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The First Finding of Serpentinite in Bedrock Outcrops of Crimean Mountains

L. I. Demina, M. Yu. Promyslova, N. V. Koronovskii, and V. V. Tsarev

Department of Geology, Moscow State University, Moscow, Russia
e-mail: lidem06@rambler.ru, maru_promyslova@gmail.com, koronovsky@dynamo.geol.msu.ru, Charev2011@yandex.ru

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Abstract—The geological setting and composition of serpentinites and serpentinized peridotites that were found for the first time in Crimean Mountains are described. Jointly with pillow lavas, gabbros, fragments of a parallel dike complex, and jaspers, they form an ophiolitic association that is attributed to the ancient crust that formed in a backarc basin that evolved to the spreading stage.

Keywords: serpentinites, serpentinized peridotites, pillow lavas, complex of parallel dikes, geodynamic setting, backarc basin, Crimean Mountains

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INTRODUCTION

Serpentinites and serpentinized ultrabasites are one of the most important units in ophiolite associations of fold zones. These associations are fragments of the ancient oceanic crust that are preserved in suture zones; in their order, suture zones are closure traces of large basins (oceans and backarc marginal spreading-type seas). In Crimean Mountains, V.V. Yudin (1995) identified the Predgornaya collision suture of Jurassic–Early Cretaceous age (Fig. 1). V.V. Yudin believed that the identified suture formed during the closure of the Mesothetys Ocean. The basis for this was the traces of an ophiolitic association, viz., serpentinized ultrabasic rocks that were recovered from the core of a well that was drilled 15 km NE of Simferopol (Shnyukov et al., 1979). Serpentinites were also found and described in pebbles of Lower–Middle Jurassic conglomerates that belong to the Bitak Fm. (Yudin, 1995); in addition, serpentinites were recovered by drilling at the Heraclean Plateau, in SW Crimea and by dredging at the Lomonosov submarine rise, 24 miles SW of Cape Fiolent (Yudin, 2011). Nevertheless, bedrock outcrops in Crimean Mountains have not been reported, because their geological positions and locations relative to other rock complexes were not absolutely clarified.

During the field works in 2014 we found the outcrops of serpentinized ultrabasic rocks and serpentinites at coastal escarpments 3.5 km west of Cape Fiolent. Mesh-textured serpentinites after dunite were also found among metamorphozed breccias of basic and ultrabasic rocks that are widely distributed east of Cape Lermontov.

THE GEOLOGICAL SETTING AND COMPOSITION OF SERPENTINIZED ULTRABASIC ROCKS AND SERPENTINITES

Igneous units in the area of Cape Fiolent compose the rocky escarpments in the coastal part of Heraclean Peninsula (the segment is approximately 7 km long). On the east, the outcrops are confined by the Georgievskii Fault that sharply separates this area from the rest of Crimea. Magmatism in the area of Cape Fiolent is traditionally compared to the Karadag backarc type (Lebedinskii and Soloviev, 1988; Yudin, 2003, 2011) and the manifestation time is attributed to the Middle Jurassic (Bajocian). It is supposed that the base of the Fiolent paleovolcano is Tauric Series deposits (T_3–J_1). However, no units of this age have been found in the area of Cape Fiolent as yet, either on land and the sea floor or in the well that was drilled north of the cape, at the Heraclean Plateau (Shnyukova, 2013). Igneous rocks are overlain by horizontally bedding limestones of the Sarmatian stage (Neogene). The dominating type of igneous rocks here is pillow lavas (predominantly basalts) that compose approximately 70% of the visible outcrops. Gabbro and peridotites are located in the western part of the area, where bedrock serpentinite outcrops were revealed.

Serpentinized Ultrabasic Rocks and Serpentinites in the Area of Mount Utyug

Mount Utyug is a lens-shaped NW-elongated (Figs. 2a and 2b) cliff that is located at the western termination of the igneous rock outcrops of Cape Fiolent. It is composed of highly cracked and altered gab-

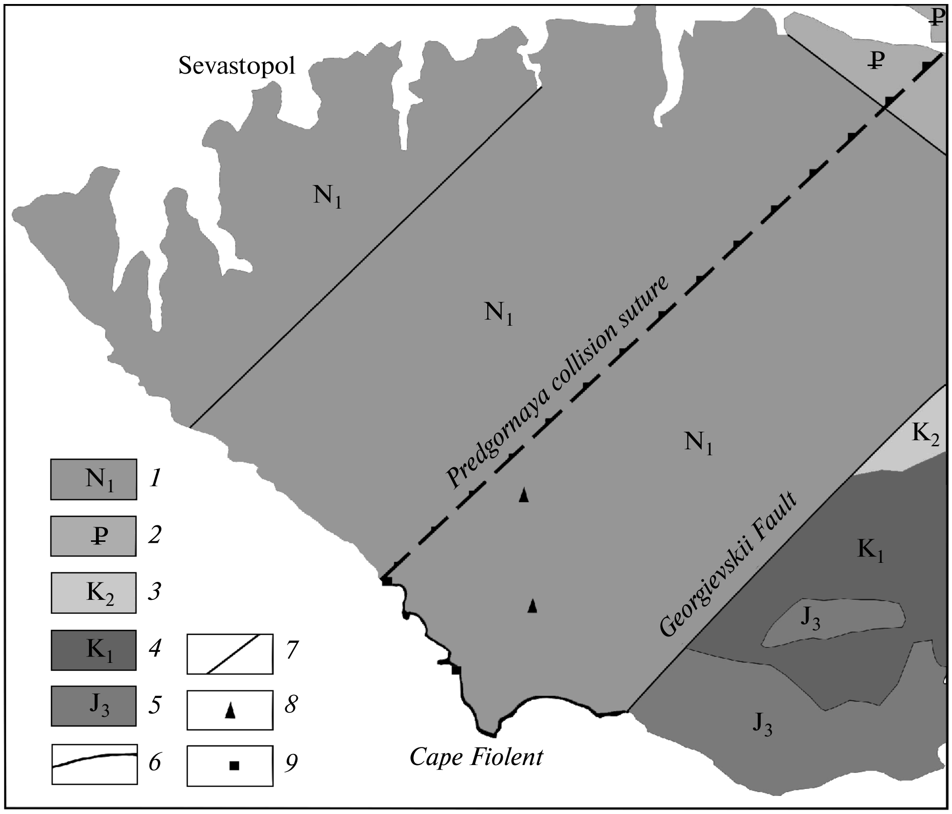


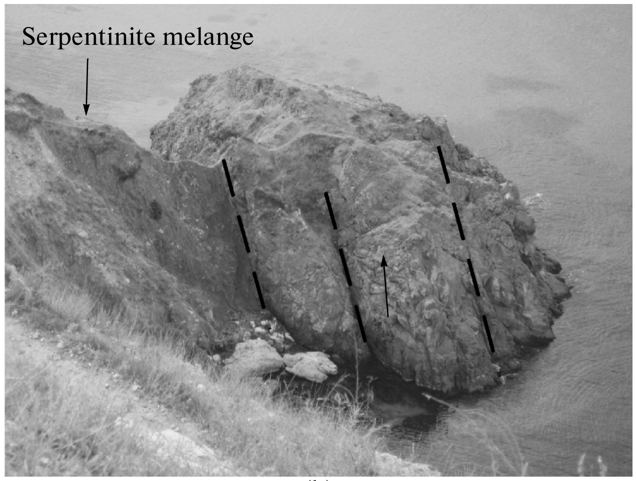
Fig. 1. The schematic geological structure of the Heraclean Peninsula, Crimea, after (*Gosudarstvennaya*..., 2005). The position of the Predgonaya suture is after (Yudin, 2009). (*1*)–(*5*) deposits: (*1*) Miocene, (*2*) Paleocene, (*3*) Upper Cretaceous, (*4*) Lower Cretaceous, (*5*) Upper Jurassic; (*6*) igneous rocks; (*7*) faults; (*8*) holes where igneous rocks were recovered; (*9*) findings of serpentinites.

bros with shattered clinopyroxene (rarely orthopyrocene) grains and table-shaped basic plagioclase, which is saussuritized and albitized on rims (Fig. 3a). Among minor minerals, the most sharply dominant one is chlorite associating with fine grains of ore mineral. Outcrops of bedrock serpentinized ultramafites and serpentinites coincide with the crossing of two (NE- and NW-trending) subvertical faults that confine the escarpments of Mount Utyug (Figs. 2a and 2b). West of the cliff, altered and brecciated pillow lavas are represented in coastal escarpments. Some pillow units can be identified from the filling of the space between them with epidotized breccias and green jaspers. Lavas are represented by aphyric amygdaloid basalts that possess a typically spilitic texture (Fig. 3b). Amygdules are mostly filled by epidote, rarely by carbonates.

Pillow lava outcrops are confined on the east by a fault, along which they contact with serpentinized ultramabasic rocks: the contact is characterized by numerous slickensides and foliation planes that provide foliated and lenticular structures of the rocks. Serpentinization is nonuniformly manifested and tends to occur at fine cracks that are oriented in parallel to the foliation planes (Fig. 3c). Serpentine is represented by antigorite flakes, rarely by thin fibrous chrysotile aggregates. On cleavage surfaces that are perpendicular to the foliation direction, the rocks possess an augen structure that is expressed in the presence of particular fragmented large (up to 2 mm) clinopyroxene grains ("eyes") surrounded by serpentine, chlorite, and, rarely, actinolite aggregates. The primary composition of the ultrabasic rocks is hardly identifiable. Most probably, they can be attributed to wehrlites or lherzolites because their thin sections contain, in addition to clinopyroxene, relics of rhomboid pyroxene grains. At the eastern contact of serpentinized ultrabasites, a dike of fine-grained dolerites with abundant ore minerals is located (Fig. 3d).

Further eastwards, in the immediate vicinity of Mount Utyug, the zone of cataclasites and mylonites is located; serpentinite outcrops are also confined to this zone, forming rounded convex surfaces (Fig. 4a) on the background of shattered rocks. These units can be generally characterized as a serpentinite melange, whose visible thickness at the NW-directed outcrop is up to 40 m. Due to its considerably lower strength compared to gabbros, melange is destroyed more intensively and composes an isthmus between the cliff and coastal escarpments.

(a)



(b)

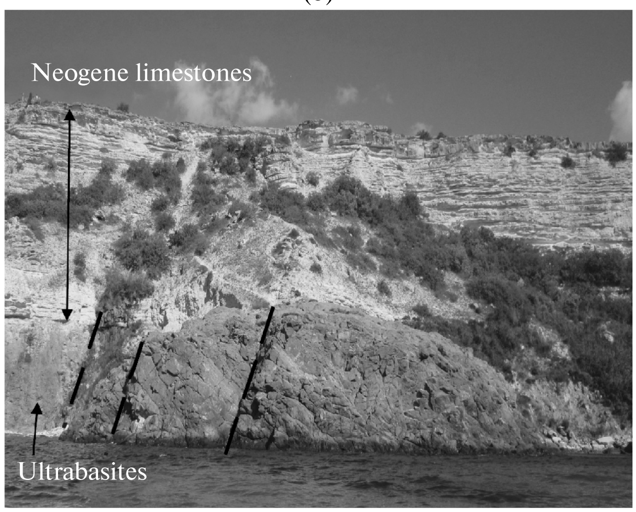


Fig. 2. Bedrock outcrops of serpentinized ultrabasites and serpentinites in the area of Mount Utyug as viewed from northwest (a) and southeast (b). Dashed lines denote faults.

Serpentinites are characterized by the presence of coarse-flaked and lens-shaped units, a brownish dark-gray color on their weathered surface, and spotted silky colors of different green tones on fresh cleavages (Fig. 4b). Serpentinites are composed by aggregates of thin acicular serpentine (mostly chrysotile) units that are either oriented in parallel to each other, or form sheaf-like groups (Figs. 5a and 5b). Small amounts of chlorite, actinolite, carbonate, tremolite, talc, and ore minerals are presented. Relics of shattered clinopyroxene grains (Fig. 5c) or its separated fragments are nonuniformly distributed in serpentinite (but in a quantity that is considerably smaller than that in serpentinized ultramafites). This indicates that serpentinization affected the same rocks and its intensity depended on their permeability for marine water and metamorphing brines; note that this parameter is significantly higher in fault zones.

East of Mount Utyug, ultrabasic rocks such as lherzolites, wehrlites, and dunites are represented, with typical cumulative structures and transitions through a gradual increase in the plagioclase content in gabbro (Shnyukova, 2013). The cited author attributed these rocks to a layered basite–ultrabasite complex of ophiolites that are genetically connected with the Lomonosov submarine rise. The geodynamic nature of the Lomonosov rise is disputable. A.F. Shnyukov et al. (1997) interpretted it to be the igneous fragments of a Cretaceous paleoarc, whereas V.V. Yudin (2003) attributed its units to the Upper Cretaceous–Paleogene backarc spreading complex related to the opening of the West Black Sea Basin.

Serpentinites After Dunite from Breccias

We also found serpentinites in bedrock outcrops of metamorphozed breccias (Figs. 6a and 6b) east of

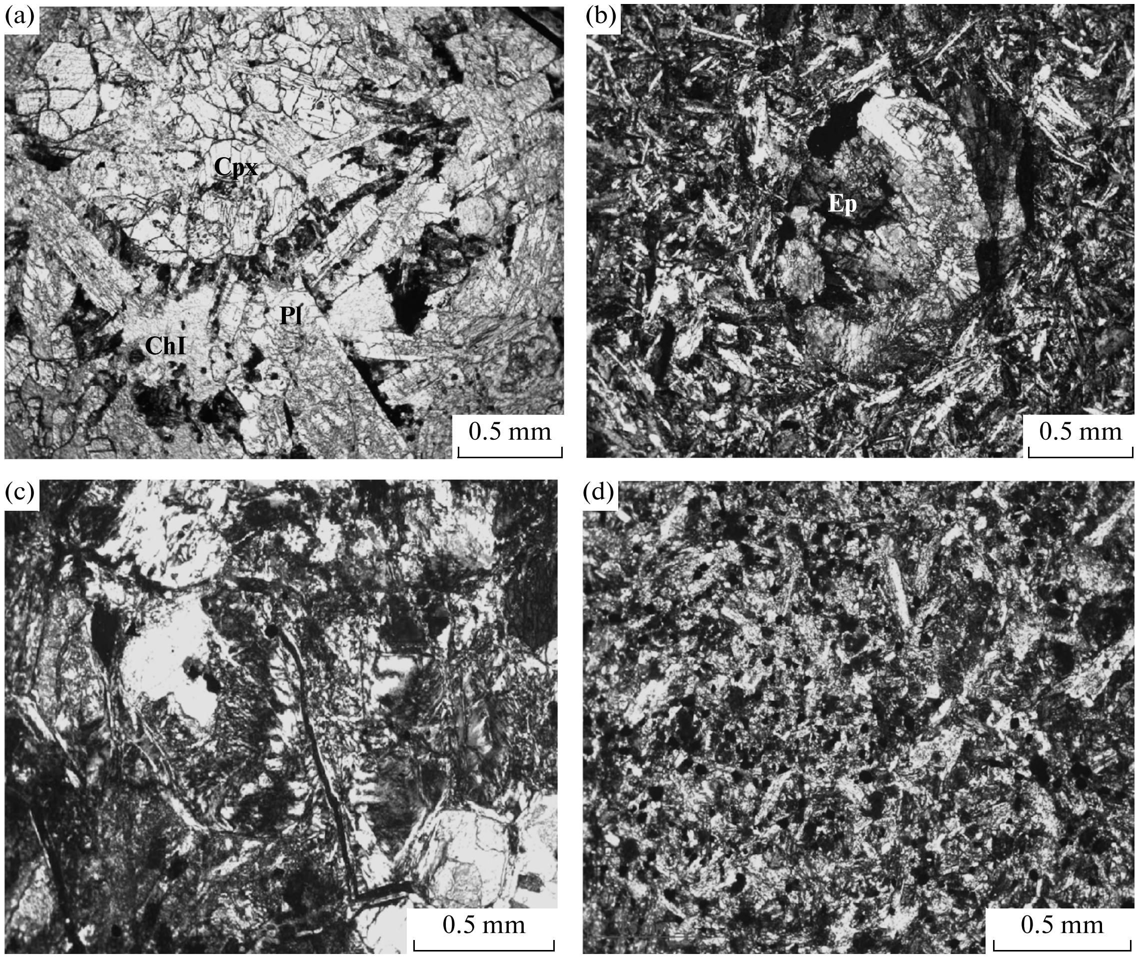


Fig. 3. Thin sections of gabbro (a), pillow lava (b), serpentinized ultrabasites (c), and dolerites (d). Nicols are parallel in panel (a) and crossed in panels (b–d). Chl means chlorite; Cpx, clinopyroxene; Ep, epidote; Pl, plagioclase.

Cape Lermontov in coastal escarpments of Tsarskaya Bay and Cape L'venok. Metamorphic breccias are overlain by pillow lavas and intruded by a series of parallel dolerite–basaltic and basaltic dikes (Fig. 7a) that acted as feeders for basitic magma. The dikes are 15 to 60 cm thick and have disturbed unclear contacts (Fig. 7b) with breccias in the screen (20–60 cm), indicating penetration into nonlithified breccias. The breccias often contain fragments of dike rocks; sometimes the dikes are separated into fragments, as is clearly seen in cliff outcrops at Cape L'venok.

Breccias are composed of angular and weakly rounded fragments of basic and ultrabasic rocks cemented with (a) a groundmass that consists of micro- and fine-fragmented material of the same rocks and (b) carbonates and silicate units (light-bluish green jaspers; similar jaspers also fill cracks in the contact zones of dikes, where multiple fine carbonate veins can be found as well). Among the breccia fragments, tabular units occur (Fig. 6b); these units are hyaloclastites that formed during the cracking of lavas due to rapid cooling under submarine conditions. Breccias are metamorphozed under high-temperature stage of greenschist facies. Fragments are represented by typical chlorite, chlorite–albite, rarely chlorite–actinolite and chlorite–epidote schists, as well as mesh-textured serpentinites after dunite (Fig. 5d). This indicates that ultrabasic rocks were exhumed the sea floor and intensively destroyed before basalts began to outflow. Similar breccias are widely distributed in ophiolites of Liguria, Lesser Caucasus, South Tien Shan, and other regions (Knipper, 1978). Their appearance is attributed to hiatuses in formation of ophiolites, when the upper parts of the section, including serpentinites, are eroded under conditions of highly cut seafloor relief (Abakumova et al., 1994). Note that this evolutionary stage of rift zones in oceans and spreading-type backarc seas is regarded as tectonic or destructive (in contrast to the volcanic one, which is constructive). Such a cyclicity of tectonic activity indicates slow-spreading ridges (Zonenshain and Kuz'min, 1993).

(a)

(b)

Fig. 4. Images of the serpentinite outcrop (a) and core (b).

THE GEODYNAMIC SETTING OF SERPENTINITE FORMATION

Almost all researchers attribute the magmatism of Crimean Mountains to the island-arc type and the so-called Fiolent volcano is one of its representatives. However, no united volcanic edifice exists in the area of Cape Fiolent. In coastal rocky escarpments west of Cape Fiolent, multidirectional flows of pillow lavas are well seen (Fig. 8), indicating several eruption centers. Lava flows differ in the direction, thickness, pillow size, and composition of the material that fills the space between the lava pillows.

The feeders were parallel cracks filled with dolerites, dolerite–basalts, and basalts that belong to the complex of parallel dikes. Fragments of this complex were revealed by the authors for the first time in coastal outcrops at Tsarskaya, Mramornaya (Ekho), and Karavella (Lermontova dacha) bays. The younger plagiorhyolites and their breccias, which make up no more than 10% of the total volume of the igneous rocks in the area, predominantly compose dikes and bosses; extrusive domes with a fan-shaped columnar structure are the differentiation products of basaltic magmas (Promyslova et al., 2014). Three independent eruption centers of acid magmas can be distinguished only in the coastal escarpments of Yashmovaya Bay; zones of intensive postmagmatic hydrothermal reworking coincide with these centers and are expressed in the form of silicification, ferruginization, and sulfide mineralization.

The finding of serpentinites and fragments of complex of parallel dikes, jointly with the widely represented pillow lavas, gabbros, peridotites, and jaspers, provides solid ground to distinguish the ophiolitic association. Serpentinized unltramafites and serpentinites are tectonized and metamorphozed upper mantle relics that belong to the fourth layer of oceanic crust (Abakumova et al., 1994; Abramovich et al.,

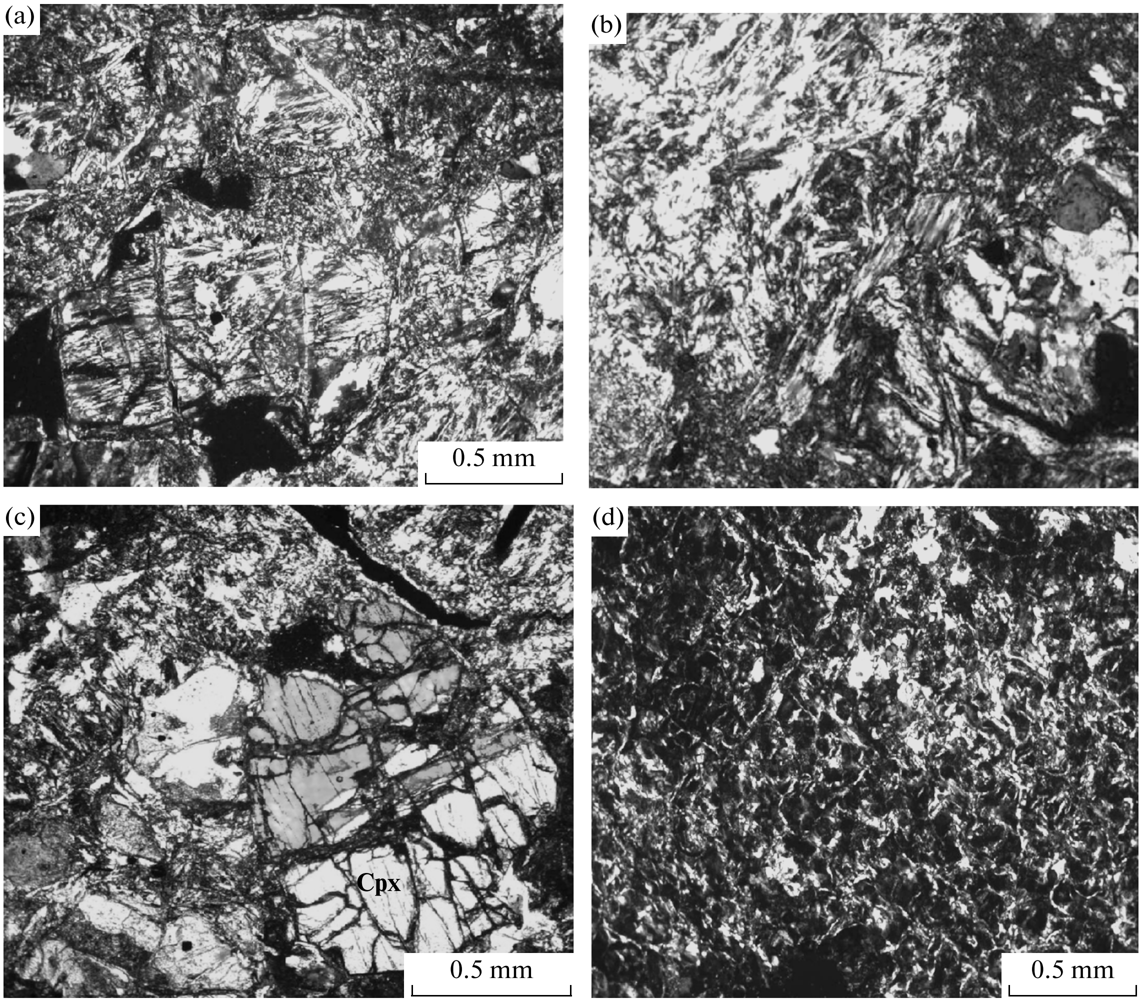


Fig. 5. Thin sections of serpentinites from the area of Mount Utyug (a–c) and Cape L'venok (d); nicols are crossed. Cpx means clinopyroxene.

1997). Note that the possible presence of ophiolites in the area of Cape Fiolent was described by E.E. Shnyukova (2005) and M.Yu. Promyslova et al. (2014). The issue arises of what basin the ophiolitic association belonged to.

V.V. Yudin (2011) hypothesized that the Kimmerian (Late Triassic–Early Cretaceous) geodynamic cycle in the evolution of Crimea was related to the existence of the northern fragment of the Mesothetys Ocean in this region: the opening of this paleoocean first divided the terrane of Crimean Mountains (Gornokrymskii terrane, or Krymiya) from the southern margin of Laurasia, and later, at the stage of convergence, Krymia collided with Pontiya and then with Eurasia, which formed at this time from Laurasia as a result of the opening of the Atlantic Ocean. V.V. Yudin attributed magmatism of Crimean Mountains, including that in the area of Cape Fiolent, to a subduction zone that is marked by the north-dipping Izmir–Ankara suture in Anatolia. A similar opinion was published by Meijers et al. (2010). According to V.V. Yudin (2008), Middle Jurassic–Early Cretaceous magmatism in Plain Crimea (at that time this region was the active margin of Laurasia) is genetically related to the north-dipping Predgornaya suture, at whose southwestern termination the outcrops of igneous rocks of Cape Fiolent are located (Fig. 1). The age of the fragments of ultrabasic rocks in ophiolites from clastolites of the Prisuturnyi (Near-Suture) and Simferopol melanges is Late Triassic–Early Jurassic. Previously, L.P. Zonenshain and M.I. Kuz'min (1990) hypothesized that a backarc basin existed in the back of the Kimmerian ensimatic island arc.

The Greater Caucasus (Bol'shekavkazskii) backarc basin, whose western part incorporated the territory of present-day Crimean Mountains, was reconstructed as of the Early and Middle Jurassic (Nikishin et al., 1997). However, these reconstructions did not contain the position of Jurassic magmatism in Crimean Mountains, whereas the Pontic–Transcaucasian magmatic belt (which is related to subduction of the Tethys

(a)

(b)

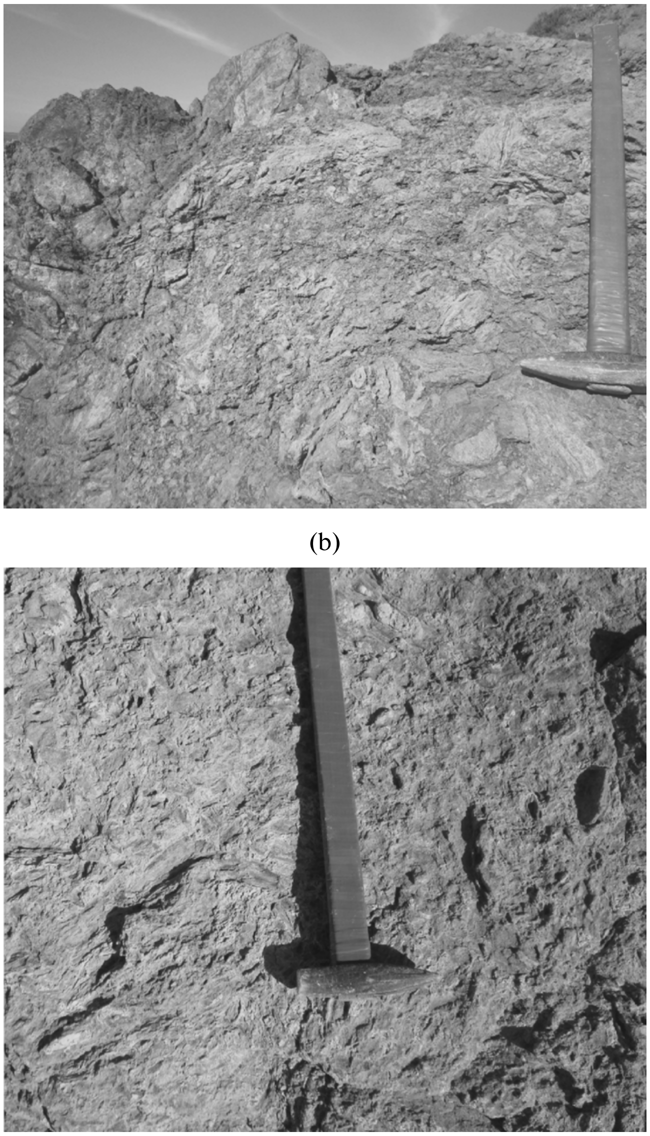


Fig. 6. Images of metamorphozed breccias outcrops in coastal cliffs of Tsarskaya Bay (a) and Cape L'venok (b).

(a)

(b)

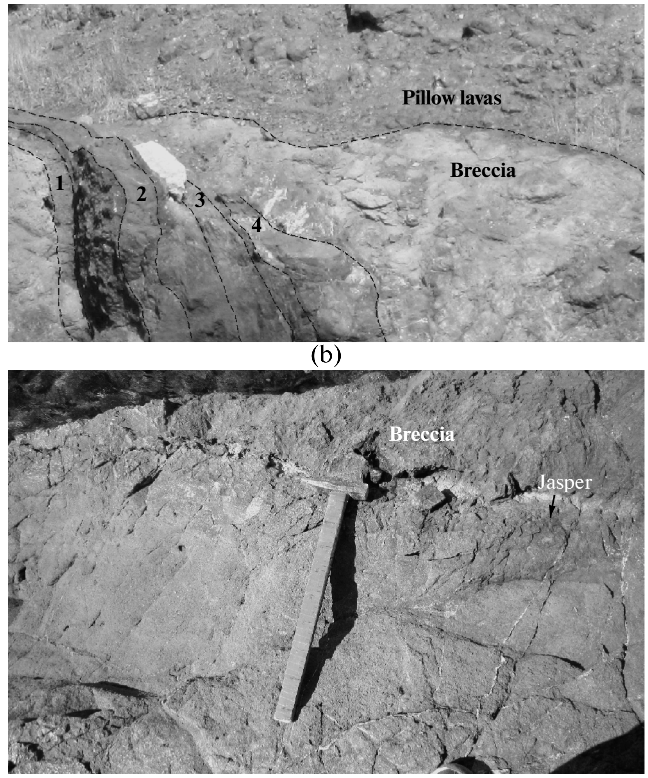


Fig. 7. Images of parallel basaltic dikes (a, b) at Cape L'venok.

Ocean) was distinguished south of the Greater Caucasus basin. According to V.S. Mileev et al. (1997), the Tauric deepwater riftogenic basin existed in the Late Triassic–Early Jurassic in the area of the present-day Crimean Mountains and this basin divided two terranes: Scythia (the present-day Steppe Crimea) and Euxinia (the present-day Black Sea water area). These terranes approached at the end of the Early to the beginning of the Middle Jurassic and the crust of the Tauric basin was subducted in the northward direction beneath Scythia. An island arc occurred here in the second half of the Bajocian, when intrusions of the Pervomaiskoe–Ayu-Dag complex penetrated and the Bodrak–Karadag volcanic rock series formed (note that most researchers attribute the igneous rocks at Cape Fiolent to this series). At the end of the Middle Jurassic, the Tauric basin completely closed, while Euxinia and Scythia collided with each other; as a result, a suture formed (the Lozovskaya shear zone). We emphasize that V.V. Yudin (2008) attributed both the Lozovskaya shear zone and the area of Cape Fiolent to the Simferopol melange.

A detailed study of the chemical composition, including the distribution of RRE and other microelements, of pillow lavas and dolerites in the area of Cape Fiolent indicated a suprasubduction nature of these rocks and their formation in a backarc basin that evolved until the spreading stage (Promyslova et al., 2014, 2015). The issue of the interval of the existence of the basin remains disputable. Single absolute-age datings of igneous rocks from the area of Cape Fiolent were obtained by E.E. Shnyukova (2005, 2013). Three zircon grains from a basaltic dike located at Cape Fiolent were analyzed by the U–Pb SHRIMP method to yield a Precambrian age (1771 ± 28 Ma). Another more ancient Precambrian age (2091 ± 10 Ma) was obtained on six zircon grains from wehrlite of the layered complex. Plagiorhyolite demonstrated the Bajocian age of the Middle Jurassic (174 Ma) by the K–Ar method. The Precambrian age datings most probably indicate the age of the upper mantle (a basitic magma melted in equilibrium with it) recorded in the ancient

Fig. 8. Multidirected pillow lava flows in the outcrop of the coastal cliff west of Cape Fiolent.

zircons. The correlation of igneous rocks in the area of Cape Fiolent with complexes in other areas of Crimean Mountains requires further study and discussion.

CONCLUSIONS

(1) The finding of serpentinized ultrabasites, serpentinites, and complex of parallel dikes in bedrock outcrops of Crimean Mountains in the area of Cape Fiolent together with gabbro, pillow lavas, and siliceous units significantly added to the composition of the ophiolitic association, which was previously identified in the region on the basis of separate fragments.

(2) The ophiolitic association is of a suprasubduction nature and belongs to the oceanic crust of a backarc basin that evolved until the spreading stage.

(3) These data are important for paleogeodynamic studies of the region and for modeling the tectonic evolution of Crimean Mountains during the Mesozoic.

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