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First Fission-Track Dating of Zircons from Mesozoic Complexes of the Crimea

A. V. Solov'ev and M. A. Rogov

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia
e-mail: solov@ilran.ru

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Abstract—The fission-track dating of detrital zircon from Mesozoic terrigenous complexes of the Crimean mountains has been carried out for the first time. A young zircon population from the Tavria Group of sandstones of the Yaman ravine was dated at 220.1 ± 12.6 Ma, and the zircon population from the same deposits of the Crimea's southern coast, at 193.6 ± 13.1, 167.1 ± 12.1, and 154.0 ± 10.2 Ma. Sandstones from the lowermost parts of the Demerdzhi Formation on Mount Yuzhnaya Demerdzhi comprise the Middle Jurassic young zircon population (169.9 ± 8.6 Ma). The age of the young zircon population from the Chenka Formation in the region of the Settlement of Observatoriya corresponds to the initial Middle Jurassic (178.9 ± 9.1 Ma). The timing of the cooling of the Mount Kastel massif was established at 149.0 ± 10.9 Ma. In all the considered cases, the age of terrigenous complexes is close to the age of enclosed zircons. Volcanic and/or magmatic rocks that formed synchronously with accumulation of terrigenous complexes in the sedimentary basin are likely to have been sources of zircons. Hence, the data obtained allow the timing of the Triassic–Jurassic magmatism in the Crimean mountains to be refined and three stages of magmatism to be distinguished: Late Triassic (Carnian?), poorly expressed Early Jurassic, and Middle Jurassic (Aalenian–Bathonian).

Key words: Mesozoic, zircon, fission-track dating, Tavria Group, Yaman, Chenka, and the Demerdzhi formations, Crimea.

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INTRODUCTION

The development of equipment and methods of geochronological investigations and, first of all, the determination of the age of individual grains made it possible to suggest new approaches for studying clastic rocks. For dating individual zircon detrital grains, we applied fission-track dating (for instance, Wagner and Van den Haute, 1992; Bernet and Garver, 2005; Solov'ev, 2008). The analysis of the ages of individual detrital zircons from sandstones represents a powerful tool for establishing the provenances of terrigenous material and testing regional paleogeographic and paleogeodynamic reconstructions. Using a series of regional examples, it was shown that the age of the youngest zircon population in sediments, which was determined by the fission-track method, is close to the timing of the sedimentation of terrigenous sequences (Garver et al., 2000; Solov'ev, 2008). In this case, products of volcanism synchronous to sedimentation (the timing of crystallization), as well as blocks of older basement rocks of the active margin, which were brought to the surface from deep levels (the age of cooling) could be the source of these zircons. Magmatic activity and the fast exhumation of blocks are characteristic for geodynamically active regions, and for basins of terrigenous sedimentation in such regions, the fission-track dating of zircons can be regarded as one of the important methods of determining the age of terrigenous sequences (Solov'ev, 2008).

The fission-track dating of detrital zircon was carried out for the first time for Mesozoic terrigenous complexes of the Crimean mountains. The fission-track age was established for zircons separated from sandstones of the Tavria Group (4 samples), Demerdzhi (1 sample), and Chenka (1 sample) formations, as well as for zircons from a diorite intrusion of Mount Kastel. The data we have obtained give an idea of the fission-track age of detrital zircons in Mesozoic complexes of the Crimean mountains and can be used in reconstructing the evolution history of Mesozoic sedimentary basins.

MESOZOIC TERRIGENOUS COMPLEXES OF THE CRIMEA AND THE RESULTS OF ZIRCON FISSION-TRACK DATING

The Crimea represents a good regional polygon, within which complexes of the Mesozoic sedimentary paleobasin, which were formed under active geodynamic conditions, are widespread. Good exposure, the absence of late granitoids, and well-developed stratigraphy also determined the choice of the object

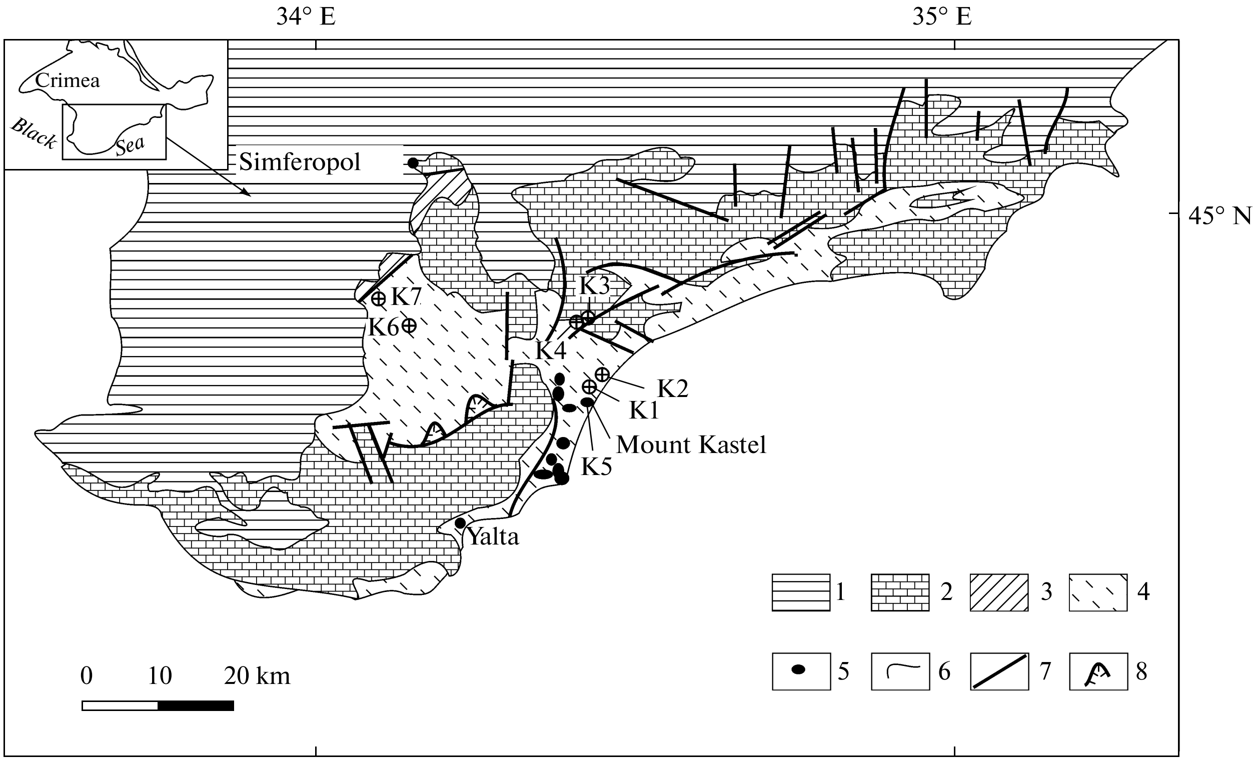


Fig. 1. Geological scheme of the Crimean mountains (*Geological* ..., 1989). (1) Cretaceous–Neogene deposits; (2) Upper Jurassic deposits; (3, 4) Middle Triassic–Middle Jurassic Crimean complex: (3) Eskiorda and Karadag groups, (4) Tavria Group; (5) Bajocian intrusions; (6) geological boundaries; (7, 8) faults: (7) normal–reversed, (8) thrust. (K1, K2, K3, K4, K5, K6, K7) sampling sites for fission-track dating.

(*Geological* ..., 1989; Tseisler et al., 1999; Yudin, 2000, 2001; Panov et al., 2001, 2004; Bolotov et al., 2004). At the same time, we note the complicated tectonic structure of the Triassic–Middle Jurassic deposits and the considerable difference in the interpretation of one and the same geological bodies (regarding both the tectonic pattern and stratigraphic position) by different researchers. The method of detrital thermochronometry was successfully used previously for Mesozoic complexes (Solov'ev, 2008). Moreover, the Crimea has been a geological polygon for many years, on which students from numerous geological institutes of Russia carry out practical work; however, it is the Triassic–Jurassic complexes of the Crimea that have not been adequately explored.

Mesozoic complexes of the Middle Triassic–Middle Jurassic age are widely developed within the Crimea (*Geological* ..., 1989) (Fig. 1). The Tavria Group is substantially deformed and occupies the lowest structural position. It is represented by the flyschoid alternation of the Middle Triassic–Middle Jurassic sandstones, siltstones, and mudstones (*Geological* ..., 1989; Yudin, 2000; Panov et al., 2001; Mileev and Rozanov, 1995; Mileev et al., 2006). No visible base of the group has been found anywhere in the Crimea, and the relationships with the underlying sequences are also unknown. The Tavria Group is overlain with structural unconformity by the Upper Jurassic deposits on the south and east of the Kachin Uplift and by the Lower Cretaceous rocks on the north and west. The group is made of proximal and distal turbidites, which formed in the basin that separated the Scythian Plate and the Euxinian Terrane in the Late Triassic–Middle Jurassic (Mileev and Rozanov, 1995). An alternative subdivision of the Tavria Group into formations was suggested for different regions of the Crimean mountains; there is no consensus of opinion on the subdivision of the Tavria Group amongst different researchers. This is mainly related to its complicated tectonic structure and rare finds of fossils. In this work, we use with some modifications the subdivision of the Tavria Group, suggested by D.I. Panov and colleagues (Panov et al., 2001).

For the higher Jurassic levels of the Crimea, within the four structural–facies zone, successions of formations, united into eight horizons, were suggested (Permyakov et al., 1991). Unfortunately, detailed descriptions for sections of the formations and the distribution of fossils (and their images) in them are few in number, which, along with the complicated thrust structure of the Crimean mountains (Mileev et al., 2009), prevent the revelation of the real relationships of a series of the distinguished stratigraphic units.

Fission-track ages of detrital zircons from Mesozoic complexes of the Crimea

Sample no	Group, formation, sampling site	Amount of dated grains	Population age, Ma		
			P1	P2	P3
K1	Tavria, Mount Kastel region (CSC)	40	193.6 ± 13.1 Nf = 30.2 W = 43%	586.6 ± 89.7 Nf = 9.8 W = 31%	–
K2	Tavria, Settl. Lazurnoe (CSC)	30	154.0 ± 10.2 Nf = 14.5 W = 22%	527.4 ± 42.3 Nf = 15.5 W = 31%	–
K3	Demerdzhi, Mount Yuzhnaya Demerdzhi	45	169.9 ± 8.6 Nf = 36.5 W = 21%	320.8 ± 40.9 Nf = 5.3 W = 24%	689.6 ± 123.0 Nf = 3.2 W = 32%
K4	Tavria, Mount Yuzhnaya Demerdzhi	28	167.1 ± 12.1 Nf = 17.3 W = 25%	597.3 ± 73.0 Nf = 10.7 W = 39%	–
K6	Chenka, Settl. Observatoriya	45	178.9 ± 9.1 Nf = 40.1 W = 23%	538.1 ± 94.3 Nf = 4.1 W = 34%	–
K7	Tavria, Yaman ravine	42	220.1 ± 12.6 Nf = 36.9 W = 27%	630.2 ± 121.8 Nf = 5.1 W = 39%	–

Note: (Nf) are amounts of grains of the population which form a peak. (W) is the peak "width," relative standard peak deviation expressed as a percentage (Brandon, 2002). The age determination error makes up ±1σ. Zircons were dated using the external detector method (Hurford and Carter, 1991). Zircon grains were pressed into plates FEP Teflon^{MT} of size 2 × 2 cm^2. Two plates were prepared for each sample. The plates were roughed out on abrasive wheel and then polished by diamond pastas (9 and 1 μm) and Al_2O_3 pasta (0.3 μm) at the final stage. Chemical etching was carried out by NaOH–KOH solution at the temperature of 228°C for 15 (the first plate) and 30 hours (second plate). After etching, the plates were covered with detector (mica with a low U content) and exposed to the thermal neutron flux of about 2 × 10^{15} neutron/cm^2 (thermal reactor of University of Oregon) simultaneously with zircon standard samples FCT (Fish Canyon Tuff) and BL (Buluk Tuff), as well as with glass–dosimeter with the known U content (CN-5) (Hurford, 1998). The fission tracks were calculated under microscope Olympus BH-P with an automated system and a digital plotter, maximal magnification 1256, dry method. The Z-factor calculated for 12 age standards (7 FCT samples, 5 BL samples) was found to equal 310.66 ± 6.47 (Hurford, 1998).

Sandstone samples for dating fission-track zircon were collected on the southern coast of the Crimea from the Tavria Group (Yaman Formation) and the Yaila Horizon (Demerdzhi Formation, lower subformation), as well as in the region of the polygon of Moscow State University, Geological Faculty, from the Tavria Group (Yaman and Chenka formations).

From 28 to 40 zircon grains were dated in each sample (see the table). The Zetaage 4.7 program elaborated by M.T. Brandon from Yale University, in the U.S., was used for calculating the age of individual zircon grains (Brandon, 1996, 2002). The age of the grains in all the samples varies within a wide range (see table and Figs. 2, 3), which suggests the presence of several zircon populations that are different in age. Two zircon populations were established in most samples (samples K1, K2, K4, K6, and K7) and three populations, in sandstone from the Demerdzhi Formation (sample K3). This suggests that after accumulation, the sandstones were not heated above the temperature of the closure of the fission-track system in zircon (215–240°C) and the ages of the zircons reflect the time of their cooling in their place of origin.

The age of a young zircon population can be regarded as the lower limit for the time of terrigenous sedimentation. The data were tested on the dependency of the fission-track ages on the sampling height.

Fig. 2. Distribution of fission-track ages of zircon grains. (a) Sample K1 (Tavria Group sandstone), (b) Sample K2 (Tavria Group sandstone); (c) Sample K3 (Demerdzhi Formation sandstone). The broken line represents the observed curve; the unbroken line represents populations separated by Program BinomFit 1.8 (Brandon, 2002). The time scale is logarithmic.

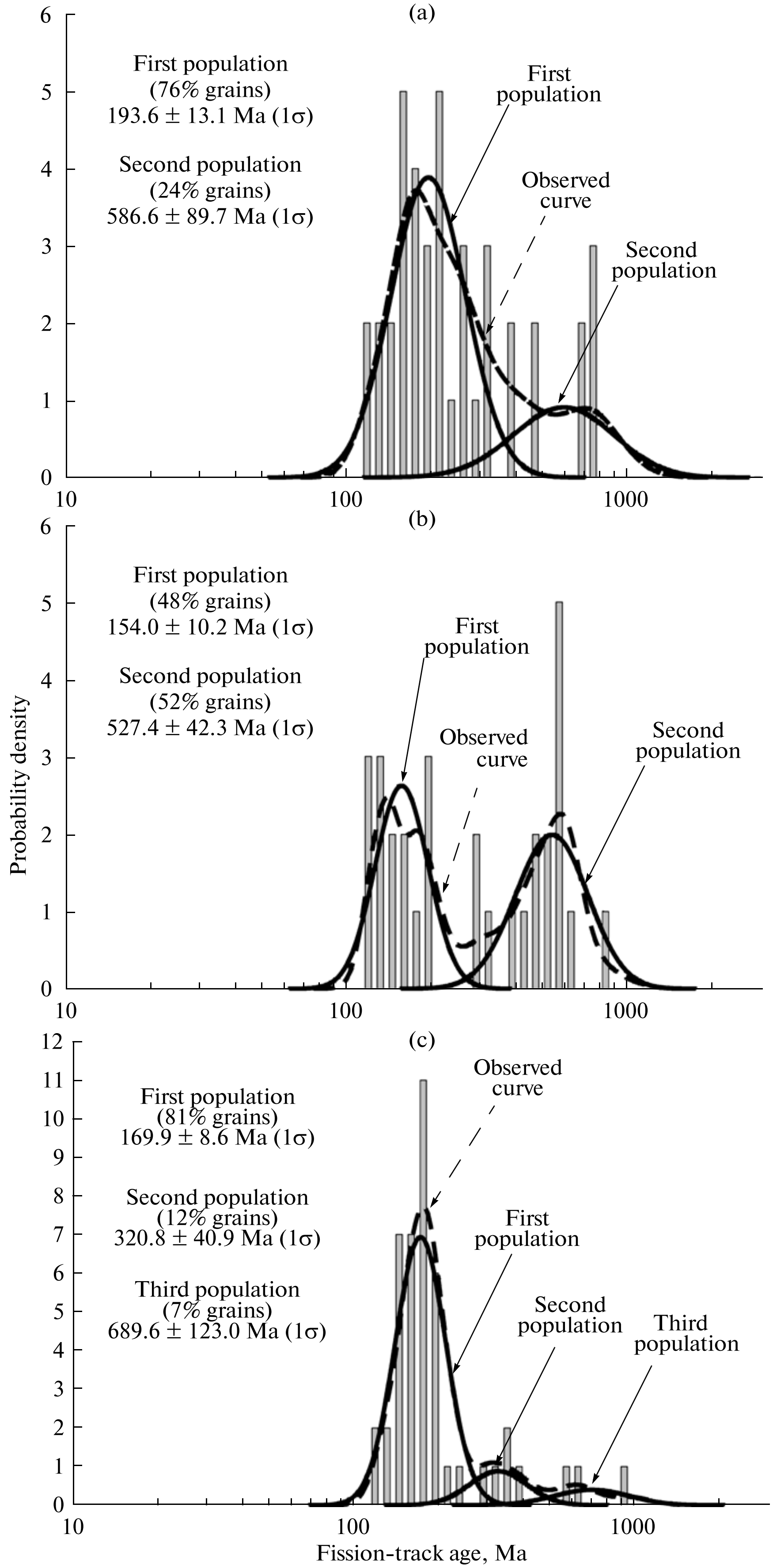

(a)
First population
(76% grains)
193.6 ± 13.1 Ma (1σ)
Second population
(24% grains)
586.6 ± 89.7 Ma (1σ)
First population
Observed curve
Second population
(b)
First population
(48% grains)
154.0 ± 10.2 Ma (1σ)
Second population
(52% grains)
527.4 ± 42.3 Ma (1σ)
First population
Observed curve
Second population
Probability density
(c)
First population
(81% grains)
169.9 ± 8.6 Ma (1σ)
Second population
(12% grains)
320.8 ± 40.9 Ma (1σ)
Third population
(7% grains)
689.6 ± 123.0 Ma (1σ)
Observed curve
First population
Second population
Third population
Fission-track age, Ma

Fig. 3. Distribution of fission-track ages of zircon grains. (a) Sample K4 (Tavria Formation sandstone), (b) Sample K6 (Chenka Formation sandstone); (c) Sample K7 (Tavria Group sandstone). The broken line represents the observed curve; the unbroken line represents populations separated by Program BinomFit 1.8 (Brandon, 2002). The time scale is logarithmic.

No correlation has been established between the age and height of sampling (Fig. 4).

It is most likely that the age of the young zircon population is close to the timing of the terrigenous sedimentation. According to fission-track dating, the age of the young zircon population from sandstones of the Tavria Group (Yaman Formation[1]) in the Yaman ravine corresponds to the Late Triassic (220.1 ± 12.6 Ma), and from the same deposits on the southern coast of the Crimea it is younger—from the Early Jurassic to the terminal Middle/initial Late Jurassic (193.6 ± 13.1, 167.1 ± 12.1, 154.0 ± 10.2 Ma). The age of the young zircon population from the Chenka Formation in the region of the Settlement of Observatoriya corresponds to the terminal Early Jurassic–initial Middle Jurassic (178.9 ± 9.1 Ma). Sandstones from the lowermost parts of the Demerdzhi Formation on Mount Yuzhnaya Demerdzhi comprise the Middle Jurassic young zircon population (169.9 ± 8.6 Ma).

FISSION-TRACK AGE OF ZIRCON FROM THE MOUNT KASTEL MASSIF

Idiomorphic zircons were separated from a diorite sample (K5) collected in the Mount Kastel massif. The fission-track dating of 20 grains (the χ^2 test is positive) yielded 149.0 ± 10.9 Ma (Fig. 5), which corresponds to the Late Jurassic. However, according to current ideas, the diorites of Mount Kastel are of the Middle Jurassic (Bajocian–early Bathonian) age. The obtained fission-track age is likely to reflect the timing of the massif cooling below the temperature of the closure of the fission-track system in zircon corresponding to 215–240°C (Brandon and Vance, 1992).

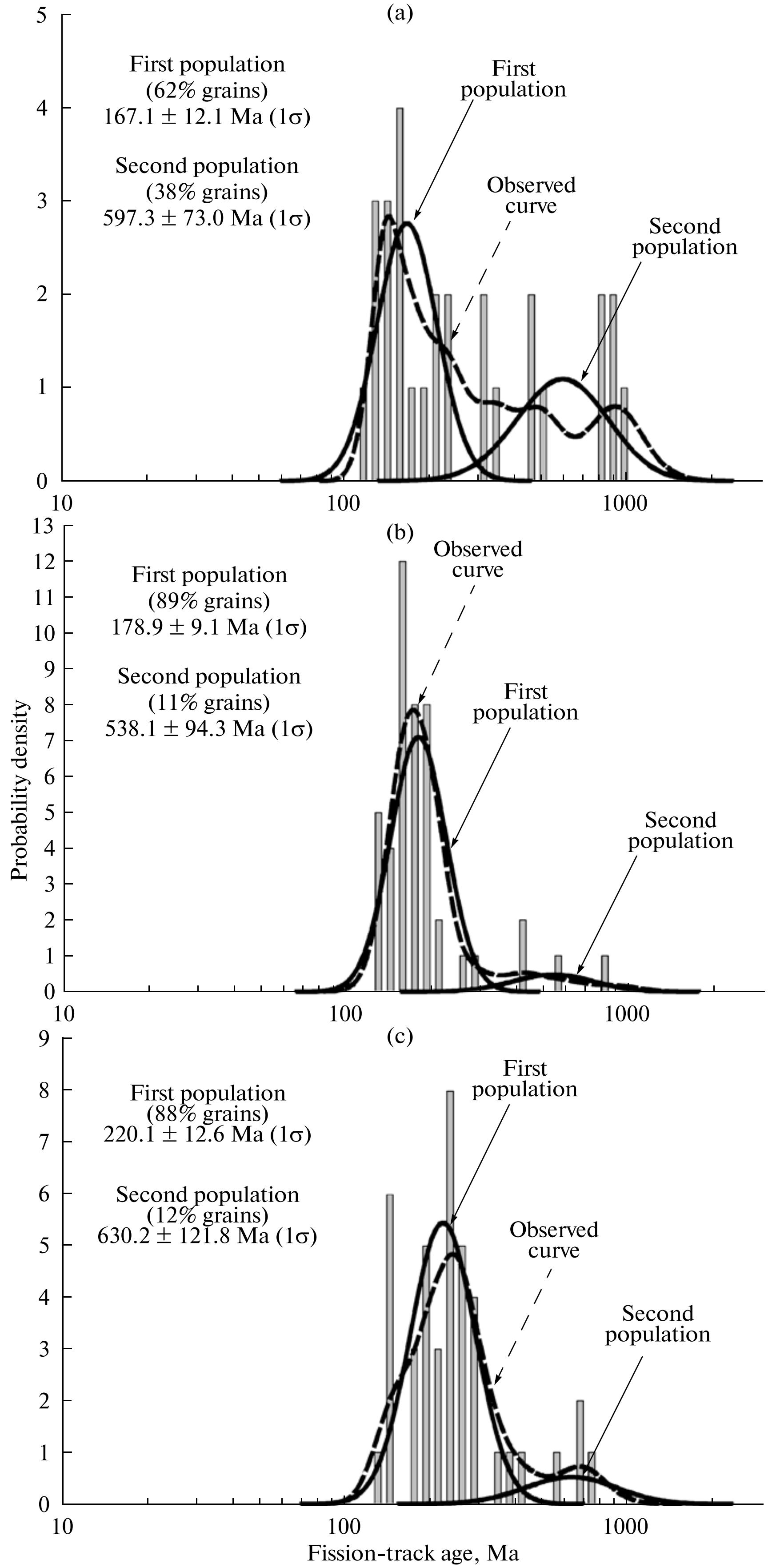
DISCUSSION

The obtained data allow the refining of the ages of Mesozoic (Triassic–Jurassic) magmatic rocks and part of the sedimentary complexes in the Crimea. The oldest of the obtained dates (220.1 ± 12.6 Ma, Yaman Ravine, Yaman Formation) corresponds to the terminal Middle Triassic–Late Triassic (Gradstein et al., 2008). The manifestation of Triassic magmatism in the Crimea was noted previously as well. It is believed at present that the low-alkaline fluidal rhyolite, dacite, and their tuffs occurring in association with flyschoid rocks of the Kichik Sequence and considered as elements of an island-arc assemblage can be reliably attributed to it (Spiridonov et al., 1990a). The sills developed in the upper reaches of the Bodrak River inside the Tavria Group were also attributed to the Triassic magmatic complexes (Lebedinskii, 1962; Bagdasaryan and Lebedinskii, 1967); however, it was shown later (Zaika–Novatskii, 1981; Mudrenko et al., 1983) that the sills intruded after folding ceased. Traces of Triassic magmatic activity are also revealed in the Crimean steppes, in which quartz-dolerite and quartz-diorite as old as 210 Ma are known near the Village of Severnyi (Spiridonov et al., 1990a).

The late Triassic(?)–Middle Jurassic age of zircons from the Tavria Group (193.6 ± 13.1, 167.1 ± 12.1, 154.0 ± 10.2 Ma) is in conformity with the interval of its formation, except for the youngest of the obtained dates which corresponds to the Late Jurassic (154 ± 10.2 Ma); however, taking into account the determination error, it may comply with the Middle Jurassic as well. This suggests that although the youngest parts of the Tavria Group do not go beyond the lowermost Middle Jurassic by paleontological data, the accumulation of these sediments in places could proceed longer, at least, up to the terminal Middle Jurassic. It should be noted that the obtained dates may indicate to an extent the possible manifestation of Early Jurassic magmatism in the Crimea. Although some researchers (Lebedinskii and Shalimov, 1967; Lebedinskii, 1969) recognized its manifestation, later it was widely considered that there is no reliable evidence of Early Jurassic magmatism in the Crimea (Mudrenko et al., 1982; Spiridonov et al., 1990a). It is only recently that new data have been obtained, which confirm the activity of Early Jurassic (late Pliensbachian–early Toarcian) magmatism in the Crimea (Stafeev et al., 2009). The presence of Middle Jurassic zircons is most likely to be accounted for by the partial overlapping of the time of the Tavria Group formation and the onset of active Middle Jurassic volcanism. The generation of zircons selected from sandstones of the Demerdzhi Formation in the Mount Yuzhnaya Demerdzhi (169.9 ± 8.6 Ma) may also be related to the Middle Jurassic (Bajocian). According to paleontological data, the subformation of the Demerdzhi Formation, from which samples were collected, is also of middle–late Oxfordian age (Permyakov et al., 1991).

The age of the zircon population from the Chenka Formation (178.9 ± 9.1 Ma), corresponding to the terminal Early–initial Middle Jurassic is also inconsistent with current ideas about its stratigraphic position. Initially, some researchers (Panov et al., 1978) reported about the finds of Triassic bivalves *Monotis* and Triassic brachiopods in the Chenka Formation,

[1] Following V.M. Tseisler and colleagues (Tseisler et al., 1999), we refer to the "Yaman" and "Ust-Mender" formations instead of the "Upper Tavria" and "Lower Tavria" formations respectively.


(a)
First population
(62% grains)
167.1 ± 12.1 Ma (1σ)
Second population
(38% grains)
597.3 ± 73.0 Ma (1σ)
First population
Observed curve
Second population
(b)
Observed curve
First population
(89% grains)
178.9 ± 9.1 Ma (1σ)
Second population
(11% grains)
538.1 ± 94.3 Ma (1σ)
First population
Second population
Probability density
(c)
First population
(88% grains)
220.1 ± 12.6 Ma (1σ)
Second population
(12% grains)
630.2 ± 121.8 Ma (1σ)
First population
Observed curve
Second population
10
100
1000
Fission-track age, Ma

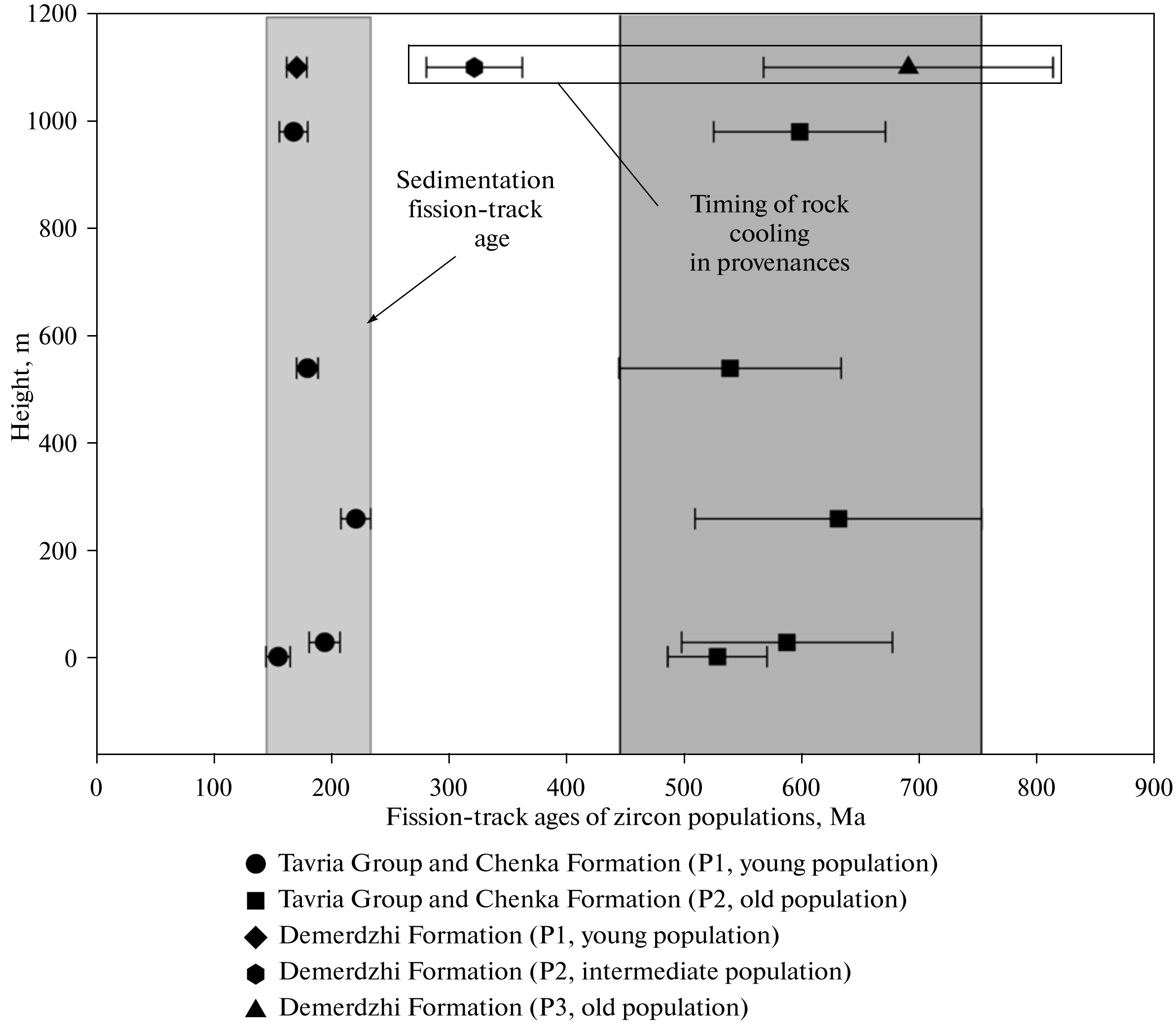


Fig. 4. Fission-track zircon ages versus the height of sampling (data for the Tavria Group, Demerdzhi and Chenka formations of the Crimea). Horizontal lines near ages reflect determination errors ($\pm 1\sigma$).

though, later the finds were apparently attributed to other formations, and the age of the Chenka Formation was determined on the basis of the stratigraphic position between the Tavria's lower and upper subformations (Panov et al., 2001). The obtained data suggest that the contact between the Chenka and Yaman formations (Tavria's lower and upper subformations) may be tectonic, and the first formation may be regarded as an analog of the Toarcian–Bajocian Bitak Formation, in whose composition sandstones and conglomerates prevail (Permyakov et al., 1991).

The age of zircons from a diorite sample collected in the Mount Kastel massif (149.0 ± 10.9 Ma) corresponds to the Late Jurassic, whereas the K–Ar dating of rocks from the massif yielded 160–170 Ma (Bagdasaryan and Lebedinskii, 1967; Spiridonov et al., 1990b). The presence of pebbles of the Kastel complex in the Upper Jurassic conglomerates (middle–upper Oxfordian) of Mount Demerdzhi and the Balaklava vicinity also agree well with the Middle Jurassic age of the massif. As mentioned above, the obtained fission-track age is likely to reflect the timing of the massif cooling below ~200°C.

CONCLUSIONS

(1) The fission-track dating of detrital zircons from Mesozoic terrigenous complexes of the Crimean mountains showed that the young zircon population from the Tavria Group's sandstones in the Yaman ravine is as old as 220.1 ± 12.6 Ma, and the population from the same deposits of the Crimea's southern coast (CSC), 193.6 ± 13.1, 167.1 ± 12.1, and 154.0 ± 10.2 Ma, which in general corresponds to the time interval of the Tavria Group's formation. Sandstones in the lowermost parts of the Demerdzhi Formation on Mount

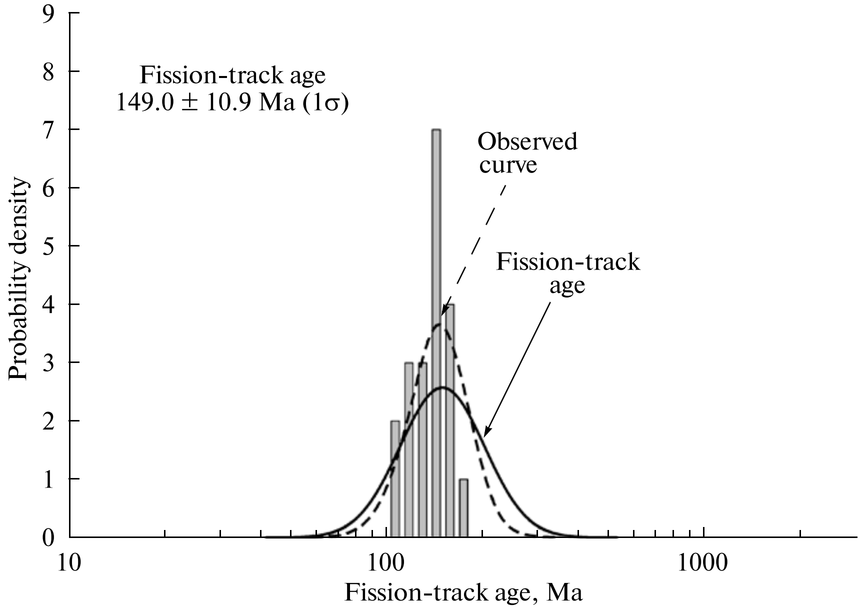


Fig. 5. Distribution of fission-track ages of zircon grains in sample K5 (diorite of the Mount Kastel massif). Broken line represents the observed curve; unbroken line, one population. Time scale is logarithmic.

Yuzhnaya Demerdzhi comprise the Middle Jurassic young zircon population (169.9 ± 8.6 Ma). The age of the young zircon population from the Chenka Formation in the region of the Settlement of Observatoriya corresponds to the initial Middle Jurassic (178.9 ± 9.1 Ma).

(2) The results of fission-track dating made it possible to refine the time range for the Tavria Group and extend its upper limit to the terminal Middle Jurassic. The dating of zircons from the Chenka Formation gives grounds to consider it to be younger than it was traditionally believed, and to regard its contact with the Yaman Formation as tectonic instead of stratigraphic.

(3) The age of terrigenous rocks in the Crimea is very close to the age of the zircons they comprise. The volcanic and/or magmatic rocks that formed synchronously with the accumulation of terrigenous complexes in the sedimentary basin are likely to have been the source of the zircons. Hence, the obtained data permit refining the timing of the Triassic–Jurassic magmatism in the Crimean mountainous and distinguishing three stages of magmatism: Late Triassic (Carnian?), slightly expressed Early Jurassic, and Middle Jurassic (Aalenian–Bathonian).

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