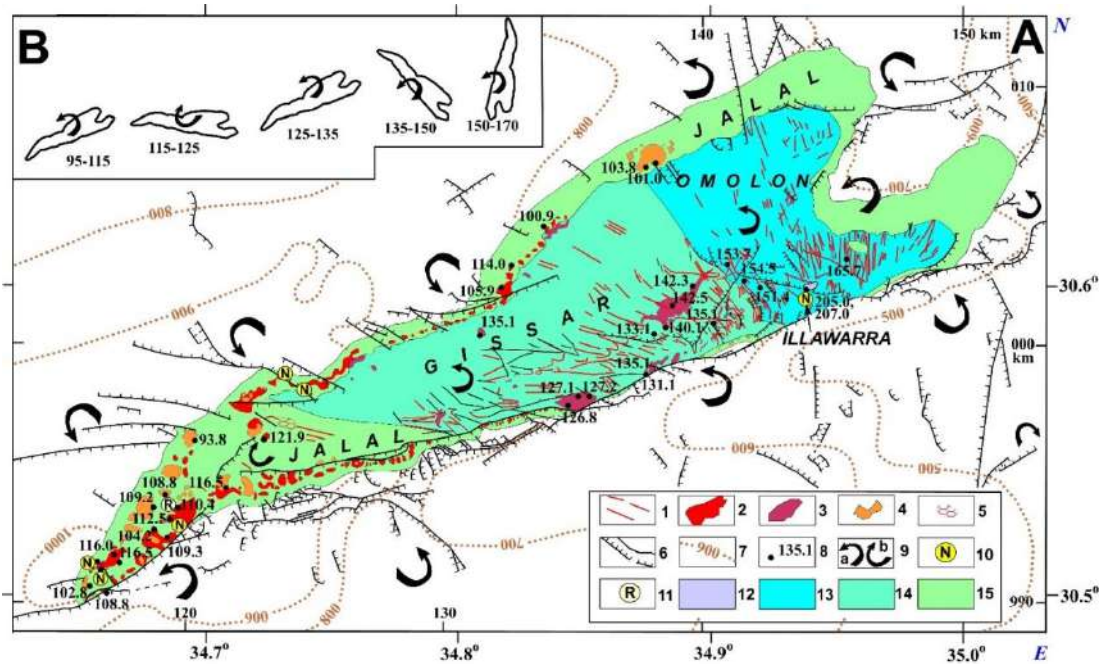


Fig. 9. Makhtesh Ramon geodynamic–paleomagnetic map (modified and supplemented after Eppelbaum et al. (2023)). (A) Geodynamic–paleomagnetic indicators. (B) Geodynamic changes in Makhtesh Ramon subterranean displacement in the Middle Mesozoic. (1) Pre-collisional–collisional basalt dikes, (2) post-collisional alkalic olivine basalt flows and volcanoclastic rocks, (3) pre-collisional association of alkalic olivine gabbro, monzogabbro, and syenites, (4) post-collisional association of basanites and nefelinites, (5) quartzitic hexagonal prisms, (6) faults, (7) hypsometric isolines within the Makhtesh Ramon plateau (1-7) from Garfunkel, Katz, 1967; Zak, 1968; Baer, Reches, 1991; Baer, 1993; Sneh et al., 1998; Avni, 2001b; Zilberman, Avni, 2004; Vapnik et al., 2007; Yudalevich et al., 2014, 2018; Eppelbaum, Katz, 2015; Avni et al., 2017), (8) radiometric age of the magmatic rocks Lang, Steinitz, 1989; Segev, 2000; Segev et al., 2005), (9) counterclockwise (a) and clockwise (b) rotation of the linear structures (faults, dikes, and volcanic ridges), (10)–(11) magmatic rocks with normal (10), and reversal (11) paleomagnetic polarity (from Ron, Baer, 1988; Baer et al., 1995; Gvirtzman et al., 1996; Dembo et al., 2022), (12)–(15) paleomagnetic zonation inside the magmatic complexes: (12) Illawarra, (13) Omolon, (14) Gissar, (15) Jalal

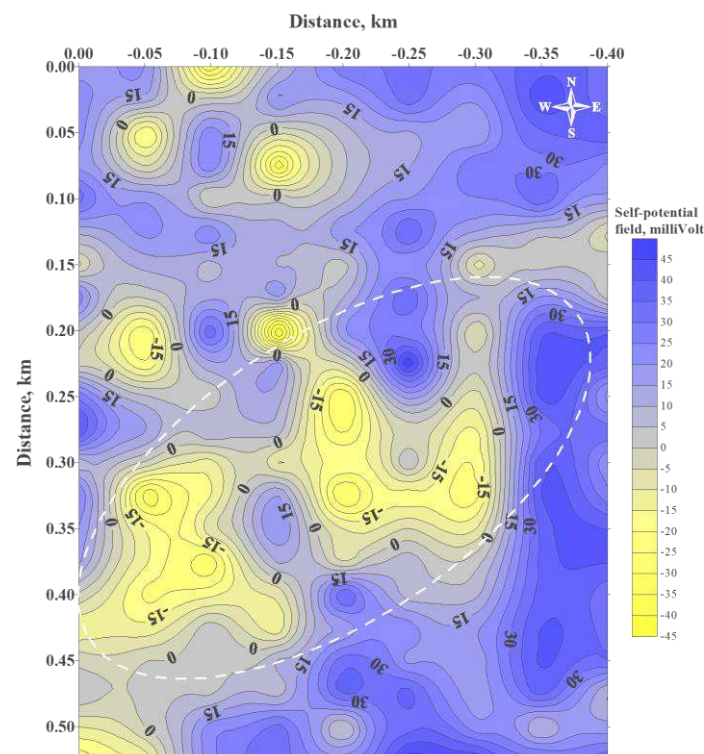


Fig. 10. Results of self-potential method application at the area I of the western Makhtesh Ramon

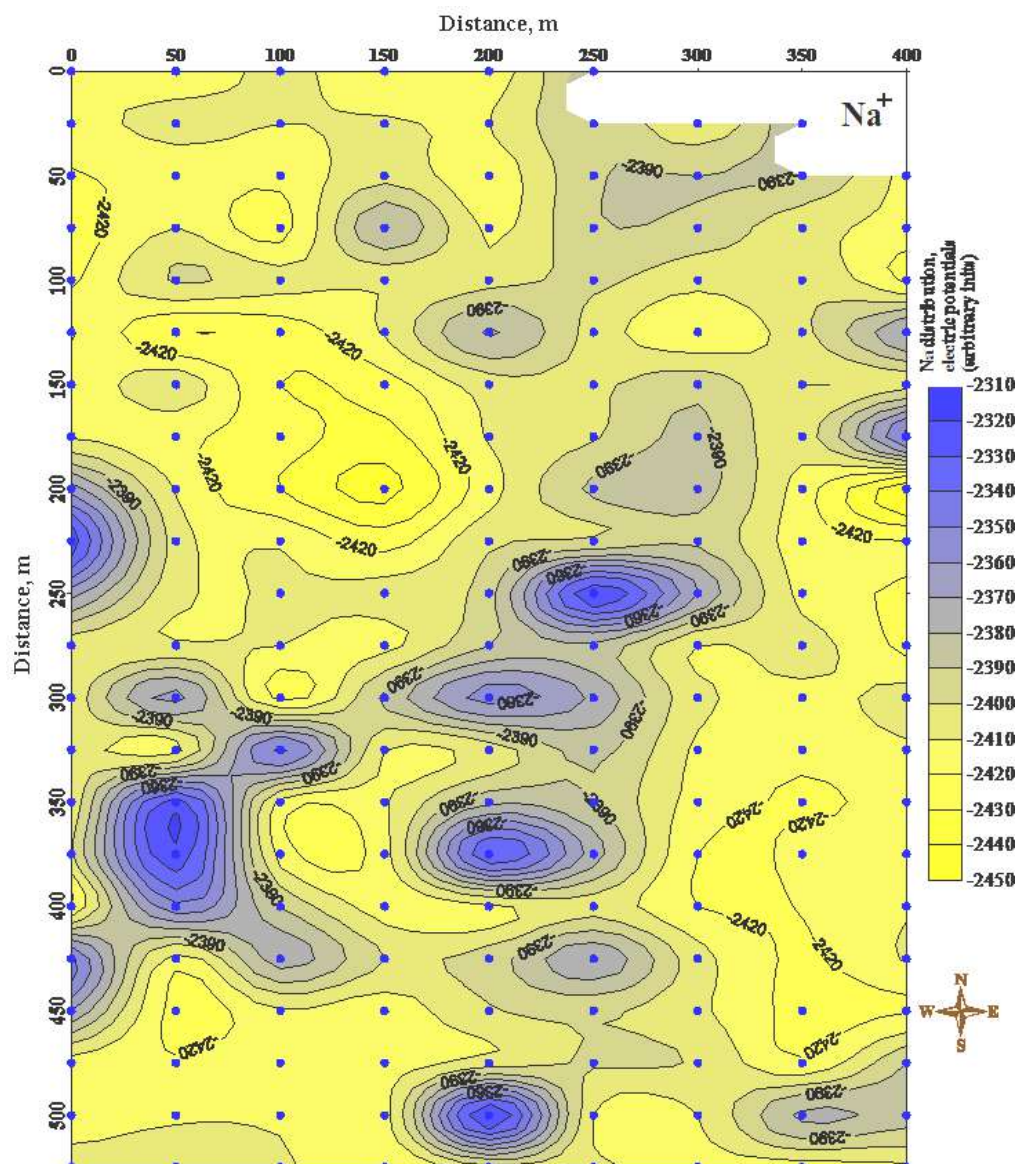


Fig. 11. Map of Na⁺ observations in area I of the western Makhtesh Ramon

Barite is a known kimberlite-generative mineral (Bobrievich et al., 1959; Ahrens et al., 1975; Mitchell, 1995). Most of the barite is concentrated in the upper part of the kimberlite pipe (Bobrievich et al., 1959). In the developed map of barite isopotentials (Ba²⁺) (Fig. 12), a fault is clearly traced. Anomalous zones point out the most prospective areas for near-surface well drilling or bore-pit excavation.

Mineralogical, Petrological and Geochemical Data Analysis

Interestingly, Kaminsky et al. (1995), in the scheme 'Diamondiferous territories of the World', distinguished an Eastern Mediterranean diamondiferous province.

The first microdiamond in Israel was discovered in the Negev Desert 30 km north of Makhtesh Ramon (Israel) in the Cretaceous/Paleogene boundary iridium layer and was attributed to a meteorite fall (Flexer et al., 1988b). However, the habit, size, and characteristic impurities in the microcrystal suggest that it was washed out from diamondiferous igneous rocks.

Samples from the near-surface layer were withdrawn in the western Makhtesh Ramon (depth interval 10-80 cm), processed at the temporary base in Mizpe Ramon town, and later thoroughly analyzed in laboratories of the Moscow State University and Moscow State Geological-Prospecting University (Eppelbaum et al., 2002, 2003; Samykina et al., 2005; Surkov et al., 2008).

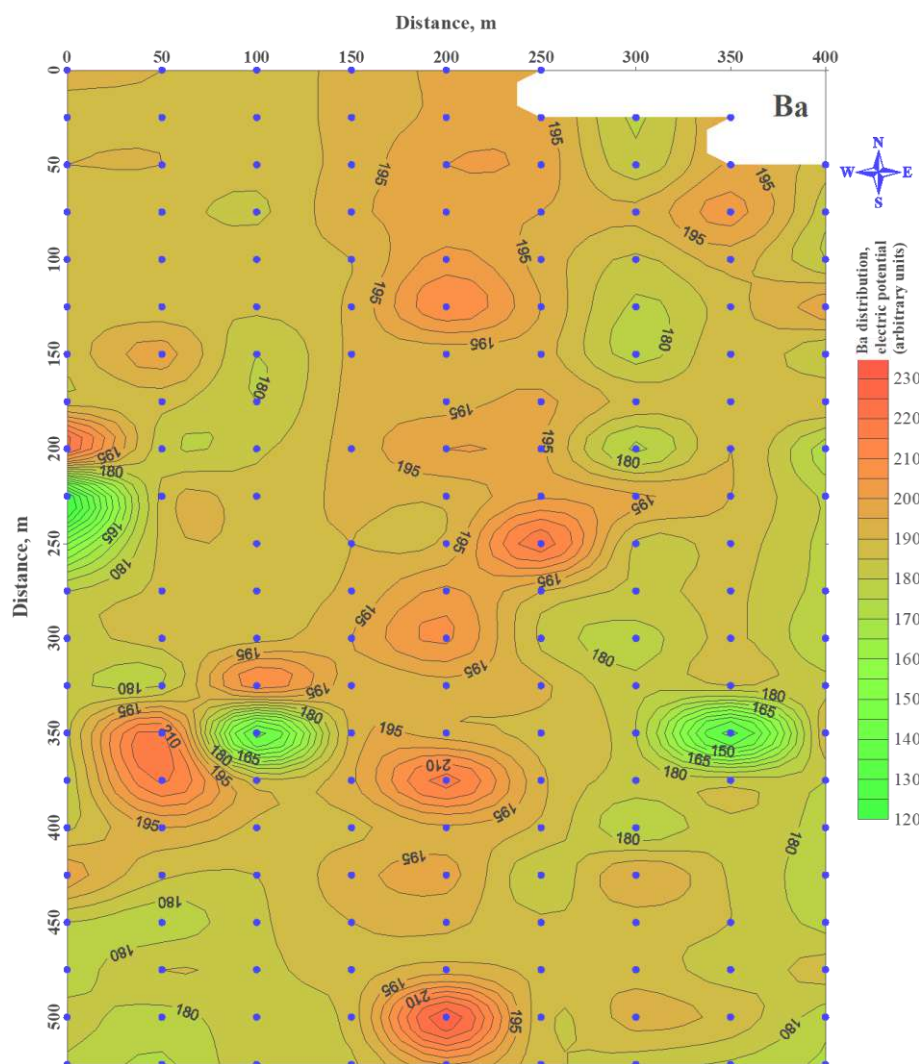


Fig. 12. Map of Ba^{2+} observations in area 'I' of the western Makhtesh Ramon

The minerals of the diamondiferous association in these samples can be divided into two groups. The *first group* includes chromediopside (e.g., Fig. 13a and 13b), orange garnet, bright crimson pyrope (e.g., Fig. 14), picroilmenite, chromspinel (e.g., Fig. 15), olivine, moissanite, perovskite, anatase, corundum, titanomagnetite, and tourmaline (including black species). This mineral list includes almost all the main satellite minerals of diamond. The total content of these minerals is very high (in 150 kg of concentrate, more than 15 000 grains were identified).

Chromediopside is a well-known satellite mineral of diamond. Orange garnets, bright crimson pyropes, and tourmalines also indicate diamondiferous associations in this area. Corundum and moissanite are even better satellite minerals in this regard (Mitchell, 1986; Ilupin et al., 1990; Kharkiv et al., 1997). Most associated mineral grains are not rounded or oxidized, sug-

gesting proximity to diamondiferous bedrock associations. Moissanite (SiC), widely known as a rare high-pressure mineral of mantle origin, offers an important window into oxygen-deficiency processes deep in the Earth. Researchers found moissanite samples in both Makhtesh Ramon (Eppelbaum et al., 2006) and the Qishon Valley (northern Israel) (Eskel et al., 2007; Griffin et al., 2016). For the first time, researchers found the 4H SiC polytype *in situ* in the Qishon Valley (Mukhin et al., 2015). A comprehensive examination of this sample indicates a mantle origin for the 4H SiC polytype and possible redox conditions in a significantly larger volume of the lithosphere in Israel than previously thought. A thick lithosphere is a prominent signature (together with other indicators) for the discovery of diamond-bearing regions (Ilupin et al., 1990; Mitchell, 1995; Morgan, 1995; Kutinov, Chistova, 2016).

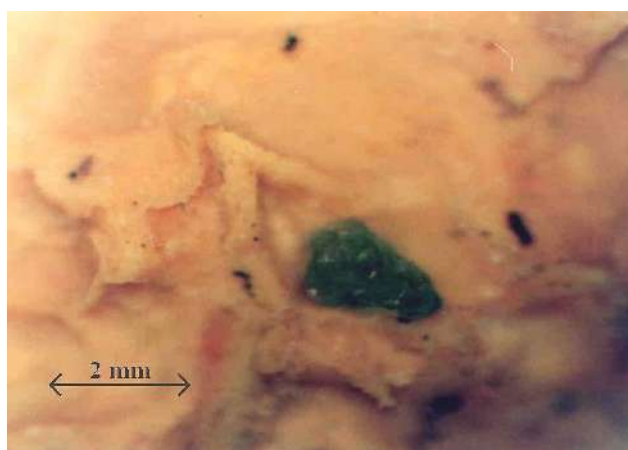


Fig. 13a. Crystal of chromediopside No. 1243 withdrawn in selected geological associations of the Makhtesh Ramon deposit

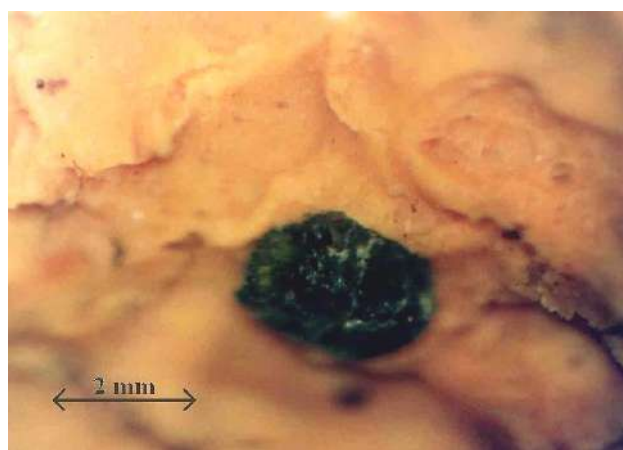


Fig. 13b. Crystal of chromediopside No. 1517 withdrawn in selected geological associations of the Makhtesh Ramon deposit

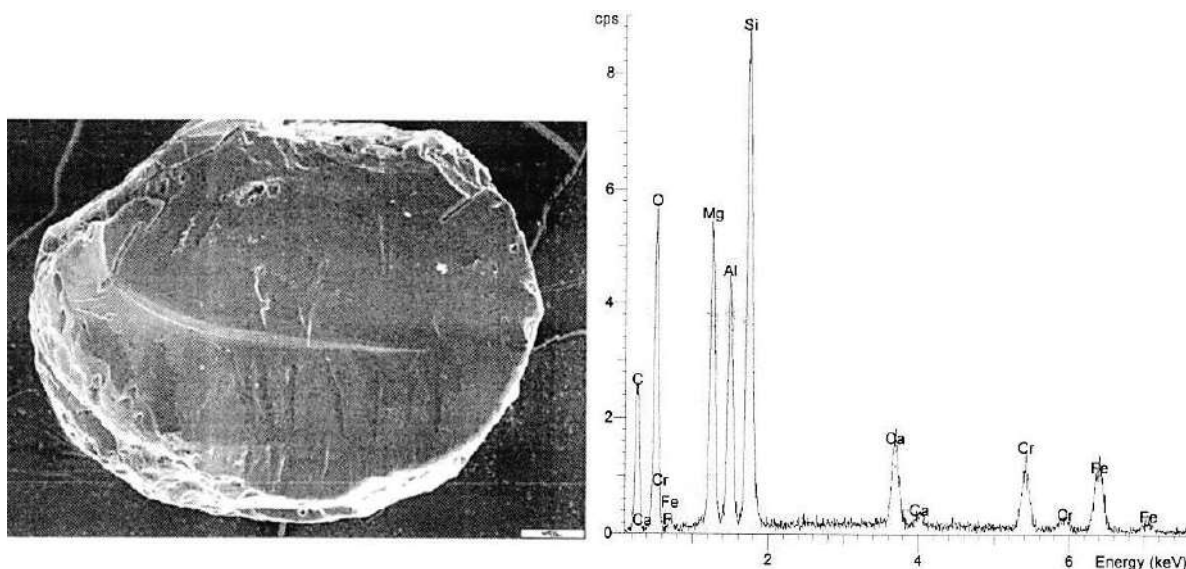


Fig. 14. Pyrope: back-scattered electron image (left) and electrodispersion spectrum (right)

The *second group* includes hexagonal quartz, feldspars, pyroxenes (black, green, dark-green, gray-green, brown-green), magnetite, hematite, ilmenite, galena, pyrite, limonite, small magnetic spheres, mica, hydro-mica, chromite, leucoxene, zircon (Fig. 16), rutile, secondary minerals of cuprum (green and blue), calcite, etc. These minerals, combined with the minerals of the first group, also suggest the diamond potential of this area.

Mineral coesite, identified in large volumes, is an important signature of the deep origin of the investigated rocks, according to Sobolev (2006).

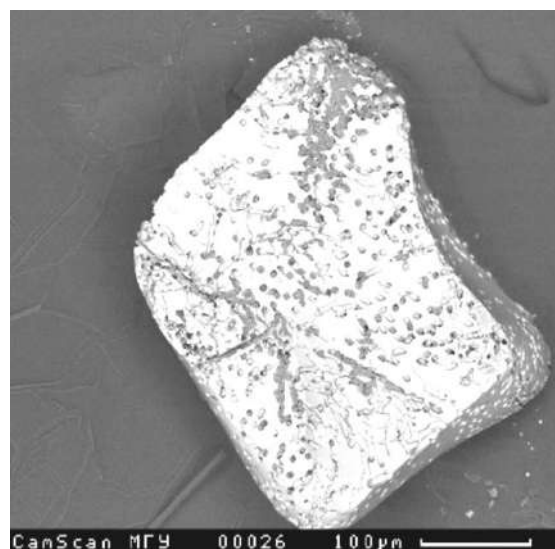


Fig. 15. Chromspinel. Back-scattered electron image

Examining rocks with fluoric and other acids revealed several gold and silver flakes, accompanied by traces of REE: La, Ce, Th, Nb, and Ta. These elements can also indicate proximity to kimberlitic rocks (Kaminsky et al., 1974; Le Roex et al., 2003; Shcheka et al., 2006; Giuliani et al., 2013).

Yttrium phosphate (Figs. 17a and 17b) is usually associated with the nearest kimberlite (Mitchell, 1986; Ilupin et al., 1990).

Experimental testing of detrital sediments from the western Makhtesh Ramon identified a set of minerals typical of an arid climate, multiply re-deposited from older deposits, and rounded in form: quartz, pyroxene, rutile, leucosene, zircon, and tourmaline (Eppelbaum, Vaksman, 2017). However, minerals of a “fresh pattern” are not rounded and are more stable in weathering conditions: green pyroxene, olivine, native silver, gypsum, calcite, barite, and feldspars. From the withdrawn samples, we selected a group of minerals with similar fragment size and weight (Table 1). However, their densities differ. This fact indicates that conventional gravitational concentration in this area may not be effective (Samykin et al., 2005). Therefore, in the Makhtesh Ramon area, an enhanced mineral concentration scheme (Surkov, 2000) was applied.

Due to microscopic analysis, 1459 grains were selected and measured from 8 sites (the results reflect only the preliminary stage of the investigations), among which were identified pyrope, garnet, diopside, chromediopside, ilmenite, tourmaline, spinel, rutile, pyroxenes, zircon (Table 2), as well as galena, pyrite, chalcopyrite, secondary minerals of cuprum, etc. (Eppelbaum et al., 2006). In probes selected from deposits of temporary flows (alluvium) and conglomerates (Table 3), all identified minerals occurred as secondary minerals.

As is noted in Table 3, many samples were collected in the dry channel ('wadi') of Nahal Ramon (Fig. 18).

We should underline the fact that minerals revealed in the possible diamondiferous association: pyrope, garnet, diopside, chromediopside, picroilmenite, ilmenite, and spinel (according to the investigations carried out using an optical microscope MBS-10) have no traces of wear (they are not smoothed), which indicates the occurrence of indigenous sources.

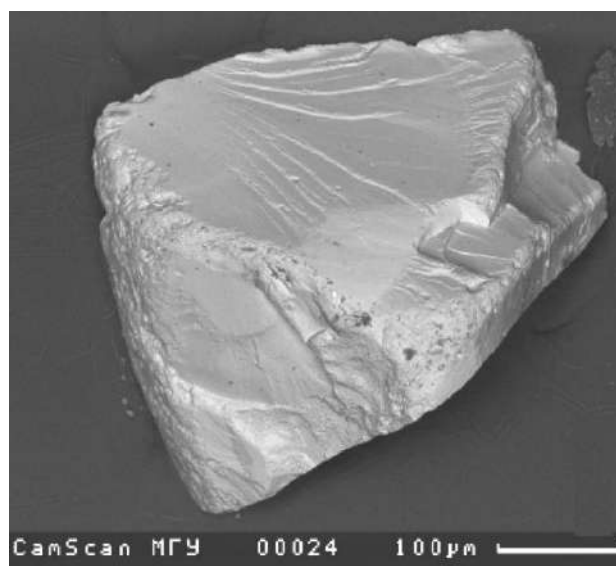


Fig. 16. Zircon. Back-scattered electron image

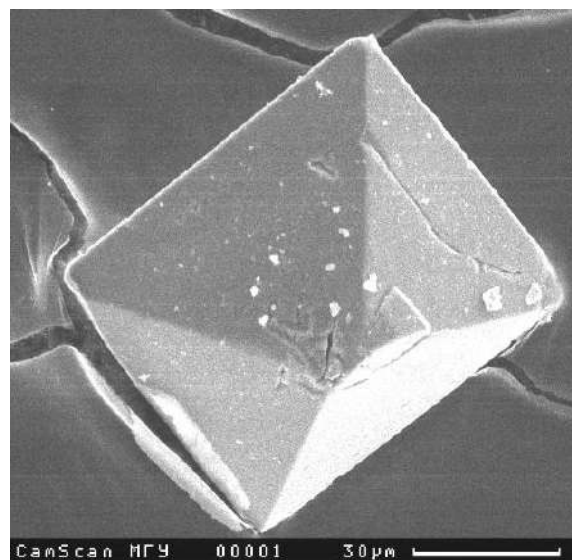


Fig. 17a. Back-scattered image of yttrium phosphate crystal

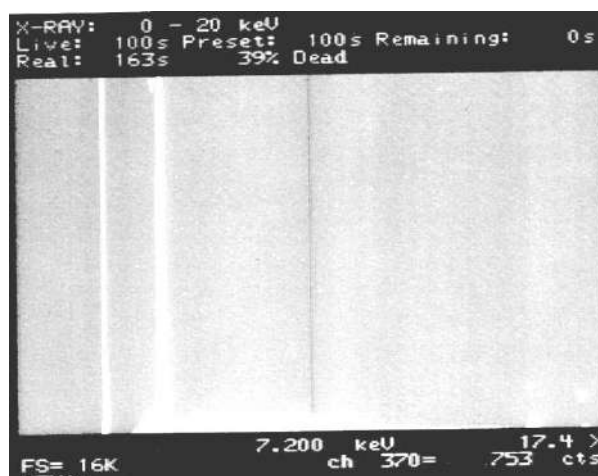


Fig. 17b. Energy dispersion spectrum of the yttrium phosphate crystal

We observed and examined all prerequisites for the presence of the desired diamondiferous associations (volcanism, structural-tectonic environments, and geomorphological conditions) (Eppelbaum et al., 2002, 2003, 2006). We studied the most representative mineral indicators

using the scanning electron microscope JSM-5300, which obtained images in reflected electrons and energy-dispersive spectra reflecting their chemical composition. Altogether, we studied about 100 minerals using the aforementioned methodology (preliminary stage).

Table 1

Results of some mineral investigations in the western Makhtesh Ramon area (southern Israel)
(after Eppelbaum et al., 2002)

N/n	Mineral	Size, mm	Average density, kg/m ³	Weight of crystal, milligrams
1	Olivine	1.36 x 1.20 x 0.72	3500	4.11
2	Diopside	1.34 x 1.19 x 0.79	3300	4.15
3	Diamond	1.35 x 1.15 x 0.75	3510	4.09
4	Ilmenite	1.36 x 1.16 x 0.55	4750	4.13
5	Gold	1.31 x 0.90 x 0.20	1740	4.18
6	Quartz	1.34 x 1.17 x 1.01	2650	4.19

Table 2

Results of detailed granulometric analysis of monofractions of possible genetic and dynamic indicators of diamonds (density of diamond $\rho = 3510 \text{ kg/m}^3$)

$\rho, \text{ kg/m}^3$		3580	3220	4750	3300	3270	3350	4210	4600	Σ
№	№ of sites	garnet	diopside	microilmenite	spinel	tourmaline	pyroxenes	rutile	zircon	
1	S1	-	-	7	-	1	-	1	-	9
2	S2 III.1	13	12	58	9	80	13	6	23	214
3	S2 congl.	11	24	59	4	75	55	169	95	492
4	S3	44	24	85	-	12	86	21	5	277
5	S3	-	2	5	-	23	-	59	14	103
6	S3	7	22	42	2	45	49	100	19	286
7	S4	2	2	10	-	17	10	12	1	54
8	S7	1	1	2	-	2	-	6	-	12
Σ		78	87	268	15	245	213	374	157	1447

Total number of measurements: **4341**



Fig. 18. Valley of temporary channel (“wadi”) Nahal-Ramon (western Makhtesh Ramon)

Table 3

Description of selected samples (western Makhtesh Ramon)

No. of sample	Volume, m ³	Weight, kg	Weight of concentrate, kg	Notes
S1	0.0025	7	0.3	Selected from small bore pit (0.3 m) in dry channel (Nahal Ramon)
S2	0.03	60	3.0	Cut out from the exposed conglomerates and crushed in a mortar till obtaining grain sizes of 1 mm
S2.III1	0.1	50	4.0	Selected from a small-bore pit with dimensions of 0.6 x 0.6 x 0.6 m in a dry channel, with the fraction less than 1.6 mm
S3	1.5	2000	10.0	Composed of four bore pits located at distance of 30 m between themselves in the channel of a dry rivulet, with a removal fraction less than 1.6 mm
S4	0.02	50	2.0	Cut out from the output of indigenous rocks with the following crushing and removing fraction less than 1.6 mm (tuff breccia)
S7	0.04	70	2.0	Cut out from the outputs of acid basaltoids with the following crushing in a mortar and removing the fraction less than 1.6 mm

A short description of the discovered main mineral indicators of diamonds is presented below.

Picroilmenite is a well-known high-pressure mineral of kimberlites (Haggerty, 1995; Nixon, 1995; Kharkiv et al., 1997). The mineral grating is composed of titanium, iron, and oxygen. As admixtures, Mg, Al, and Cr (possibly involved in microphases), and calcium (from calcite) were detected. The detected phase 'calcium-titan' from perovskite is also well-known in kimberlites (Haggerty, 1995; McClenaghan et al., 2000; Nixon, 1995). Such revealed admixtures as cobalt, nickel, and natural Ferrum (reflecting the ultrabasic consistency of magma) are also typical for kimberlites. Manganese reflects the exogenetic hydroxides and carbonaceous dust, increasing conductivity. Thus, the observed picroilmenite crystals correspond to known indicators of diamondiferous associations (Cullers et al., 1996; Griffin, Ryan, 1995; Mitchell, 1986, 1995). Electronic imaging indicates that the studied grains have a complex structure. Their micro-aggregates resemble nodules (micro-nodules) with little transport from the indigenous source (the crystal surface is not rolled).

Pyrope is one of the most important mineral indicators of diamond association (both for kimberlites and lamproites) (Mitchell, 1986; Nixon, 1995; Kharkiv et al., 1997). The studied grains are characterized by a light crimson and

red color with a lilac tint. The crystal surface is not rolled. Electron microscope examination indicates that the main elements are magnesium (magnesia pyrope), aluminum, silicon, and oxygen, confirming the visual diagnosis. Admixtures of chrome and magnesium in pyrope unambiguously indicate that the mineral originated under high pressures (large depths). Calcium clearly reflects the calcite micro-phases and carbon-rich dusting.

Pyroxenes were detected in the various probes selected in the area (from 3-5 up to 15 units of this mineral) (see Table 2). Pyroxenes are dark green, brown, and sometimes black. These minerals are also not eroded. Pyroxenes are essential components of kimberlites, along with products of alteration of ultrabasic and basic rocks. Most of the known diamondiferous associations contain these minerals (Bulanova, 1995; McClenaghan et al., 2000; Kharkiv et al., 1997).

Chromediopside is a well-known mineral associated with diamonds (Mitchell, 1986, 1995; McClenaghan et al., 2000; Nixon, 1995). A key peculiarity of this mineral is that it is unstable under alluvial transport and hypogene weathering (Marshall, Baxter-Brown, 1995; Mitchell, 1995; Kharkiv et al., 1997). This mineral is the generic isomorphic type of diopside-hedenbergite (Mitchell, 1995). Diopside contains mainly calcium, magnesium, silicon, and oxygen. Chrome admixture is rich in 7%

chrome and 18% MgO. The chromediopside samples studied are lighter in color than typical chromediopside grains. Titanium admixture is typical of such titanium varieties of ultrabasic rocks as kimberlites and lamproites. The mineral is hardly eroded, indicating the nearest occurrence of endogenic rocks.

Figure 19 presents the technological scheme for diamond recognition from the withdrawn concentrate. In addition to conventional procedures (grain-size separation, magnetic separation, visual identification, X-ray luminescence, electron microscopy, etc.), we used

concentrated solutions. We used these solutions ($3\text{HCl} + \text{HNO}_3$, HF) with boiling because many desired minerals were redeposited several times under the extremely arid climate of southern Israel (e.g., Bentor, 1969) and were covered by hard shells. Removing these shells was impossible without using these solutions (Eppelbaum et al., 2002). This also explains why diamonds were not found earlier in the area (excluding Flexer et al., 1988b). Applying the mentioned technological scheme at a final stage allowed us to discover numerous microdiamonds and several diamonds.

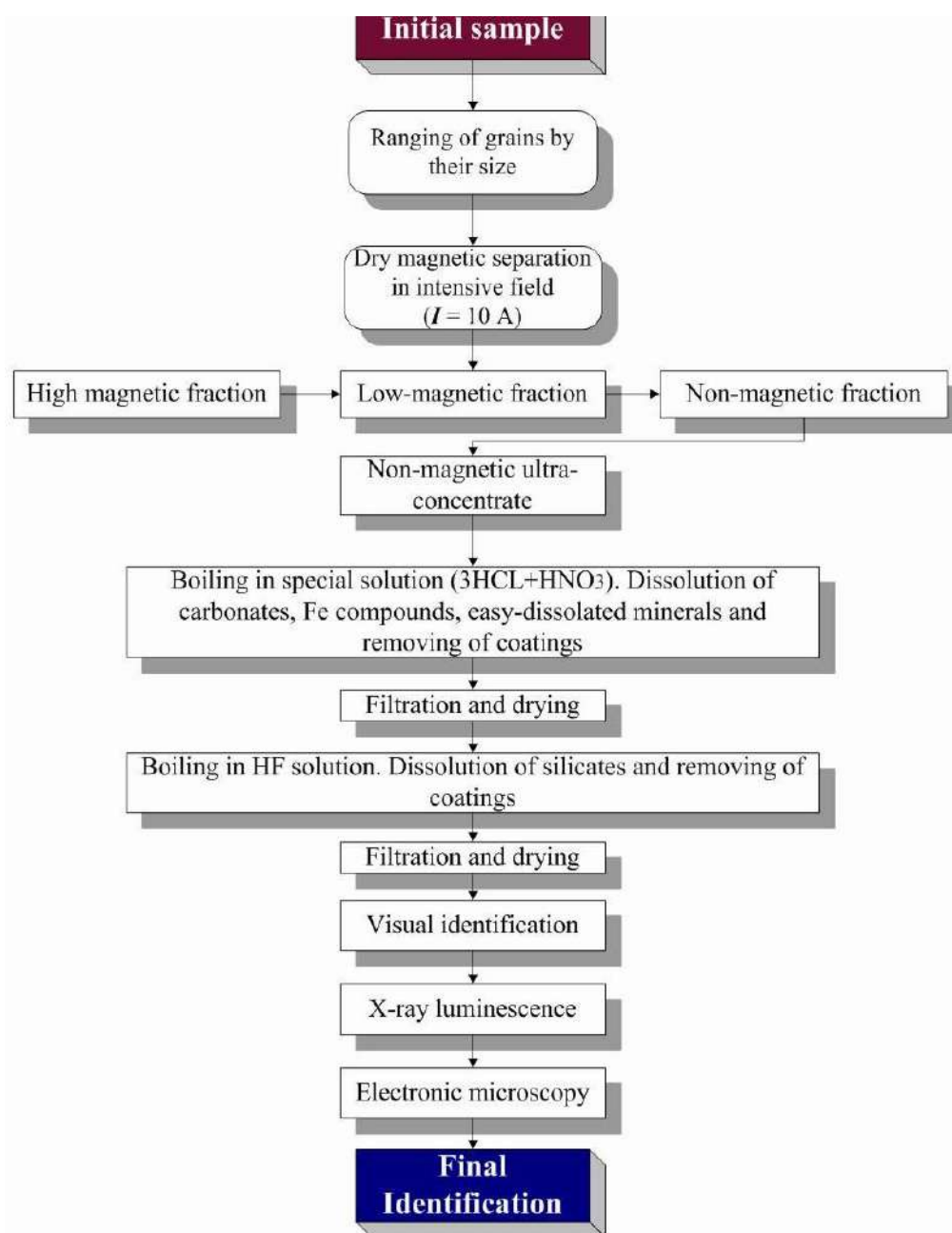


Fig. 19. Fractionation of selected samples of titanomagnetite association: A technological scheme

After conducting visual and qualitative/quantitative analyses using a binocular microscope, we investigated the polyminerals fractions using a Camscan-DV scanning electron microscope equipped with an energy-dispersive Link AN10000 microprobe. The most significant result was the discovery of more than 300 microdiamonds (< 1 mm and << 1 mm) and five

diamonds ranging from 1 to 1.35 mm (along the longest axis). Most of them were characterized by a cubic habit, and hexagonal species were less. Figure 20 shows a microdiamond associated with quartz. Two large discovered diamond crystals (which are fragments of a larger crystal (Surkov et al., 2008)) measured 1.35 mm (Fig. 21) and 1.20 mm.

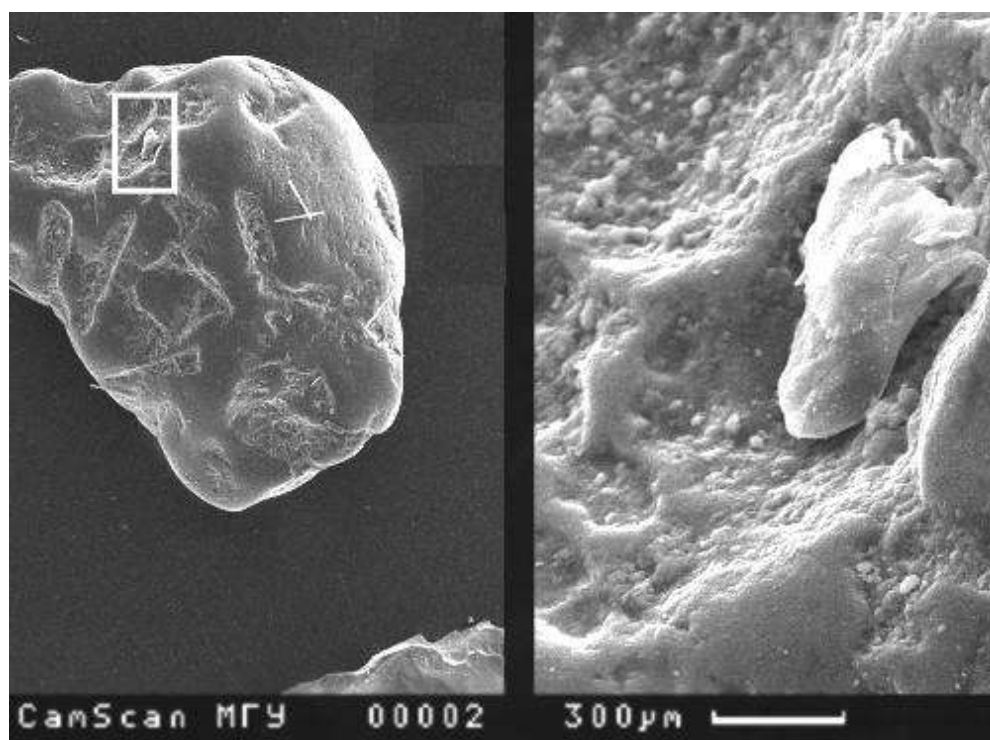


Fig. 20. Left panel: quartz with diamond. Right panel: enlarged image of the diamond. Back-scattered electron images

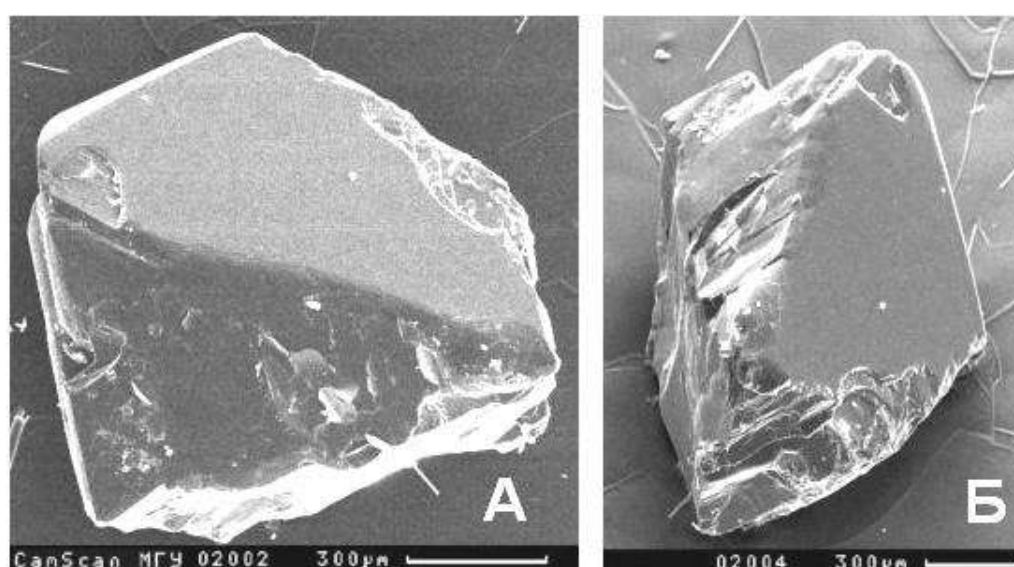


Fig. 21. The largest diamond crystal ever identified (A and B are the back-scattered electron images of the same crystal from different sides)

Figure 22 shows the chemical composition of the identified meimechite rock sample, which is very similar to kimberlite associations (e.g., Arndt et al., 1995; Eppelbaum et al., 2003).

In the western part of the Makhtesh Ramon Canyon, we studied exposed volcanic and volcanic-fragmentary rocks. These outcrops form hills up to 150 m high and, from a geological point of view, represent relics of volcanic flows (Bentor, 1952), for which columnar (prismatic) individuality is often typical. Sometimes small subvolcanic bodies break up these flows. Some outcrops show a typical presence of volcano-genic-fragmental rocks. Magmatic rocks are sometimes covered by Lower Cretaceous deposits that define the upper limit of the area's magmatic activity; at the same time, these rocks intrude rocks older than the Lower Triassic. Thus, geological data indicate that all magmatic activity occurred during the Lower Triassic–Upper Cretaceous (Bentor, 1952). K-Ar isotope dating determined the magmatic rocks' age to be about 125-115 Ma (Lang, Steinitz, 1985, 1989; Lang et al., 1988; Recanati et al., 1989).

We studied about 100 bright, transparent sections using a polarized microscope, an electronic microscope (Camscan 4DV), and an energy-dispersive microprobe analyzer (Link-10000). The effusive rocks were divided by

their composition into (1) plagioclase-containing and (2) not containing plagioclase.

The main volume of samples, withdrawn at point 100 (probes 100-15; 100-15A; 100-16) (Fig. 23) and points 124 and 125, consists of olivine, clinopyroxene, titanomagnetite, nepheline, and glass. Albite and potassic feldspars were sometimes recognized. The content of nepheline reaches 5-10%.

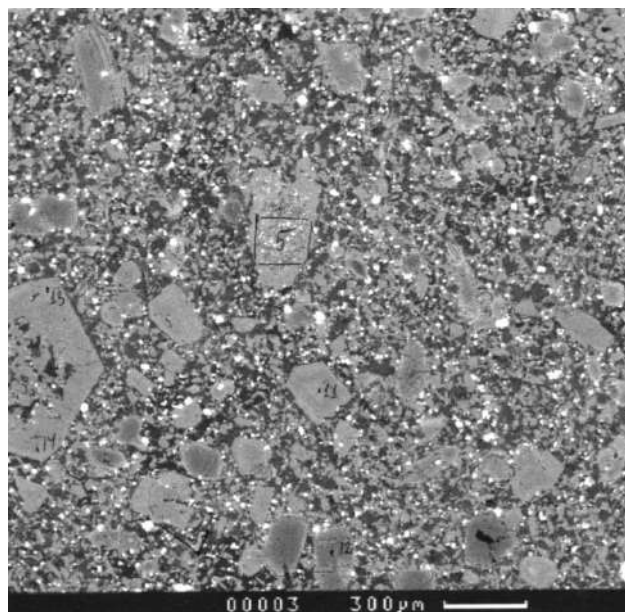


Fig. 22. Sample of meimechite rock. Back-scattered electron image

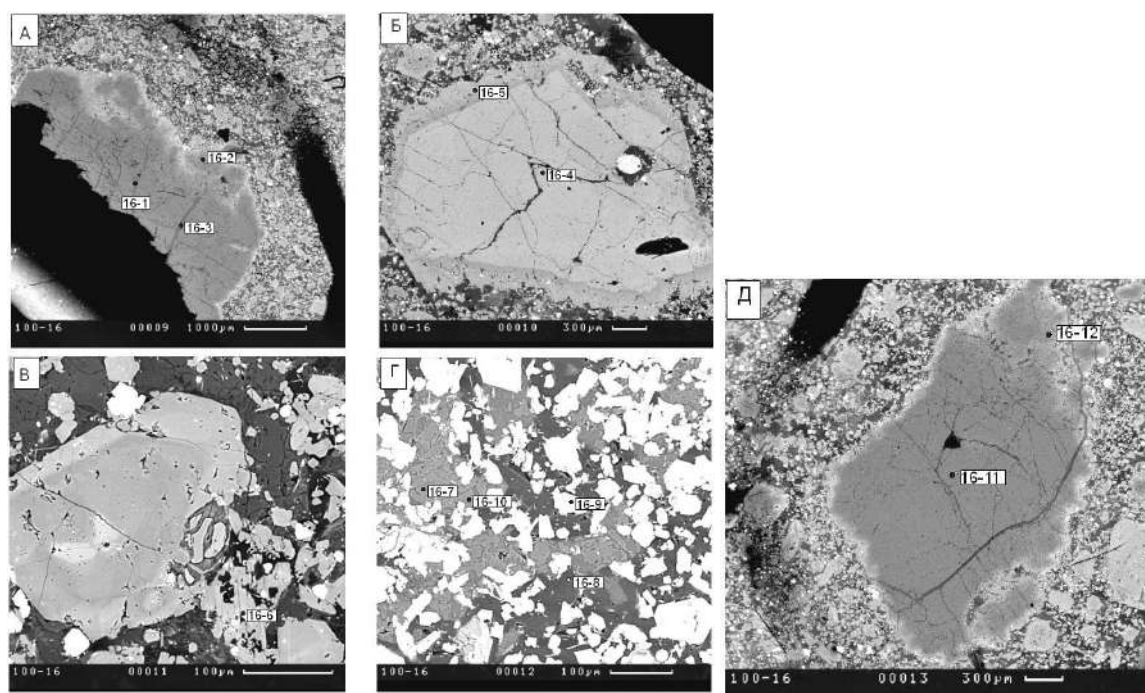


Fig. 23. Samples were withdrawn in probe № 100_16 in Makhtesh Ramon. **А** and **Д** – olivine of I and IV generations, **Б** and **В** – clinopyroxenes, **Г** – main mass presented by nepheline points 16-7 and 16-10), titanomagnetite (point 16-9), and glass (point 16-8)

Contains Cr_2O_3 in clinopyroxenes from the sedimentary deposits of the Makhtesh Ramon range in the range of 0.5-1.2% (Table 4; here only part of the measurements is presented); the content of FeO changes from 2.5 up to 6%, which is typical for chrome diopsides and kimberlites and other associations (deep inclusions, basalts, and carbonates) (Ilupin, 1984). The Al_2O_3 content in the studied clinopyroxenes ranges from 2.3 to 6.6%, and Na_2O from 0.5 to 1.5% (Table 4). The Al_2O_3 – Na_2O diagram of the studied clinopyroxenes (according to Ilupin's (Ilupin, 1984) classification) falls within the domain of chromediopsides in deep inclusions in basalts and kimberlites of North America. Comparison of the studied clinopyroxenes (western Makhtesh Ramon) with the chromediopsides from kimberlites of the "Arkhangelskaya" pipe (Winter Coast, Siberia, Russia) (Kharkiv et al., 1995) indicates that chromediopsides of sedimentary deposits of Makhtesh Ra-

mon are similar to low-baric group of clinopyroxenes generated from the disintegrated spinel peridotites propagating by magmatic melts from the upper mantle (spinel peridotites are a composite part of the deep spinel-pyroxene phase). Comparison of chromediopsides from the sedimentary deposits of Makhtesh Ramon (Eppelbaum et al., 2003) with the clinopyroxenes of the Zolotnitsky field of the Arkhangelsk province (Bogatikov et al., 1999) shows their close relationship to clinopyroxenes in diamondiferous lherzolites and websterites. Thus, chromediopsides of Makhtesh Ramon fall within the high-alumina, low-sodium field in diagrams by various authors. These inclusions may originate from deep basalt xenoliths (Ilupin, 1984), encountered in kimberlite pipes as fragments of spinel peridotites (Kharkiv et al., 1995), peridotites, and pyroxenes (Bogatikov et al., 1999).

Table 4

Composition of chrome clinopyroxenes (chromediopsides) from the sedimentary deposits in the western Makhtesh Ramon

	100/ 1_50	100/ 1_20	100/ 1_21	100/ 1_27	100/ 1_28	100/ 1_29	100/ 1_30	100/ 1_31	100/ 1_32	100/ 1_34	100/ 1_35
SiO_2	52.68	51.32	50.81	53.25	52.67	52.61	52.22	53.36	53.16	53.02	50.19
TiO_2	0.36	0.62	0.54	0.00	0.00	0.32	0.29	0.00	0.24	0.25	1.25
Al_2O_3	2.81	5.38	5.64	4.81	5.01	5.28	5.84	4.21	4.28	2.32	4.38
FeO	4.70	4.35	4.44	2.67	2.69	3.01	2.78	2.77	2.99	3.05	4.55
MnO	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	15.55	16.00	16.35	15.71	15.97	15.77	15.65	16.26	16.13	17.24	14.26
CaO	22.49	20.33	20.19	21.61	21.63	20.70	20.97	21.59	21.70	22.13	23.83
Na_2O	0.56	0.77	0.82	1.17	1.18	1.39	1.13	0.98	0.78	0.98	0.39
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr_2O_3	0.62	0.98	1.22	0.77	0.85	0.93	1.13	0.82	0.73	1.00	1.14
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	114/ 2_3	114/ 2_66	114/ 2_67	114/ 2_68	114/ 2_69	114/ 2_70	114/ 2_71	114/ 2_72	114/ 2_74	114/ 2_75	114/ 2_76
SiO_2	52.34	52.77	47.55	52.83	52.84	52.91	52.43	52.33	52.20	52.83	47.69
TiO_2	0.38	0.42	1.77	0.21	0.00	0.00	0.25	0.25	0.32	0.29	1.88
Al_2O_3	5.22	2.95	6.59	5.55	5.26	4.99	4.90	5.31	5.56	5.01	6.20
FeO	2.98	4.74	6.03	3.18	2.79	2.94	2.67	2.98	3.20	2.76	5.97
MnO	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	15.96	14.68	12.90	15.26	14.92	15.55	15.97	15.82	15.13	15.70	13.06
CaO	20.91	22.94	23.64	20.78	22.40	20.58	20.97	21.06	20.79	21.29	24.05
Na_2O	0.92	0.83	0.60	1.35	1.11	1.71	1.42	1.29	1.66	1.12	0.50
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr_2O_3	1.01	0.46	0.90	0.85	0.68	1.34	1.39	0.94	1.14	0.99	0.65
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Comprehensive mineralogical and geochemical analyses enabled the detection of several native small gold plates (Eppelbaum et al., 2003, 2006). The identified gold plates were investigated using Surkov's (2000) advanced methodology (Fig. 24). Lavi et al. (1988) earlier identified higher concentrations of gold and Rare Earth Elements (REE) in Makhtesh Ramon sediments. Flexer et al. (1988a) and Rosenfeld et al. (1989) have reported detecting some platinum-group elements in the vicinity of the Makhtesh Ramon area. Besides this, Adatte et al. (2005) found Platinum Group Elements in trace quantities in another member of the makhteshim family – Makhtesh Gadol.

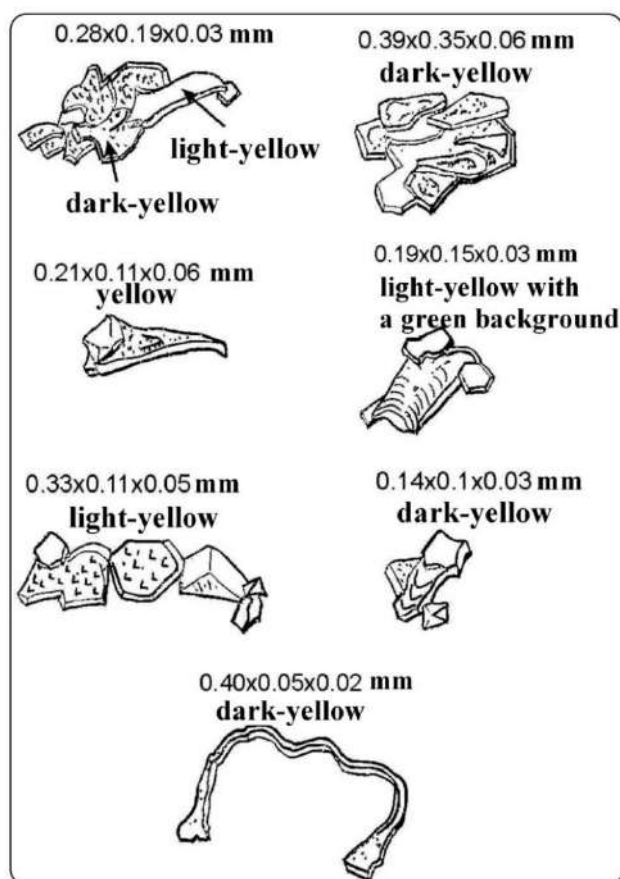


Fig. 24. Forms of native gold plates discovered in the channel deposits of Nahal Ramon in the western Makhtesh Ramon (Eppelbaum et al., 2006)

The presence of gold and platinum-group elements may also testify (Kaminsky et al., 1974; McDonald et al., 1995; Paul et al., 1979) to the nearest occurrence of basic kimberlite pipes. At the same time, gold, platinum, and REE may be important on their own. We propose that Makhtesh Ramon – the window to

Earth's upper mantle – contains a compound commercial ore deposit containing several strategically important elements.

Discussion and conclusions

The maximum number of kimberlite pipes that have been formed in the world (by radiometric data) is in the interval of 125-63.5 Ma (Katz, Eppelbaum, 1998). It coincides with the maximal magmatic activation in the region under study (120 Ma). The geophysical, tectonic, mineralogical, petrological, geochemical, and other factors described in the previous sections indicate the presence of rocks of abyssal origin (including diamondiferous and other economic components) in the Makhtesh Ramon area.

Analyzing the Makhtesh Ramon complex deposit (Eppelbaum et al., 2006) together with the discovery of diamonds and kimberlite indicator minerals in the Qishon Valley (northern Israel) (Eskel et al., 2007; Griffin et al., 2016), NW Syria (Mahfoud, 2002), and Central Eastern Desert, Egypt (Barakat, Kandil, 2019) resulted in a map showing the Eastern Mediterranean–Nubian diamondiferous belt (modified after Eppelbaum, Katz, 2012) (Fig. 25). The developed scheme can be used to predict further diamond discoveries in the region.

Available geological and geophysical data indicate that the Makhtesh Ramon area (southern Israel) is favorable for discovering a diamondiferous deposit (Eppelbaum et al., 2003, 2006). Judging from petrographic, geophysical, and geomorphological data, the diamondiferous sources are situated at shallow depths (Eppelbaum et al., 2002). Unfortunately, further investigations in the Makhtesh Ramon area are hampered because it is a state geological reserve where all mining is prohibited. However, further combined mineralogical, geochemical, and geophysical studies, integrated with mining works, will likely be rewarded with the discovery of diamondiferous rocks and other useful minerals. The presence of useful components such as gold and Rare Earth Elements (especially the latter) may be as significant as diamonds. Undoubtedly, this area may become a center of mining exploration in Israel (a country characterized by the world's most advanced diamond-manufacturing industry).

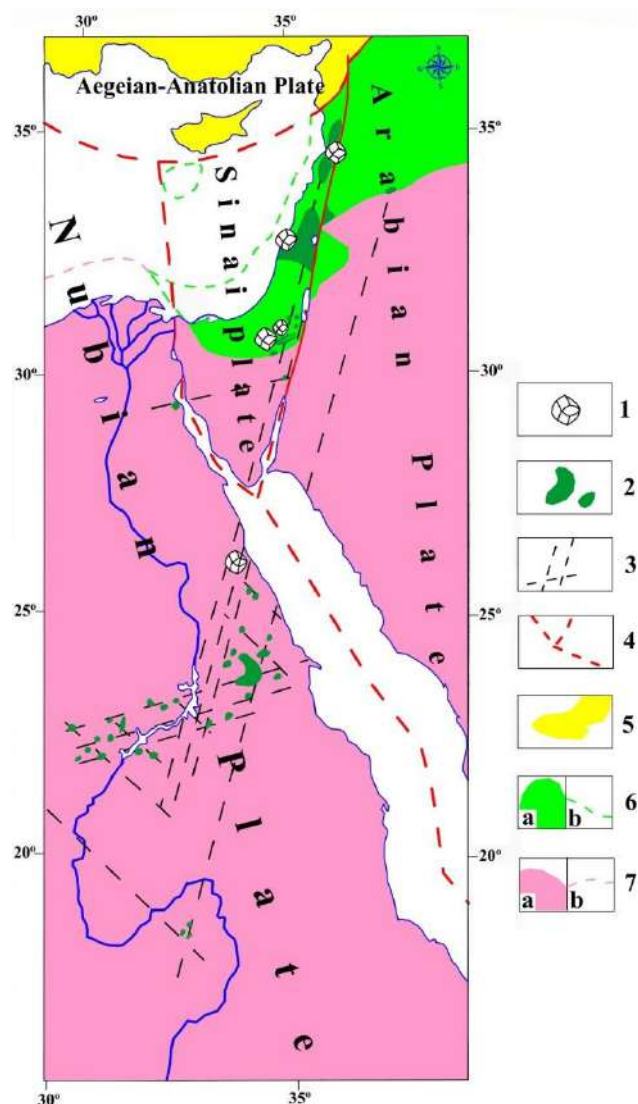


Fig. 25. East Mediterranean–Nubian diamondiferous belt. (1) areas of the diamond discovery (after Mahfoud, 2002; Eskel et al., 2007; Eppelbaum et al., 2006; Griffin et al., 2016; Barakat, Kandil, 2019), (2) Cretaceous magmatic, (3) Levantine-Nubian volcanic fault system, (4) boundaries between the tectonic plates, (5) Aegean-Anatolian plate, (6) province of the terrane belt with a thinned Precambrian crust (a – land, b – marine), (7) province located on the ancient Nubian-Arabian Precambrian platform (a – land, b – marine)

Analysis of the tectonic evolution model indicates that significant erosion processes substantially reduced the thickness of sedimentary deposits in the area studied. This allows the most cost-effective open-cut mining method.

The revealed horizons of technical water of superficial occurrence (e.g., Issar, 1983; Ben-David et al., 2002) are crucial for the process of withdrawn sample enrichment. A mild climate allows us to carry out integrated mining-geological work year-round while minimizing energy costs. Another important factor is the lack of jobs in nearby towns and settlements (creating a mining center may provide several hundred new jobs). Finally, the projected water channel between the Red and Dead Seas (Abu Ghazleh et al., 2009; Fine, 2018) is located near the discovered deposit, which will allow us to connect additional communication (including the channel and railway) and electric (hydroelectric power station) capacities.

A very simplified calculation may be carried out using elementary principles of probability theory. We have six independent indicators (regional tectonics, regional geophysics, local geophysics, mineralogy, petrology, and geochemistry) that positively estimate the diamond bearing of the Makhtesh Ramon area. For simplicity, let's treat these indicators as equivalent and assign each a weight of $\frac{1}{2}$. The significance of mineralogical indicators (revealing diamonds and indicator minerals) is greatly higher than $\frac{1}{2}$. The probability of the random coincidence of these factors (according to the trivial rules of probability theory (e.g., Korolov, Sinai, 2007)) in this case is $(\frac{1}{2})^6 = 0.0156 = 1.56\%$; e.g., the positive assessment of the diamond-bearing potential of the Makhtesh Ramon area is 98.44%. Really, this parameter is higher.

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REFERENCES

- Abu Ghazleh S., Hartmann J., Jansen N., Kempe S. Water input requirements of the rapidly shrinking Dead Sea. *Naturwissenschaften*, Vol. 96, No. 5, 2009, pp. 637-643, <https://doi.org/10.1007/s00114-009-0514-0>.
- Adate T., Keller G., Stüben D., Harting M., Kramar U., Stinnesbeck W., Abramovich S., Benjamini C. Late Maas-trichtian and K/T paleoenvironment of the eastern Tethys (Israel): mineralogy, trace and platinum group elements, biostratigraphy and faunal turnovers. *Bulletin de la Société Géologique de France*, Vol. 176, No. 1, 2005, pp. 37-55, <https://doi.org/10.2113/176.1.37>.

- Ahrens L.H., Dawson J.B., Duncan A.R., Erlank A.J. (Eds.). *Physics and Chemistry of the Earth*, Vol. 9. Selected Papers presented at the First International Conference on Kimberlites (Cape Town, 1973). Pergamon Press, 1975.
- Arndt N., Lehnert K., Vasil'ev Y. Meimechites: highly magnesian lithosphere-contaminated alkaline magmas from deep subcontinental mantle. *Lithos*, Vol. 34, No. 1-3, 1995, pp. 41-59, [https://doi.org/10.1016/0024-4937\(95\)90009-8](https://doi.org/10.1016/0024-4937(95)90009-8).
- Avni Y. Structure and landscape evolution of the Makhteshim Country – interrelations between monoclines, truncation surfaces and the evolution of the Makhteshim. In: Krasnov B. and Mazor E. (eds.) *The Makhteshim Country: A Laboratory of Nature*. Pensoft, Bulgaria, Sofia, 2001a, pp. 33-58.
- Avni Y. Har Loz, Sheet 21-III. Geological Map of Israel 1:50,000. Geological Survey of Israel, Jerusalem, 2001b.
- Avni Y., Beker A., Zilberman E. Be'erot Oded, Sheet 21-IV. Geological Map of Israel 1:50,000. Geological Survey of Israel, Jerusalem, 2017.
- Baer G. Flow directions in sills and dikes and formation of cauldrons in eastern Makhtesh Ramon. *Israel Journal of Earth Sciences*, Vol. 42, 1993, pp. 133-148.
- Baer G., Heimann A., Eshet Y., Weinberger R., Mussett A., Sherwood G. The Saharonim Basalt: A Late Triassic – Early Jurassic intrusion in southeastern Makhtesh Ramon, Israel. *Israel Journal of Earth Sciences*, Vol. 44, 1995, pp. 1-10.
- Baer G., Frieslander U., Goldman M. The Red Valley – an Early Cretaceous Caldera in eastern Makhtesh Ramon. *Israel Journal of Earth Sciences*, Vol. 38, 1989, pp. 163-172.
- Baer G., Reches Z. Mechanics of emplacement and tectonic implications of the Ramon dike systems, Israel. *Journal of Geophysical Research*, Vol. 96, No. B7, 1991, pp. 11895-11910, <https://doi.org/10.1029/91JB00371>.
- Barakat A.A., Kandil S.M.R. Diamond in the newly discovered kimberlite and related rocks, Central Eastern Desert, Egypt. In: *Magmatism of the Earth and Related Strategic Metal Deposits. Proceedings of XXXVI International Conference*, St. Petersburg University, Russia, May 23-26, 2019, pp. 36-42.
- Ben-Avraham Z., Ginzburg A., Makris J., Eppelbaum L. Crustal structure of the Levant Basin, eastern Mediterranean. *Tectonophysics*, Vol. 346, Issues 1-2, 2002, pp. 23-43, [https://doi.org/10.1016/S0040-1951\(01\)00226-8](https://doi.org/10.1016/S0040-1951(01)00226-8).
- Ben-David R., Eyal Y., Zilberman E., Bowman D. Fluvial systems response to rift margin tectonics: Makhtesh Ramon area, southern Israel. *Geomorphology*, Vol. 45, Issues 1-2, 2002, pp. 147-163, [https://doi.org/10.1016/S0169-555X\(01\)00194-5](https://doi.org/10.1016/S0169-555X(01)00194-5).
- Ben-David R., Mazor E. Stages in the evolution of Makhtesh Ramon and its drainage system. *Israel Journal of Earth Sciences*, Vol. 37, No. 2-3, 1988, pp. 125-135.
- Benjamini C. The geological history of central and southern Israel during the Eocene. Ph.D. Thesis, Hebrew University, Jerusalem, 1979, pp. 1-41.
- Bentor Y.K. Magmatic intrusions and lava sheets in the Ramon area in the Negev (Southern Israel). *Geological Magazine*, Vol. 89, No. 2, 1952, pp. 129-140, <https://doi.org/10.1017/S0016756800067479>.
- Bentor Y.K. On the evolution of subsurface brines in Israel. *Chemical Geology*, Vol. 4, Issues 1-2, 1969, pp. 83-110, [https://doi.org/10.1016/0009-2541\(69\)90041-2](https://doi.org/10.1016/0009-2541(69)90041-2).
- Bentor Y.K., Vroman A., Zak I. The geological map of Israel, scale 1:250,000, southern sheet. Geological Survey of Israel, 1965.
- Bobrievich A.P., Bondarenko M.N., Gnevushev M.A., Krasov L.M., Smirnov G.I., Yurkevich R.K. Diamond deposits of Yakutia. Sobolev V.S. (ed.). *Gosnauchtekhizdat*, Moscow, 1959, 526 p. (in Russian)
- Bogatikov O.A., Vasilyeva E.R., Verzhak V.V., Verichev E.M., Garanin V.K., Kononova V.A., Kudryavtseva G.P., Parsadanyan K.S., Posukhova T.V. Arkhangelsk diamondiferous province (geology, petrography, geochemistry and mineralogy). Bogatikov O.A. (ed.). Moscow State University Press, Moscow, 1999, 524 p. (in Russian)
- Bulanova G.P. The formation of diamond. *Journal of Geochemical Exploration*, Vol. 53, Issues 1-3, 1995, pp. 1-23, [https://doi.org/10.1016/0375-6742\(94\)00016-5](https://doi.org/10.1016/0375-6742(94)00016-5).
- Chang S.-J., van der Lee S. Mantle plumes and associated flow beneath Arabia and East Africa. *Earth and Planetary Science Letters*, Vol. 302, Issues 3-4, 2011, pp. 448-454, <https://doi.org/10.1016/j.epsl.2010.12.050>.
- Cherepanova Y., Artemieva I.M., Thybo H., Chemia Z. Crustal structure of the Siberian craton and the West Siberian basin: An appraisal of existing seismic data. *Tectonophysics*, Vol. 609, 2013, pp. 154-183, <https://doi.org/10.1016/j.tecto.2013.05.004>.
- Condie K.C. *Mantle Plumes and Their Record in Earth History*. Cambridge University Press, Cambridge, 2001, <https://doi.org/10.1017/CBO9780511810589>.
- Cullers R.L., Dorais M.J., Berendsen P., Chaudhuri S. Mineralogy and petrology of Cretaceous lamproite sills, southeastern Kansas, USA. *Lithos*, Vol. 38, Issues 3-4, 1996, pp. 185-206, [https://doi.org/10.1016/0024-4937\(96\)00010-2](https://doi.org/10.1016/0024-4937(96)00010-2).
- Dembo N., Kraus E., Seliverstov I., Weissman G., Granot R. Geomagnetic field behaviour during the early Cretaceous Normal Superchron from palaeomagnetic analysis of the Ramon Volcanics, Israel. *Geophysical Journal International*, Vol. 231, Issue 3, 2022, pp. 1982-1995, <https://doi.org/10.1093/gji/ggac300>.
- Eppelbaum L.V. (Ed.) *New Developments in Paleomagnetism Research. Earth Sciences in the 21st Century*. Nova Science Publishers, New York, 2015, 195 p.
- Eppelbaum L.V. Review of processing and interpretation of self-potential anomalies: Transfer of methodologies developed in magnetic prospecting. *Geosciences*, Vol. 11, Issue 5, 2021, pp. 1-31, <https://doi.org/10.3390/geosciences11050194>.

- Eppelbaum L., Ben-Avraham Z., Katz Y. Does mantle diapir produce Hebron magnetic anomaly? Transactions of the Conference of the Israel Geological Society, Annual Meeting, Moshabim Country Logging (Negev), Israel, 2005, p. 26.
- Eppelbaum L.V., Ben-Avraham Z., Katz Y.I., Cloetingh S., Kaban M.K. Giant quasi-ring mantle structure in the African-Arabian junction: Results derived from the geological-geophysical data integration. *Geotectonics* (Springer), Vol. 55, No. 1, 2021, pp. 58-82, <https://doi.org/10.1134/S0016852121010052>.
- Eppelbaum L.V., Katz Y.I. Mineral deposits in Israel: A contemporary view. In: Ya'ari A. and Zahavi E.D. (eds.) *Israel: Social, Economic and Political Developments*. Nova Science Publishers, Inc. New York, 2012, pp. 1-41.
- Eppelbaum L.V., Katz Y.I. Eastern Mediterranean: Combined geological-geophysical zonation and paleogeodynamics of the Mesozoic and Cenozoic structural-sedimentation stages. *Marine and Petroleum Geology*, Vol. 65, 2015, pp. 198-216, <https://doi.org/10.1016/j.marpetgeo.2015.04.008>.
- Eppelbaum L.V., Katz Y.I., Ben-Avraham Z. Geodynamic aspects of magnetic data analysis and tectonic-paleomagnetic mapping in the Easternmost Mediterranean: A review. *Applied Sciences*, Special Issue "Ground-Based Geomagnetic Observations: Techniques, Instruments and Scientific Outcomes", Vol. 13, No. 18, Article number 10541, 2023, <https://doi.org/10.3390/app131810541>.
- Eppelbaum L.V., Katz Y.I., Ben-Avraham Z. Giant quasi-ring mantle structure beneath the Eastern Mediterranean: Interpretation of new magnetic, paleobiogeographic, and seismic tomography data. *Geotectonics*, Vol. 59 No. 2, 2025, pp. 101-126, <https://doi.org/10.1134/S001685212570013X>.
- Eppelbaum L.V., Khesin B.E. *Geophysical Studies in the Caucasus*. Springer. Heidelberg – N.Y., 2012, 441 p.
- Eppelbaum L.V., Khesin B.E., Itkis S.E., Ben-Avraham Z. Advanced analysis of self-potential data in ore deposits and archaeological sites. In: *Proceeding of the 10th European Meeting of Environmental and Engineering Geophysics*, Utrecht, the Netherlands, 2004, pp. 1-4, <https://doi.org/10.3997/2214-4609-pdb.10.P054>.
- Eppelbaum L., Kouznetsov S., Vaksman V., Klepatch C., Smirnov S., Sazonova L., Korotaeva N., Surkov A., Itkis S., Shemesh M. Results of integrated geological-geophysical examination of Makhtesh Ramon area (southern Israel) on diamond-bearing associations. *Proceedings of SPIE – The International Society for Optical Engineering*, Vol. 5239, Barcelona, Spain, 2003, pp. 109-120, <https://doi.org/10.1117/12.512403>.
- Eppelbaum L.V., Pilchin A.N. Methodology of Curie discontinuity map development for regions with low thermal characteristics: An example from Israel. *Earth and Planetary Science Letters*, Vol. 243, Issues 3-4, 2006, pp. 536-551, <https://doi.org/10.1016/j.epsl.2006.01.003>.
- Eppelbaum L.V., Vaksman V.L. Makhtesh Ramon Complex Deposit (Southern Israel) – A Window to the Upper Mantle. *International Journal of Mining Sciences*, Vol. 3, Issue 1, 2017, pp. 1-28, <https://doi.org/10.20431/2454-9460.0301001>.
- Eppelbaum L.V., Vaksman V.L., Klepatch C.A., Modin I., Kouznetsov S.V., Surkov A.V., Korotaeva N.N., Smirnov S.A., Bezlepkin B.A. Discovering of diamondiferous association in the Makhtesh Ramon area, Negev Desert (Southern Israel). *Romanian Journal of Mineral Deposits*, Vol. 80, 2002, pp. 25-28.
- Eppelbaum L.V., Vaksman V.L., Kouznetsov S.V., Sazonova L.M., Smirnov S.A., Surkov A.V., Bezlepkin B.M., Katz Y.I., Korotaeva N.N., Belovitskaya G.I. Discovering of microdiamonds and minerals-satellites in Canyon Makhtesh Ramon (Negev Desert, Israel). *Doklady Earth Sciences* (Springer), Vol. 407, No. 2, 2006, pp. 202-204, <https://doi.org/10.1134/S1028334X06020097>.
- Eskel M., Kalmanovich E., Roup A. The diamonds and kimberlite indicative minerals within the context of stratigraphy and source in Shefa Yamim drill SY-15, Pliocene-Pleistocene, Qishon River Valley, Israel. Transactions of the Conference of the Israel Geological Society, Annual Meeting, Neve Zohar, Dead Sea, Israel, 2007, p. 29.
- Eyal M., Becker A., Samoylov V. Mt. Arod – an Early Cretaceous basanitic volcano with a fossil lava lake. *Israel Journal of Earth Sciences*, Vol. 45, No. 1, 1996, pp. 31-38.
- Flexer A., Rosenfeld A., Honigstein A. The periodicity of possible extraterrestrial signatures in the Mesozoic-Cenozoic succession of Israel. Transactions of the Conference of the Israel Geological Society Annual Meeting, En Boqeq, 1988a, pp. 27-28.
- Flexer A., Rosenfeld A., Honigstein A., Dvorachek M. A microdiamond additional support for extraterrestrial signatures near the K/T boundary in Israel. *Lunar and Planetary Science Conference*, 19th, Abstracts, Vol. 1, Houston, 1988b, p. 337.
- Folkman Y., Yuval Z. Aeromagnetic map of Israel, 1:250,000. Israel Institute for Petroleum Research and Geophysics, Holon, Israel, 1976.
- Garfunkel Z. The Arod Pass area: structural-stratigraphic relations and their implications for the history of the Ramon lineament. *Israel Journal of Earth Sciences*, Vol. 42, 1993, pp. 165-175.
- Garfunkel Z., Derin B. Reevaluation of the latest Jurassic-Early Cretaceous history of the Negev and the role of magmatic activity. *Israel Journal of Earth Sciences*, Vol. 37, No. 2-3, 1988, pp. 43-52.
- Garfunkel Z., Katz A. New magmatic features in Makhtesh Ramon, southern Israel. *Geological Magazine*, Vol. 104, Issue 6, 1967, pp. 608-629, <https://doi.org/10.1017/S0016756800050275>.
- Giuliani A., Kamenetsky V.S., Kendrick M.A., Phillips D., Wyatt B.A., Maas R. Oxide, sulphide and carbonate minerals in a mantle polymict breccia: metasomatism by proto-kimberlite magmas, and relationship to the kimberlite megacrystic suite. *Chemical Geology*, Vol. 353, 2013, pp. 4-18, <https://doi.org/10.1016/j.chemgeo.2012.09.025>.

- Green H.W. II, Gueguen Y. Origin of kimberlite by diapiric upwelling in the upper mantle. *Nature*, Vol. 249, 1974, pp. 617-620, <https://doi.org/10.1038/249617a0>.
- Griffin W.L. Major transformations reveal Earth's deep secrets. *Geology*, Vol. 36, No. 1, 2008, pp. 95-96, <https://doi.org/10.1130/focus012008.1>.
- Griffin W.L., Gain S.E.M., Adams D.T., Huang J-X., Saunders M., Toledo V., Pearson N.J., O'Reilly S.Y. First terrestrial occurrence of tistarite (Ti₂O₃): Ultra-low oxygen fugacity in the upper mantle beneath Mount Carmel, Israel. *Geology*, Vol. 44 No. 10, 2016, pp. 815-818, <https://doi.org/10.1130/G37910.1>.
- Griffin W.L., Ryan C.G. Trace elements in indicator minerals: area selection and target evaluation in diamond exploration. *Journal of Geochemical Exploration*, Vol. 53, Issue 1-3, 1995, pp. 311-337, [https://doi.org/10.1016/0375-6742\(94\)00015-4](https://doi.org/10.1016/0375-6742(94)00015-4).
- Gvartzman Z., Bartov Y., Garfunkel Z., Rotstein Y. Mesozoic magmatism in the central Negev (southern Israel): implications from magnetic anomalies. *Israel Journal of Earth Sciences*, Vol. 43, Issue 1, 1994, pp. 21-38.
- Gvartzman Z., Weinberger R. Interpretation of Ramon basalt anomalies: Magnetic modeling and a paleomagnetic study. *Israel Journal of Earth Sciences*, Vol. 43, No. 1, 1994, pp. 47-53.
- Gvartzman G., Weissbrod T., Baer G., Brenner J. The age of Aptian stage and its magnetic events: new Ar-Ar ages and paleomagnetic data from the Negev, Israel. *Cretaceous Research*, Vol. 17, Issue 3, 1996, pp. 293-310, <https://doi.org/10.1006/cres.1996.0021>.
- Haggerty S.E. Upper mantle mineralogy. *Journal of Geodynamics*, Vol. 20, Issue 4, 1995, pp. 331-364, [https://doi.org/10.1016/0264-3707\(95\)00016-3](https://doi.org/10.1016/0264-3707(95)00016-3).
- Hall J.K., Krashennnikov V.A., Hirsch F., Benjamini C., Flexer A. (Eds.). *Geological Framework of the Levant*. Vol. II: The Levantine Basin and Israel. Historical Productions-Hall, Jerusalem, 2005, 826 p.
- Ilupin I.P. Discovery of "kimberlite" minerals in non-kimberlite igneous rocks. *Transactions of TsNIGRI*, No. 188, 1984, pp. 46-51. (in Russian)
- Ilupin I.P., Vaganov V.I., Prokopchuk B.I. Kimberlites. *Nedra*, Moscow, 1990, 248 p. (in Russian)
- Issar A. Emerging groundwater, a triggering factor in the formation of the Makhteshim (erosion cirques) in the Negev and Sinai. *Israel Journal of Earth Sciences*, Vol. 32, Issues 1-2, 1983, pp. 53-61.
- Itamar A. Polymetallic mineralization in Makhtesh Ramon and Har Arif, Central Negev, Israel. *Geological Survey of Israel, Bulletin No. 80*, Jerusalem, 1988, 56 p.
- Fine S.L. Conduit for Peace in the Middle East: An Analysis of the Red Sea-Dead Sea Water Conveyance Project. *Harvard Environment Law Review* (online). March 12, 2018. Conduit for Peace in the Middle East: An Analysis of the Red Sea-Dead Sea Water Conveyance Project – Harvard Environmental Law Review (last visited 11.10.2026).
- Kaminsky F.V., Feldman A.A., Varlamov V.A., Boyko A.N., Olofinsky L.N., Shofman I.L., Vaganov V.I. Prognostication of primary diamond deposits. *Journal of Geochemical Exploration*, Vol. 53, Issues 1-3, 1995, pp. 167-182, [https://doi.org/10.1016/0375-6742\(94\)00019-8](https://doi.org/10.1016/0375-6742(94)00019-8).
- Kaminsky F.V., Frantenson Ye.V., Khvostova V.P. First information on platinum metals (Pt, Pd, Rh, Ir, Ru, Os) in kimberlitic rocks. *Proceedings of the Academy of Sciences of the USSR, Earth Science Sections*, Vol. 219, 1974, pp. 190-193.
- Katz Y.I., Eppelbaum L.V. Larson's Mid-Cretaceous Superplume Effect and a new look to Israeli territory as perspective to kimberlite pipes discovering. *Transactions of the Annual Meeting of the Geological Society of America*, Toronto, Canada, Section: Planetary Geology, Vol. 30, No. 7, 1998, p. A289.
- Kharkiv A.D., Zinchuk N.N., Kruchkov A.I. Geological-Genetical Foundations of Schlich-Mineralogical Method of Searching Diamond Deposits. *Nedra Publ.*, Moscow, 1995, 348 p. (in Russian)
- Kharkiv A.D., Zinchuk N.N., Zuev V.M. The History of Diamond. *Nedra*, Moscow, 1997, 602 p. (in Russian)
- Khesin B.E., Alexeyev V.V., Eppelbaum L.V. Interpretation of Geophysical Fields in Complicated Environments. *Modern Approaches in Geophysics*, Vol. 14. Springer. Dordrecht, 1996, XII, 353 p., <https://doi.org/10.1007/978-94-015-8613-9>.
- Korolov L., Sinai Y.G. *Theory of Probability and Random Processes*. 2nd Edition, Springer, Berlin-Heidelberg, 2007, XI, 358 p., <https://doi.org/10.1007/978-3-540-68829-7>.
- Kutinov Yu.G., Chistova Z.B. Arkhangelsk diamondiferous province on small-scale geological, tectonic and geophysical maps. *Space and Time*, Vol. 11, No. 1, 2016. (in Russian)
- Lang B., Hebeda E.H., Priem H.N.A., Steinitz G., Verdurmen E.A.Th. K-Ar and Rb-Sr ages of Early Cretaceous magmatic rocks from Makhtesh Ramon, southern Israel. *Israel Journal of Earth Sciences*, Vol. 37, No. 2-3, 1988, pp. 65-72.
- Lang B., Steinitz G. New K-Ar ages of Mesozoic magmatic rocks in Makhtesh Ramon. *Geological Survey of Israel, Jerusalem. Transactions of the Annual Meeting of the Israel Geological Society*, Yotvata, 1985, pp. 56-57.
- Lang B., Steinitz G. K-Ar dating of Mesozoic magmatic rocks in Israel: A review. *Israel Journal of Earth Sciences*, Vol. 38, 1989, pp. 89-103.
- Larson R.L. The Mid-Cretaceous superplume episode. *Scientific American*, Vol. 272, No. 2, 1995, pp. 82-86, <https://doi.org/10.1038/scientificamerican0295-82>.
- Lavi N., Lipshitz G., Neeman E., Itamar A., Baer G. Determination of trace amounts of gold in the presence of rare earth elements in rock samples from Makhtesh Ramon (Southern Israel), by instrumental epithermal neutron activation analysis. *Journal of Radioanalytical and Nuclear Chemistry*, Vol. 120, No. 1, 1988, pp. 105-112, <https://doi.org/10.1007/BF02037856>.

- Le Roex A.P., Bell D.R., Davis P. Petrogenesis of group I kimberlites from Kimberley, South Africa: Evidence from bulk-rock geochemistry. *Journal of Petrology*, Vol. 44, Issue 12, 2003, pp. 2261-2286, <https://doi.org/10.1093/petrology/egg077>.
- Mahfoud R.F. Presence of diamond in the pyrope peridotite, Dreikeesh area, Tartous province, NW Syria: a new theory on the origin of diamond. *Microchemical Journal*, Vol. 73, No. 3, 2002, pp. 265-271, [https://doi.org/10.1016/S0026-265X\(02\)00040-1](https://doi.org/10.1016/S0026-265X(02)00040-1).
- Marshall T.R., Baxter-Brown R. Basic principles of alluvial diamond exploration. *Journal of Geochemical Exploration*, Vol. 53, Issues 1-3, 1995, pp. 277-292, [https://doi.org/10.1016/0375-6742\(94\)00067-L](https://doi.org/10.1016/0375-6742(94)00067-L).
- McClenaghan M.B., Thorleifson L.H., DiLabio R.N.W. Till geochemical and indicator mineral methods in mineral exploration. *Ore Geology Reviews*, Vol. 16, Issues 3-4, 2000, pp. 145-166, [https://doi.org/10.1016/S0169-1368\(99\)00028-1](https://doi.org/10.1016/S0169-1368(99)00028-1).
- McDonald I., de Wit M.J., Smith C.B., Bizzi L.A., Viljoen K.S. The geochemistry of the platinum-group elements in Brazilian and southern African kimberlites. *Geochimica et Cosmochimica Acta*, Vol. 59, Issue 14, 1995, pp. 2883-2903, [https://doi.org/10.1016/0016-7037\(95\)00183-2](https://doi.org/10.1016/0016-7037(95)00183-2).
- Milashev V.A. Kimberlite Provinces. Nedra. Leningrad, 1974, 218 p. (in Russian)
- Mitchell R.H. Kimberlites: Mineralogy, Geochemistry and Petrology. Plenum Press. New York, 1986, 442 p.
- Mitchell R.H. Kimberlites, Orangeites, and Related Rocks. Plenum Press. New York, 1995, 410 p.
- Morgan P. Diamond exploration from the bottom up: regional geophysical signatures of lithosphere conditions favorable for diamond exploration. *Journal of Geochemical Exploration*, Vol. 53, Issues 1-3, 1995, pp. 145-165, [https://doi.org/10.1016/0375-6742\(94\)00072-J](https://doi.org/10.1016/0375-6742(94)00072-J).
- Mukhin P., Eppelbaum L., Wirth R., Schreiber A., Dobrzynetska L. First find of 4H SiC polytype *in situ* in volcanic rocks of northern Israel (Invited Lecture). Transactions of the 25th Goldschmidt Conference, European Association of Geochemistry and the Geochemical Society, Prague, Czech Republic, 2015.
- Nixon P.H. The morphology and nature of primary diamondiferous occurrences. *Journal of Geochemical Exploration*, Vol. 53, Issues 1-3, 1995, pp. 41-71, [https://doi.org/10.1016/0375-6742\(94\)00034-9](https://doi.org/10.1016/0375-6742(94)00034-9).
- Nowak P. Influence of surfactant adsorption on the leaching of copper sulfides. *ECS Transactions*, Vol. 28, No. 6, 2010, pp. 143-153, <https://doi.org/10.1149/1.3367909>.
- Paul D.K., Crocket J.H., Nixon P.H. Abundances of palladium, iridium and gold in kimberlites and associated nodules. In: Boyd F.R. and Meyer H.O.A. (eds.) *Kimberlites, Diatremes and Diamonds: Their Geology, Petrology and Geochemistry* (Proceedings of the 2nd International Kimberlite Conference, Vol. 1. American Geophysical Union, Washington, D.C., 1979, pp. 272-279.
- Recanati P., Steinitz G., Platzner I., Starinsky A. Early Cretaceous igneous activity in the northern Negev: Evidence from K-Ar dating of subsurface cores. *Israel Journal of Earth Sciences*, Vol. 38, 1989, pp. 155-162.
- Ron H., Baer G. Paleomagnetism of Early Cretaceous rocks from southern Israel. *Israel Journal of Earth Sciences*, Vol. 37, 1988, pp. 73-81.
- Rosenfeld A., Flexer A., Honigstein A., Almogi-Labin A., Dvorachek M. First report on a Cretaceous/Tertiary boundary section at Makhtesh Gadol, southern Israel. *Neues Jahrbuch für Geologie und Paläontologie – Monatshefte*, No. 8, 1989, pp. 474-488, <https://doi.org/10.1127/njgpm/1989/1989/474>.
- Rybakov M., Segev A. Top of the crystalline basement in the Levant. *Geochemistry, Geophysics, Geosystems*, Vol. 5, Issue 9, Article number Q09001, 2004, pp. 1-8, <https://doi.org/10.1029/2004GC000690>.
- Samoilov V.S., Vapnik Y. Fractional melting – the determining factor in the origin of the tephrite – basanite – nephelinite rock suite: evidence from western Makhtesh Ramon, Israel. *Neues Jahrbuch für Mineralogie, Abhandlungen*, Vol. 184, No. 2, 2007, pp. 181-195, <https://doi.org/10.1127/0077-7757/2007/0090>.
- Samykin E., Surkov A., Eppelbaum L., Semenov S. Do old spoils contain large amounts of economically valuable minerals? *Minerals Engineering*, Vol. 18, Issue 6, 2005, pp. 643-645, <https://doi.org/10.1016/j.mineng.2004.10.009>.
- Shcheka S.A., Ignat'ev A.V., Nechaev V.P., Zvereva V.P. First diamonds from placers in Primor'e. *Petrology*, Vol. 14, No. 3, 2006, pp. 299-317, <https://doi.org/10.1134/S0869591106030064>.
- Segev A. Synchronous magmatic cycles during the fragmentation of Gondwana: radiometric ages from the Levant and other provinces. *Tectonophysics*, Vol. 325, Issues 3-4, 2000, pp. 257-277, [https://doi.org/10.1016/S0040-1951\(00\)00122-0](https://doi.org/10.1016/S0040-1951(00)00122-0).
- Segev A., Weissbrod T., Lang B. ⁴⁰Ar/³⁹Ar dating of the Aptian-Albian igneous rocks in Makhtesh Ramon (Negev, Israel) and its stratigraphic implications. *Cretaceous Research*, Vol. 26, Issue 4, 2005, pp. 633-656, <https://doi.org/10.1016/j.cretres.2005.03.003>.
- Sharygin V.V., Kóthay K., Szabó Cs., Timina T.Ju., Török K., Vapnik Ye., Kuzmin D.V. Rhönite in alkali basalts: silicate melt inclusions in olivine phenocrysts. *Russian Geology and Geophysics*, Vol. 52, No. 11, 2011, pp. 1334-1352, <https://doi.org/10.1016/j.rgg.2011.10.006>.
- Sneh A., Bartov Y., Rosensaft M. Geological Map of Israel, Scale 1:200,000. Geological Survey of Israel, Ministry of National Infrastructure, Jerusalem, 1998.
- Shimshilashvili E., Yudalevich Z. Mechanism of phenocryst formation in alkaline ultrabasic and basic volcanic rocks: Evidence from Makhtesh Ramon, southern Israel. *Israel Journal of Earth Sciences*, Vol. 54, No. 2, 2005, pp. 113-120, <https://doi.org/10.1560/H09N-F2NT-B9J0-N1G4>.

- Sobolev N.V. Coesite as an indicator of ultrahigh pressures in continental lithosphere. *Russian Geology and Geophysics*, Vol. 47, No. 1, 2006, pp. 94-104.
- Starinsky A., Beilski M., Bonen D., Steinitz G. Rb-Sr whole rock ages of syenitic intrusion (Shen Ramon and Gevanim) in Ramon area, Southern Israel. *Israel Journal of Earth Sciences*, Vol. 29, 1980, pp. 177-181.
- Stein M., Garfunkel Z., Jagoutz E. Chronothermometry of peridotitic and pyroxenitic xenoliths: Implications for the thermal evolution of the Arabian lithosphere. *Geochimica et Cosmochimica Acta*, Vol. 57, Issue 6, 1993, pp. 1325-1337, [https://doi.org/10.1016/0016-7037\(93\)90069-9](https://doi.org/10.1016/0016-7037(93)90069-9).
- Surkov A.V. Atlas of Forms of Native Gold (Sketching and Measurements by Microscope Investigations). Vols. I and II. *Studia Publ.*, Moscow, 2000.
- Surkov A., Samykina E., Eppelbaum L., Semenov S. The Main Reason for Mineral Loss in Gravity Dressing. *The Open Mineral Processing Journal*, Vol. 1, 2008, pp. 37-44, <https://doi.org/10.2174/1874841400801010037>.
- Vapnik E. Melt and fluid inclusions and mineral thermobarometry of mantle xenoliths in Makhtesh Ramon, Israel. *Israel Journal of Earth Sciences*, Vol. 54, No. 1, 2005, pp. 15-28, <https://doi.org/10.1560/LDW9-WU1Q-NTKR-WPQB>.
- Vapnik Y., Sharygin V., Samoilov V., Yudalevich Z. The petrogenesis of basic and ultrabasic alkaline rocks of western Makhtesh Ramon, Israel: geochemistry, melt and fluid inclusion study. *International Journal of Earth Sciences*, Vol. 96, 2007, pp. 663-684, <https://doi.org/10.1007/s00531-006-0131-5>.
- Yudalevich Z.A., Fershtater G.B., Eyal M. Magmatism of Makhtesh-Ramon: Geology, geochemistry, petrogenesis (Conservation area Har Ha-Negev, Israel). *Lithosphere*, No. 3, 2014, pp. 70-92. (in Russian)
- Yudalevich Z., Vapnik E. Xenocrysts and megacrysts of alkali-olivine-basalt-basanite-nephelinite association Makhtesh Ramon (Israel): Interaction with transporting magmas and morphological adjustment. *Lithosphere*, Vol. 18, No. 5, 2018, pp. 718-742, <https://doi.org/10.24930/1681-9004-2018-18-5-718-742>. (in Russian)
- Zak I. Geological Map of Israel (1:20,000). Makhtesh Ramon, Har Gevanim. Israel Geological Survey, 1968.
- Zilberman E. Landscape evolution in the central, northern and northwestern Negev during the Neogene and the Quaternary. *Geological Survey of Israel, Report GSI/45/90*, 1991, 164 p. (in Hebrew, English abstract).
- Zilberman E. Formation of "makhteshim" – unique erosion cirques in the Negev, southern Israel. *Israel Journal of Earth Sciences*, Vol. 49, No. 3, 2000, pp. 127-141, <https://doi.org/10.1560/8C09-4MJ4-RY2P-8K30>.
- Zilberman E., Avni Y. The geological map of Israel, 1: 50,000. Sheet 21-II: Mizpe Ramon. Israel Geological Survey, Jerusalem, 2004.

МАХТЕШ-РАМОН – УНИКАЛЬНЫЙ ПРИРОДНО-РЕСУРСНЫЙ КОМПЛЕКС СТРАТЕГИЧЕСКОГО МНОГОКОМПОНЕНТНОГО СЫРЬЯ НА ЮГЕ ИЗРАИЛЯ

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Резюме. На основе комплексного анализа региональных геолого-геофизических факторов, Махтеш-Рамон (северный Негев, Израиль) был выбран в качестве перспективного участка для поиска алмазоносных комплексов. Важнейшим региональным фактором является максимум активности мантийного горячего пятна в средне-меловую эпоху, отчетливо проявившийся на данной территории. Многократные эрозионные процессы привели к удалению большей части осадочных отложений. Анализ данных магнитометрии, метода естественного электрического поля и результатов ионоселективных измерений однозначно указывает на наличие в западной части Махтеш-Рамона геологических тел, залегающих на небольших глубинах (8-50 м) и, вероятно, имеющих кимберлитовое (лампроитовое) происхождение. Минералогические исследования позволили выявить следующие минералы-спутники алмазов: хромдиопсид, оранжевый гранат, ярко-малиновый пироп, пикроильменит, муассанит, корунд, черную шпинель, оливин, анатаз и турмалин. Отсутствие следов окатанности или окисления служит дополнительным свидетельством их связи с коренными породами. Данные электронной микроскопии показывают, что зерна (1) пикроильменита и (2) пироба содержат соответственно: (1) кобальт, хром, магний и никель, а (2) хром, магний и алюминий. Это указывает на глубинный (гиперабиссальный) генезис данных минералов. К второстепенным минералам-спутникам относятся полевые шпаты, пироксены, магнетит, гематит, ильменит, галенит, пирит, лимонит, слюды, хромит, лейкоксен, циркон, рутил и др. Наличие этих минералов (в дополнение к первой группе) также указывает на алмазоносную минерализацию в исследуемом районе. Обнаружение мелких пластинок золота и серебра, а также значительных концентраций La, Ce, Th, Nb и Ta (редкоземельных элементов), также может быть связано с ближайшими выходами пород глубинного происхождения. Общее количество выявленных микроалмазов превышает 300; также было обнаружено пять алмазов размером более 1 мм (размеры наиболее крупных кристаллов составляют 1,2 и 1,35 мм). Выявленные признаки присутствия серебра, золота и редкоземельных элементов могут представлять самостоятельный интерес.

Ключевые слова: горячая точка, алмазы, минералы-спутники, золото, редкоземельные элементы, геофизические признаки

MAXTEŞ RAMON: CƏNUBİ İSRAİLDƏ STRATEJİ ƏHƏMİYYƏTLİ ÇOXKOMPONENTLİ MİNERAL XAMMALIN UNİKAL TƏBİİ-RESURS KOMPLEKSİ

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Xülasə. Regional geoloji-geofiziki amillərin kompleks təhlili əsasında Mahtəş-Ramon (Şimali Neqev, İsrail) ərazisi almazlı assosiasiyaların axtarışı üçün perspektivli sahə kimi seçilmişdir. Bu ərazidə özünü aydın şəkildə büruzə verən Orta Təbaşir dövründə üst mantiyada qaynar nöqtə aktivliyinin maksimumu ən mühüm regional amil hesab olunur. Təkrar eroziya prosesləri çökmə süxurlarının əksəriyyətinin yuyulmasına səbəb olmuşdur. Bu isə geokimyəvi və petroloji analizlər üçün mineral nümunələrinin götürülməsini və süxur materialının toplanmasını əhəmiyyətli dərəcədə asanlaşdırmışdır. Maqnit (paleomaqnit), təbii potensial və ion selektiv məlumatların təhlili Mahtəş-Ramonun qərb hissəsində, az dərinliklərdə (8-50 m) yerləşən və ehtimal ki, kimberlit (lamproit) mənşəli olan geoloji cisimlərin varlığını birmənalı şəkildə göstərir. Mineraloji tədqiqatlar almazın aşağıdakı peyk-minerallarını müəyyən etməyə imkan vermişdir: xromdiopsid, narıncı nar (qranat), parlaq al qırmızı pirop, pikroilmenit, moissanit, korund, qara şpinel, olivin, anataz və turmalin. Bu minerallarda oksidləşmənin və ya yuvarlaqlaşmanın olmaması onların ana süxurlarla əlaqəsinin əlavə sübutudur. Elektron mikroskopu məlumatlarına əsasən, pikroilmenit dənələrinin tərkibində kobalt, xrom, maqnezium və nikel, eləcə də pirop dənələrində isə xrom, maqnezium və alüminium aşkar edilmişdir. Bu isə sözügedən mineralların hiperabissal mənşəli olduğunu göstərir və eyni zamanda almazdaşıyan kimberlit və ya lamproit cisimlərinin mümkün mövcudluğuna işarə edir. İkinci dərəcəli peyk-minerallara isə çöl şpatları, piroksenlər, maqnetit, hematit, ilmenit, qalenit, pirit, limonit, slyudalar, xromit, leykoksen, sirkon, rutil və s. aiddir. Birinci qrup minerallarla yanaşı, bu mineralların da mövcudluğu tədqiq olunan ərazidə almaz mineralaşmasından xəbər verir. Qızıl və gümüşün kiçik lövhəciklərinin, həmçinin La, Ce, Th, Nb və Ta elementlərinin nəzərəcarpan izlərinin müəyyən edilməsi yaxınlıqda yerləşən kimberlit süxurlarının təzahürü ilə də əlaqəli ola bilər. Sahədə aşkar edilmiş mikroalmazların ümumi sayı 300-dən çoxdur; həmçinin ölçüsü 1 mm-dən böyük olan beş almaz dənəsi də tapılmışdır (ən böyük kristalların ölçüləri 1,2 və 1,35 mm-dir). Gümüş, qızıl və nadir torpaq elementləri ilə bağlı müəyyən edilmiş perspektivli geokimyəvi əlamətlər müstəqil maraq doğura bilər. Beləliklə, geoloji və geofiziki amillərin məcmusu və qeyd olunan mineralların aşkarlanması əsasında Mahtəş Ramon ərazisi həm almazlı süxurların, o cümlədən kimberlit və ya lamproit borularının, həm də yumşaq çöküntülərdə almaz kristallarının aşkar edilməsi baxımından perspektivli hesab olunur.

Açar sözlər: qaynar nöqtə, almaz, peyk-mineral, qızıl, nadir torpaq elementləri, geofiziki əlamətlər