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# A new chronostratigraphy ($^{40}$Ar-$^{39}$Ar and U-Pb dating) for the middle section of the Burdur-Fethiye Shear Zone, SW Turkey (eastern Mediterranean)

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**Abstract:** Southwestern Turkey is a tectonically active region where extensional, strike-slip, and compressional tectonics cooccur. The Burdur-Fethiye Shear Zone is located in the middle of this complex area. Understanding the tectonic evolution of this region is crucial, but the controversial Neogene chronostratigraphy does not allow robust synthesis because of poor age control. The middle section of the Burdur-Fethiye Shear Zone includes three basins: the Acıpayam, Çameli, and Gölhisar basins. All these basins represent restricted portions of ancient larger carbonate lakes. The lacustrine sediments are locally covered or cut by lamproites with sparse intercalations of tuff levels. New $^{40}$Ar-$^{39}$Ar biotite and U-Pb zircon radiometric ages from volcanics and a tuff layer in this study demonstrate that the previously suggested Pliocene ages for these sediments are incorrect and that these Neogene sediments are middle Miocene in age.

**Key words:** $^{40}$Ar-$^{39}$Ar biotite dating, U-Pb zircon dating, Neogene stratigraphy, Burdur-Fethiye Shear Zone, Acıpayam Basin, Çameli Basin, SW Turkey

## 1. Introduction

Southwestern Turkey is a tectonically complex and active region in the Anatolian Microplate. Various hypotheses have been proposed for the tectonic evolution of this region, where structures formed associated with: 1) the westward escape of the Anatolian Microplate (Dewey and Şengör, 1979; Şengör, 1979; Şengör et al., 1985); 2) the NE-SW back-arc extension of the Aegean region (McKenzie, 1978; Le Pichon and Angelier, 1979; Meulenkamp et al., 1988; Yılmaz et al., 2000); 3) the subduction-transform edge propagator fault zone related to the motion of the Hellenic and Cyprus arcs (Govers and Wortel, 2005; Hall et al., 2014a); and 4) the compressional region of the Western Taurides (Aksu et al., 2009, 2014; Hall et al., 2009, 2014a, 2014b). The Burdur-Fethiye Shear Zone is a transtensional left-lateral shear zone 75–90 km wide and 300 km long, located along the southeastern boundary of the large Aegean extensional region and forming the western part of the Isparta Angle (Figure 1; Hall et al., 2014a; Elitez et al., 2016). The middle section of this shear zone consists of an ancient basin fill including the middle Miocene to lower Pliocene sequence, accumulated in fluvial and lacustrine environments and deformed by left-lateral transtensional shearing (Elitez et al., 2016; Elitez and Yaltırak, 2016). Today this region includes the Acıpayam, Çameli, and Gölhisar basins and their modern basin fill consisting of Pliocene–Quaternary units (Elitez and Yaltırak, 2016). In most previous studies the local fluvial, lacustrine, and alluvial fan deposits were mapped together and assigned a Pliocene age (e.g., Şenel, 1997, 2002). Such terrestrial sediments were first named the Çameli Formation (Erakman et al., 1982), but were subsequently divided into three members: the basal alluvial-fan Derindere Member, the middle fluvial Kumavşarı Member, and the upper lacustrine Değne Member (Alçiçek et al., 2004, 2005, 2006). Later, Elitez and Yaltırak (2014, 2016) mapped these three sediment successions as the Gölhisar, İbecik, and Dirmil formations. Based on micromammal fauna, the lacustrine sediments of the İbecik Formation were assigned an age of 10.8–8.5 Ma (Saraç, 2003) or ~3.4 Ma (van den Hoek Ostende et al., 2015b), while the upper section of the sedimentary sequence was dated as 1.8–2.2 Ma (e.g., Alçiçek et al., 2005, 2006; van den Hoek Ostende et al., 2015a). Recent studies showed that this significant time gap caused the development of an angular unconformity between lacustrine and alluvial fan sediments (Elitez and Yaltırak, 2016; Elitez et al., 2016). In the northern part of the study area, there are volcanic rocks that cut and/or overlie the lacustrine sediments. A small number of $^{40}$Ar/$^{39}$Ar radiometric dates from these volcanic rocks were obtained by Paton (1992) and reported ages range between Tortonian and early Pliocene. Further, however,

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these sediments were assigned to the middle Miocene-upper Pliocene based on previously dated volcanic rocks, reliable micromammal fossil records, and stratigraphic relationships (Elitez and Yaltırak, 2014, 2016).

The above review of the existing literature shows that the chronostratigraphy of the Acıpayam, Çameli, and Gölhisar basins and their environs is controversial. The chronostratigraphy of these basins remains one of the most important problems in the region because of its vital role in the tectonic and kinematic history of southwestern Anatolia, including the Burdur-Fethiye Shear Zone. The data we obtain can redefine all the events along the Burdur-Fethiye Shear Zone. Based on the ages of these sediments, the timing of tectonic events both in western and southwestern Anatolia will be modified and the geological construction of the region will be reinterpreted. In an attempt to resolve the conflicting chronostratigraphic interpretation of the Neogene successions across the Acıpayam, Çameli, and Gölhisar basins and environs, we collected seven volcanics and a tuff sample for radiometric dating. U-Pb zircon and $^{40}Ar$-$^{39}Ar$ biotite methods were applied on the samples and the results show that lacustrine sediments are upper Miocene in age rather than Pliocene.

## 2. Description of local stratigraphic units

### 2.1. Basement rocks

The Neogene Acıpayam, Çameli, and Gölhisar basins developed over Paleozoic to early Miocene basement rocks. These basement rocks are composed of Lycian nappes (Brunn et al., 1970; Graciansky, 1972; Önalan,

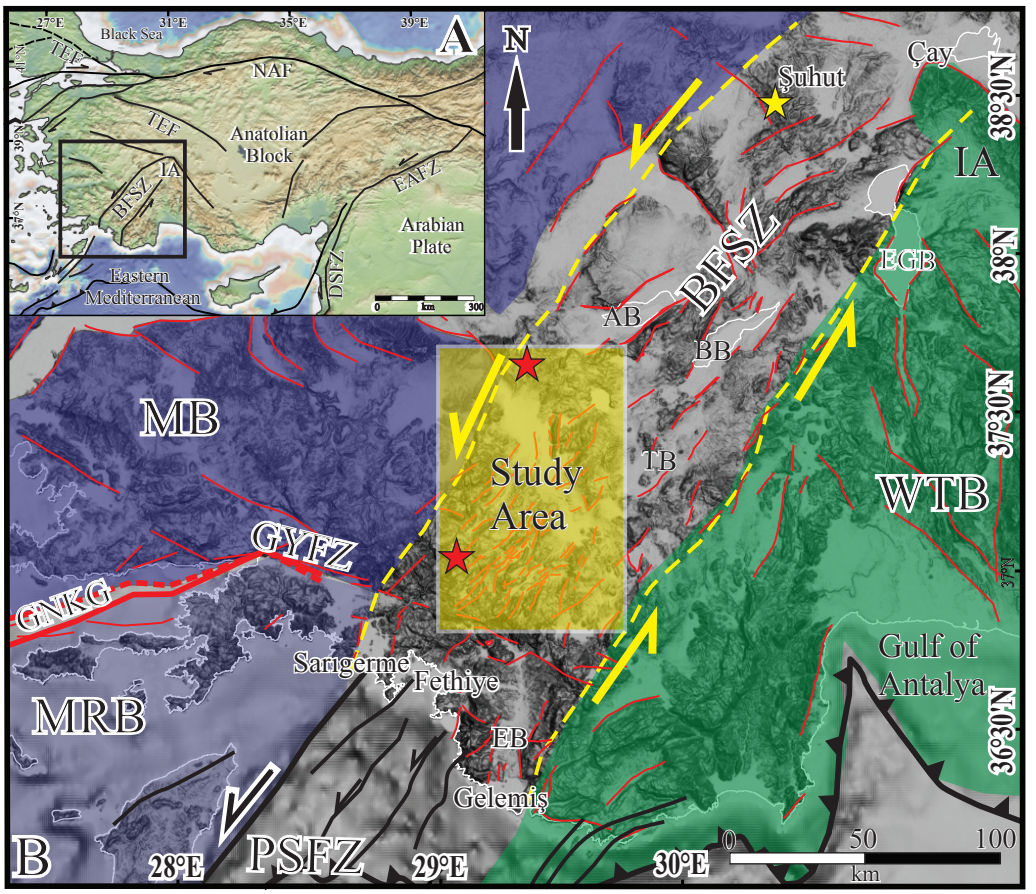


**Figure 1.** A) Simplified neotectonic map of Turkey compiled from Yaltırak et al. (2012) TEF: Thrace-Eskişehir Fault, NAF: North Anatolian Fault Zone, EAFZ: East Anatolian Fault Zone, DSFZ: Dead Sea Fault Zone, IA: Isparta Angle, BFSZ: Burdur-Fethiye Shear Zone. Rectangle indicates Figure 1B. B) Regional fault map of southwestern Anatolia compiled from Tur et al. (2015). Yellow rectangle indicates location of the study area. Dark blue region denotes the NE-SW extensional domain. (MRB: Marmaris-Rhodes Block, MB: Menderes Block, GNKG: Gökova-Nisyros-Karpathos Graben). Green region denotes the NNE-SSW compressional domain (WTB: Western Taurides Block, IA: Isparta Angle). BFSZ: Burdur-Fethiye Shear Zone, PSFZ: Pliny-Strabo Fault Zone, GYFZ: Gökova-Yeşilüzümlü Fault Zone, AB: Acıgöl Basin, BB: Burdur Basin, TB: Tefenni Basin, EGB: Eğirdir Basin, EB: Eşen Basin. Red stars indicate locations of dated samples in this study. Yellow star indicates location of dated samples of Prelević et al. (2015).

1979; Ersoy, 1990) and Yeşilbarak nappe (Önalan, 1979) and consist of Paleozoic rocks, Mesozoic volcanic rocks, Mesozoic sedimentary rocks, Mesozoic limestones, Cretaceous ophiolitic mélange, Cretaceous flysch, Paleogene sedimentary rocks, and Eocene-lower Miocene turbiditic sedimentary rocks. The Paleozoic rocks comprising limestones, dolomites, radiolarites, cherts, shales, and sandstones (Şenel, 1997) are generally exposed in the southwestern part of the study area (Figure 2). The Mesozoic volcanic rocks, including basalts, spilitic basalts, and rarely radiolarites, cherts, and shales (Şenel, 1997), crop out on the southwestern side of the study area. The Mesozoic sedimentary rocks consist of sandstones, mudstones, and conglomerates and can be observed in two small areas in the northwestern and southwestern parts of the study area. The Mesozoic limestones, composed of locally recrystallized pelagic and neritic limestones, generally cover topographically high areas (Figure 2). The Cretaceous ophiolitic mélange mainly comprises harzburgites, serpentinites, dunites, and radiolarites and covers an extensive area (Figure 2). The Cretaceous flysch is turbiditic in nature and is characterized by sandstones, claystones, cherty limestones, and conglomerates (Şenel, 1997). These rocks outcrop as small exposures in the study area (Figure 2). The Paleogene sedimentary rocks include conglomerates, sandstones, siltstones, and shales and are exposed on the western and northwestern parts of the study area. The Eocene–lower Miocene turbiditic sediments consist of sandstones, claystones, siltstones, shales, and mudstones.

**2.2. Bozdağ Formation**

The Neogene basin fills start with alternating conglomerates, sandstones, and mudstones of the Bozdağ Formation (Göktaş et al., 1989). The Bozdağ Formation unconformably overlies the basement rocks and is unconformably overlain by the Gölhisar Formation (Figure 2). The best exposures of the unit are located in the northern portion of the study area, northeast of Kelekçi and in the valley between the villages of Ören and Mevlütler (Figure 2 and 3). The Bozdağ Formation consists of medium to thick-bedded, locally massive, dark-gray, gray, light-brown, yellowish, and reddish conglomerates, sandstones, and mudstones. It is approximately 500 m thick. Based on its stratigraphic position and algae fossils such as *Schizotrix* sp. and *Scytonema* sp., Şenel (1997) dated the formation as upper Oligocene-lower Miocene. The Bozdağ Formation contains sedimentary facies representing a coastal environment under terrestrial influence.

**2.3. Gölhisar Formation**

The Gölhisar Formation contains green, greenish gray-to-gray, reddish brown, brown, and purple conglomerates and sandstones. This unit was identified by Elitez (2010). The best outcrops and cross-sections are observed north of Gölhisar, south of Acıpayam, and along the new Acıpayam–Çameli main road (Figure 2). The Gölhisar Formation unconformably or occasionally tectonically rests on the basement rocks and grades vertically and horizontally into the İbecik Formation (Figure 3). The succession starts with thick beds of granule conglomerates at the bottom and grades upward into conglomerates, conglomeratic sandstones, sandstones, and siltstones. The pebble composition of conglomerates varies depending on the characteristics of the local basement rocks (e.g., serpentinite, radiolarite, and limestone pebbles). However, around Acıpayam and north of Yeşilyuva, the pebbles are composed primarily of reworked material derived from the Bozdağ Formation.

The thickness of the unit is ~900 m. Lack of fossil data does not allow a proper dating. Therefore, the age of the formation is thought to be middle-late Miocene due to its stratigraphic position (Elitez, 2010; Elitez and Yaltırak, 2014, 2016). The Gölhisar Formation was deposited in a meandering and/or braided river system. The limestone lenses at the bottom of the unit indicate a reefal environment near Acıpayam and northern of Yeşilova.

**2.4. İbecik Formation**

The İbecik Formation (Elitez, 2010) is predominantly composed of white, beige, and yellowish sandstones, siltstones, claystones, marls, tuffs, and limestones. The best cross-sections are observed near the village of İbecik, along the NE-SW road from the Yapraklı dam to a small hill to the northeast (Figure 2). The İbecik Formation grades laterally and vertically into the Gölhisar Formation at the bottom and is unconformably overlain by the Dirmil Formation. The succession starts with beige sandstones and whitish gray claystones that grade upwards into white and grayish fractured marls and limestones. The uppermost part of the İbecik Formation includes mostly red wine-colored claystones and hard, locally fractured, thickly bedded, whitish yellow and red wine-colored silty carbonates including caliche. The thickness of this upper part is ~200 m and it records a period of aridity. There are intercalating vertical transition with tuffs rich in biotite. Especially in the southernmost part of the study area, biotites of 2–3 mm in size are observed. They are commonly found among the marl levels of the İbecik Formation. The İbecik Formation is ~850 m thick. In the northern part of the study area, the sediments of the İbecik Formation are covered or cut by Denizli lamproites (Paton, 1992) at elevations of 1300–1600 m (Figures 2 and 3).

Based on vertebrate fossils at 1400 m elevation south of the village of Elmalıyurt (36°53′18.34″N, 29°21′33.73″E), the marls and thin coal beds of the İbecik Formation are assigned a Vallesian age (Saraç, 2003). The evolutionary stages of the lacustrine deposits indicate a continuous

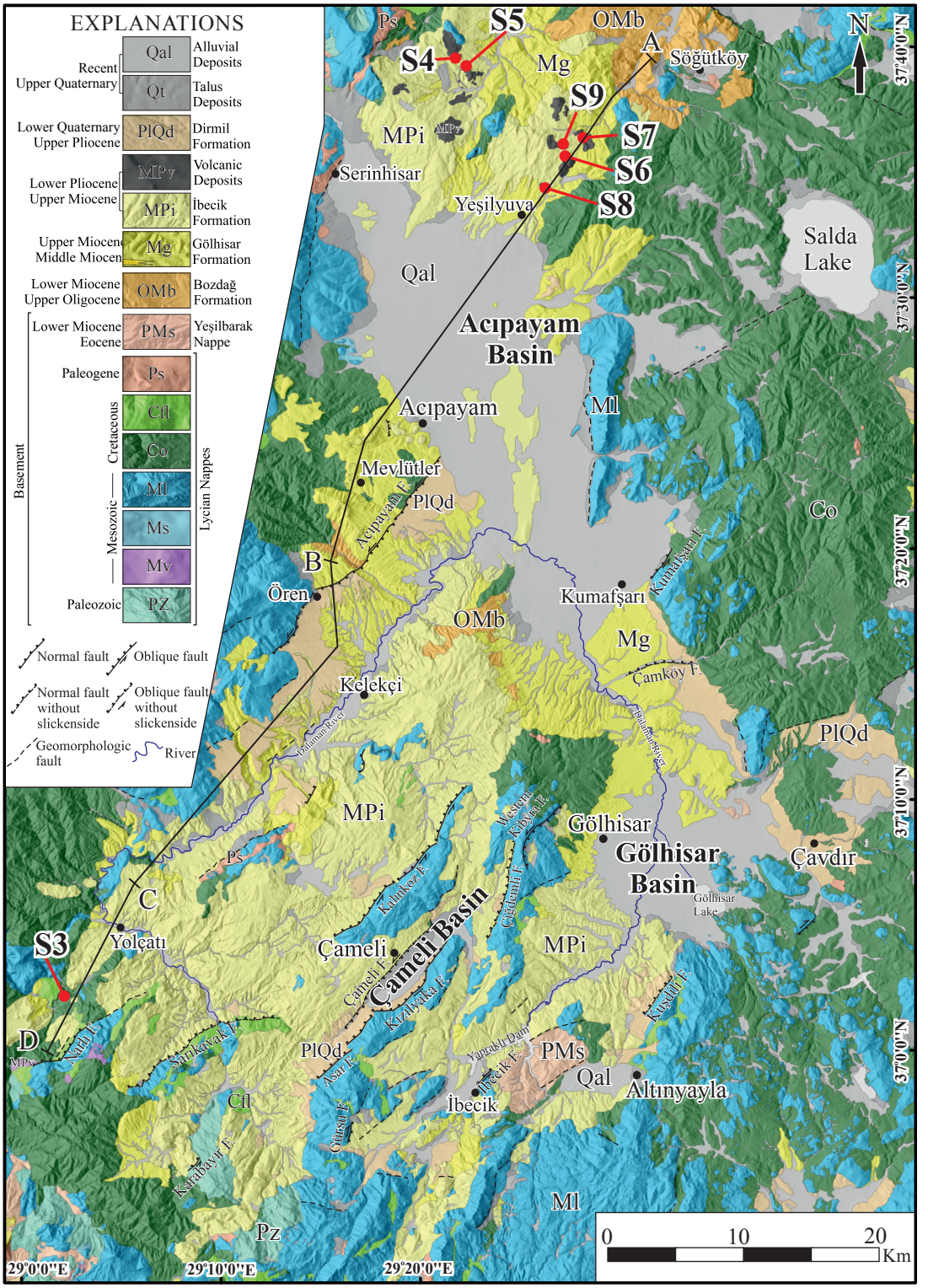


**Figure 2.** Simplified geological map of the study area (Elitez and Yaltırak, 2016). Red points show the locations of the samples.

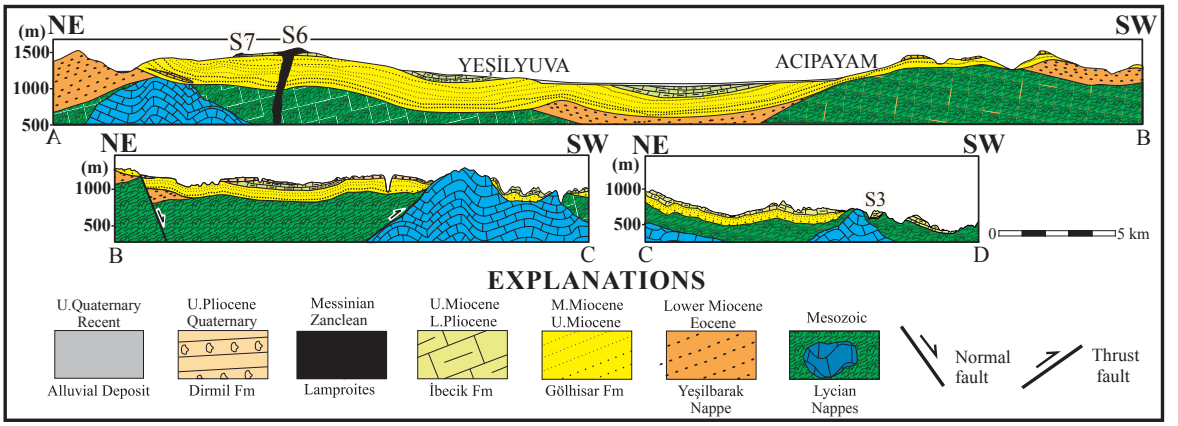


**Figure 3.** Geological cross-sections and correlation of lamproites and tuff levels.

deposition from late Miocene to early Pliocene (Elitez, 2010; Elitez and Yaltırak, 2014, 2016). The İbecik Formation contains sedimentary facies reflecting a shallow, warm lake and shoreline environments, including beach and delta.

### 2.5. Dirmil Formation

The Dirmil Formation is made of copper-colored conglomerates, mudstones, local siltstones, and claystones. This unit was named by Elitez (2010). The unit crop outs mostly north of Altınyayla (or Dirmil) on the footwall of the Kuşdili normal fault and southwest of the Çameli Basin, on the footwall of the Asar normal fault. West of the Dalaman River and south of the Acıpayam Basin, these copper-colored rocks are clearly exposed on high-elevation plains (Figure 2). The Dirmil Formation unconformably rests on the folded and tilted Gölhisar and İbecik formations. This fault-controlled deposition is observed primarily in front of the basement rocks (Figure 2). The conglomerates of the unit are poorly sorted and consist of angular to subangular pebbles supported by a matrix of mud. The total thickness of the Dirmil Formation is ~250 m. Based on its stratigraphic position and micromammal fossils (e.g., *Mimomys pliocaenicus*, *Apodemus dominans*, and *Micromys praeminutus*; Erten, 2002), a late Pliocene-early Quaternary age is assigned to the formation (Elitez and Yaltırak, 2016). The sediments of the unit indicate an alluvial fan depositional environment.

## 3. Sampling and methods

Six lamproites and one tuff sample were collected from the study area. Lamproites cut both the İbecik and the Gölhisar formations, but we only observed intercalating lamproite levels in the İbecik Formation (Figures 2 and 3), indicating the synchronous nature of the volcanism with the İbecik Formation. Samples 4, 5, 6, 8, and 9 cut or cover the İbecik Formation (Figures 2, 3, 4a, and 4b). One lamproite sample cutting the Gölhisar Formation was collected (i.e. S7; Figures 2 and 4c). A tuff level was collected from the İbecik Formation (i.e. S3; Figures 2, 4d, and 4e).

In the region, lamproite samples are generally mildly to highly altered. Therefore, we tried to collect less altered samples. However, each sample has a different degree of alteration. The tuff sample comes from the southern part of the region (Yolçatı village; Figures 2 and 3). The tuff layer is a pyroclastic fall deposit 2–12 cm thick. It is rich in idiomorphic biotite and feldspar minerals (Figure 5). This tuff layer accumulated between two marl layers. Different lithologies with different thicknesses can be observed in the road cut (Figures 4d and 4e). There are white lacustrine limestones, marls, and claystones. The tuff layer can be traced all along the road cut, indicating very extensive and continues deposition. Both biotite and zircon were extracted from this sample for age determination.

### 3.1. $^{40}$Ar-$^{39}$Ar Dating

All samples were initially processed for geochronological analysis at the Mineral Separation Laboratory of the Eurasian Institute of Earth Sciences at İstanbul Technical University. Initially rock samples were crashed to reduce grain size, and then sieved for grain classification. The grain size between 125 and 250 μm was washed and dried at 105 °C. Biotite minerals were separated repeatedly using a Frantz geomagnetic separator between 4 and 6 mA to at least 95% purity.

Samples were wrapped in Al foil and irradiated for 90 MWh at location 8B at the McMaster Nuclear Reactor at McMaster University in Hamilton, Canada, in irradiation package mc52. Standard hornblende MMhb-1 was used as a neutron fluence monitor with an assumed age of 520.4 Ma (Samson and Alexander, 1987). All samples were incrementally heated with a Coherent Innova 5 W continuous argon-ion laser until complete fusion was achieved. Samples were loaded into 3 adjacent wells of 2

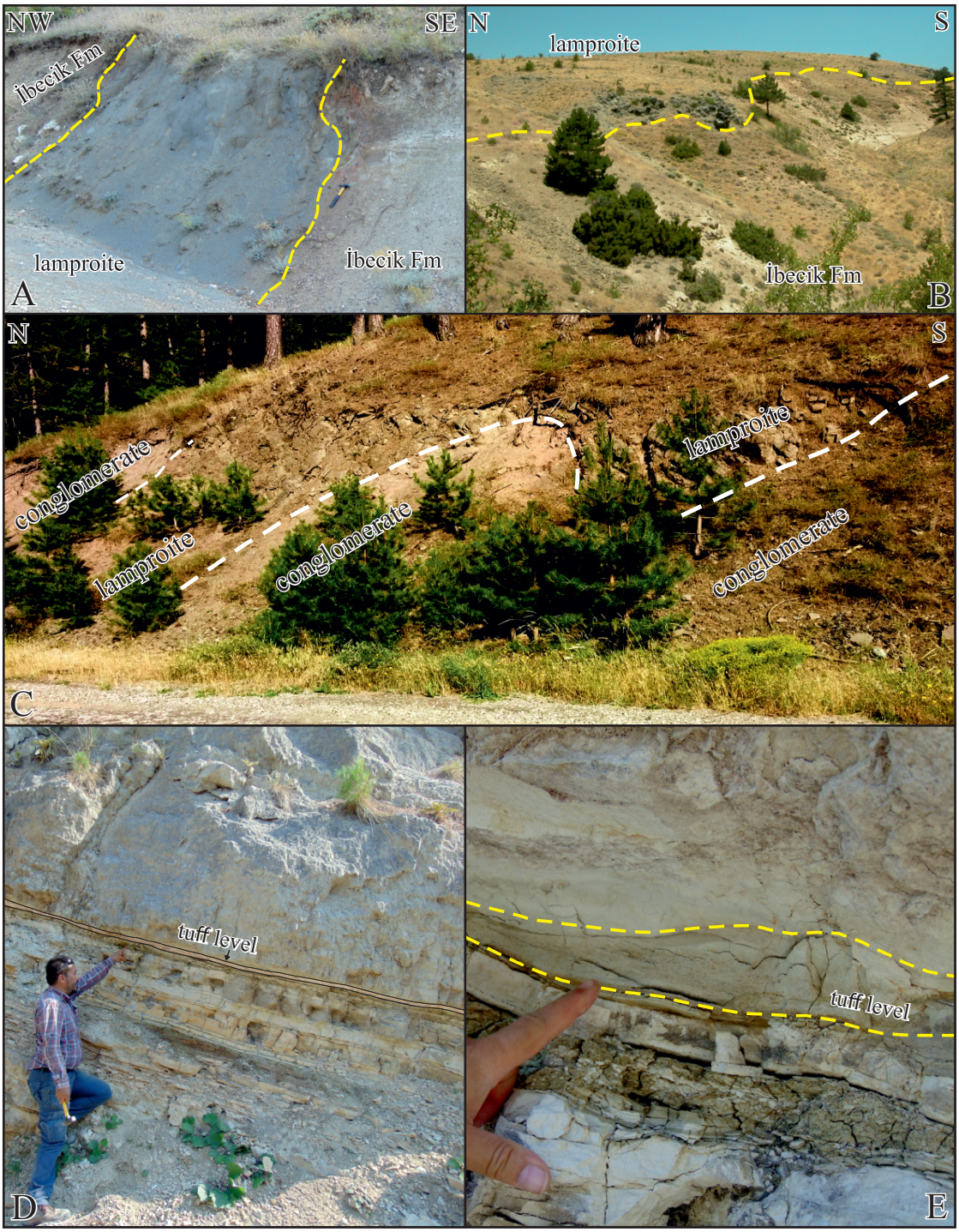


**Figure 4.** Examples from the outcrops of target volcanic rocks in the study area. A) Lamproite cutting the İbecik Formation (sample 5; 37°39′52.63″N, 29°22′32.92″E). B) Lamproites overlying the İbecik Formation (37°37′5.34″N, 29°21′1.38″E). C) Lamproites cutting the Gölhisar Formation (sample S7; 37°37′21.07″N, 29°28′28.45″E). D, E) Tuff level observed in the Ibecik Formation (sample S3; 37°2′14.60″N, 29°4′48.29″E).

mm in diameter and each laser power setting was degassed for 30 s.

Ar isotopes were measured using a VG1200S mass spectrometer with a source operating at 150 μA total emission and equipped with a Daly detector operating in analog mode. Mass discrimination was monitored daily using ~$4 \times 10^{-9}$ ccSTP of atmospheric Ar. Fusion system blanks were run every five fusion steps and blank levels from argon masses 36 through 40 (~$2 \times 10^{-14}$, ~$3 \times 10^{-14}$, ~$1 \times 10^{-14}$, ~$3 \times 10^{-14}$, and $2 \times 10^{-12}$ ccSTP, respectively) were subtracted from sample gas fractions. Corrections were also made for the decay of $^{37}$Ar and $^{39}$Ar, as well as interfering nucleogenic reactions from K, Ca, and Cl as well as the production of $^{36}$Ar from the decay of $^{36}$Cl.

### 3.2. Zircon U-Pb LA-ICP-MS dating

The whole-rock sample was crushed in a jaw crusher (crushing to <0.3–0.5 cm) and milled in a disk mill (<0.6–1 mm). After milling, the sample was washed and separated into heavy and light fractions, then dried. The heavy fraction was sieved and the non- to slightly magnetic fraction was separated using a magnetic separator. Heavy liquids (bromoform – 2.9 g/cm$^3$ and methylene iodide – 3.32 g/cm$^3$) were used to collect the zircon concentrates. The zircons were picked manually under a binocular microscope. The grains were then mounted in epoxy resin and polished. Cathodoluminescence and back-scattered images were produced at Belgrade University using a scanning SEM JSM-259 6610.

Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analyses were carried out at the Geological Institute of the Bulgarian Academy of Science. Spatial resolution was 35 μm and frequency was 8 Hz. The U-Pb fractionation was corrected using the GEMOC GJ-1 and raw data were processed using GLITTER4. $^{207}$Pb/$^{206}$Pb, $^{208}$Pb/$^{232}$Th, $^{206}$Pb/$^{238}$U, and $^{207}$Pb/$^{235}$U ratios were calculated. Th disequilibrium correction was made for the results of the LA-ICP-MS. Th gets fractionated from U, imparting a disequilibrium in $^{230}$Th (an intermediate product in the $^{238}$U decay series) that has to be corrected to get an accurate age for younger magmatic rocks (Guillong et al., 2014). U–Pb concordia ages were calculated and plotted using ISOPLOT (Ludwig, 2003).

## 4. Results

Geochronological studies were carried out by two different methods to reveal the chronostratigraphy of the middle section of the Burdur-Fethiye Shear Zone. Dating results are presented in Figures 6–8, Tables 1 and 2, and the Appendix. Six lava samples and a tuff sample were dated using the $^{40}$Ar/$^{39}$Ar method. An additional tuff sample was also dated by zircon U-Pb method. Eleven $^{40}$Ar/$^{39}$Ar dates were obtained from lamproites (samples S4–S9) located in the northern part of the study area (Figures 2, 3 and 4a–4c; Table 1). Two duplicated biotites were dated for each sample to get better results. However, the results show a wide scatter ranging from 5.83 to 12.32 Ma (Figure 6), with several ages indicating large error margins (Table 1), high MSWD values, and/or low percentages of released argon (Figure 6). Therefore, these ages were disregarded during evaluation of the chronostratigraphy of the region. Sample S4 gave two biotite ages, one of which was geologically inconsistent. Furthermore, another age had a large error range (8.23 ± 3.48 Ma; Figure 5 and Table 1). Sample S5 yielded ages of 5.06 ± 1.44 and 5.69 ± 2.34 Ma, respectively (Figure 6 and Table 1). These ages are similar considering their error margins. Sample S6 also yielded similar ages from two different biotite separates (6.08 ± 0.48 and 6.43 ± 0.29 Ma; Figure 6 and Table 1). These ages are one million years older than the ages obtained for S5. Sample S7 gave similar ages but the first age revealed a higher MSWD value and a low fraction of $^{39}$Ar released (Figure 6 and Table 1). Therefore, we accepted 6.94 ± 0.35 Ma as the age of the sample. Similar to sample S7, sample S8 yielded ages around 6.9 Ma (6.98 ± 0.31 and 6.88 ± 0.22). The results of sample S9 show a plateau profile ranging between 7.92 ± 0.55 and 6.87 ± 0.38 Ma. After excluding outliers, we calculated 6.81 ± 0.30 Ma as a weighted average age for the lamproite dykes (Figure 6). We dated one sample using both $^{40}$Ar/$^{39}$Ar and U-Pb LA-ICP-MS methods from a tuff layer in the İbecik Formation in the southwestern part of the study area (S3; Figures 2, 3, 4d, and 4e). This sample location consists entirely of laminated shales, marls, and limestone beds. The dated sample is a thin tuff lamina, consisting of mica, feldspar, quartz, and minor zircon (2–3 mm thick) intercalated with the lacustrine limestone. In the outcrop, the base contact of the tuff level is a sharp boundary (Figures 4d and 4e). This thin level is an entirely atmospheric fall-out deposit and the rest of the sequence consists of fine-grained lacustrine sediments. $^{40}$Ar/$^{39}$Ar ages of sample S3 are very different from one another. The first age data are very poor and excluded. It showed a high MSWD value and low fraction of $^{39}$Ar released. Another separate gave 5.83 ± 0.87 Ma. Figure 8a shows cathodoluminescence images of the zircon crystals extracted from sample S3. The zircons are perfectly idiomorphic and exhibit slight to well-expressed oscillatory zoning, typical for crystallization in magmatic conditions. The zircon grains in the sample are predominantly medium to short prismatic and some of them reveal a complex internal structure with recrystallized cores and inclusions of apatites. Thirty-one spots were analyzed and most of them yielded concordant ages (between 90% and 107%; Table 2). Some of the zircon zones yielded discordant ages, probably due to lead loss. The concordia age obtained from the zircons is 6.93 ± 0.041 Ma (Figure 8b) as crystallization age. Both zircon

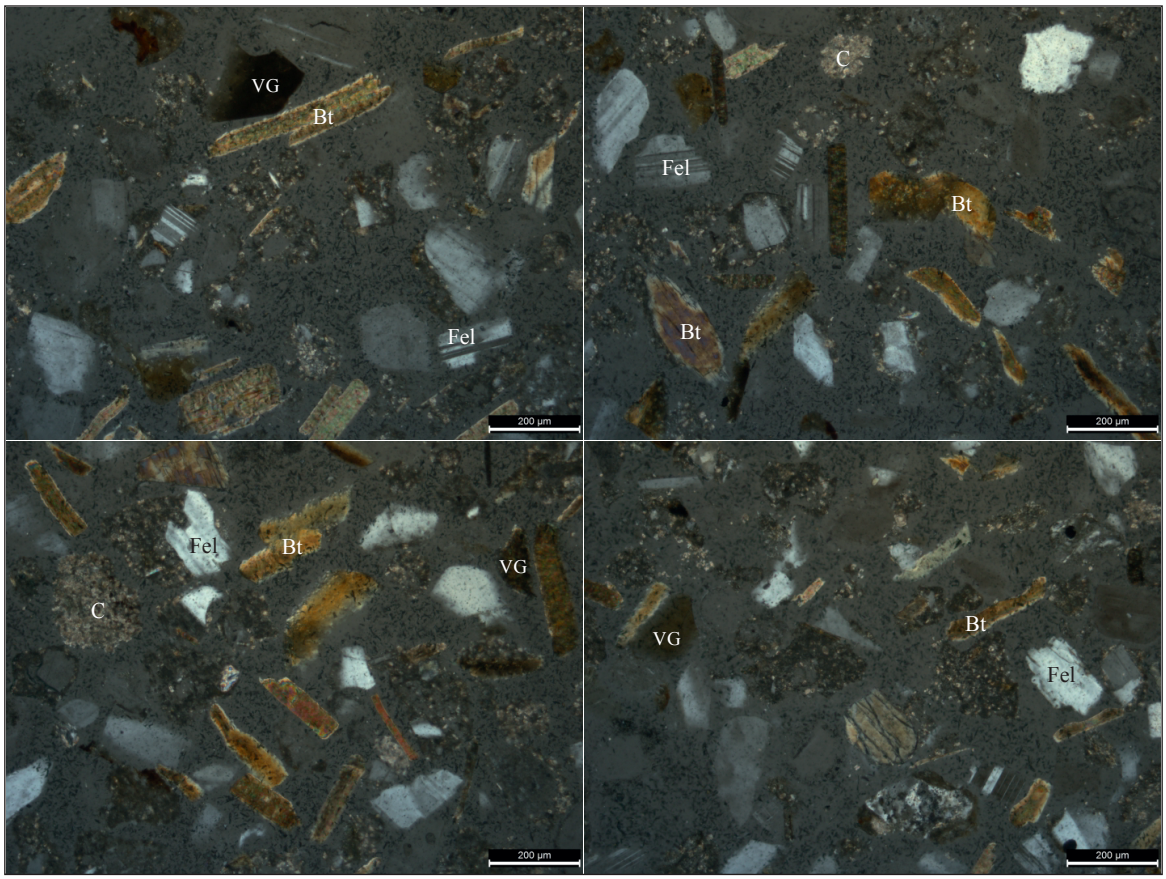


**Figure 5**. Photomicrograph showing mineral content of sample S3 under polarized optical microscope (Bt: biotite, VG: volcanic glass, Fel: feldspar, C: calcite).

U-Pb and biotite $^{40}Ar$-$^{39}Ar$ r ages are identical in error ranges and correspond to a Messinian interval.

## 5. Discussion and conclusions

The late Miocene-Pliocene terrestrial sediments occupy wide areas on the geological maps of southwestern Anatolia (see Şenel, 1997, 2002). The timing of tectonism in this region has been determined based on limited terrestrial fossil ages (e.g., Erten, 2002; Saraç, 2003; Alçiçek et al., 2005; van den Hoek Ostende et al., 2015b). In general, the upper Pliocene carbonate sequences have not been recorded in Neogene geological history in the Mediterranean literature, except for Anatolia (e.g., Popov et al., 2006; Snel et al., 2006; Rossi et al., 2015; Guerra-Merchán, 2014; Cornée et al., 2016; Frigui et al., 2016). On the contrary, pre-Messinian and especially Tortonian carbonate environments are widespread in all Mediterranean regions (e.g., Buchbinder, 1979; Jacobs et al., 1996; Brachet et al., 1998; Krijgsman et al., 2002; Tsaparas and Marcopodouluo-Dicantoni, 2005; Hüsing et al., 2009; Braga, 2016; Brandano et al., 2016; Moisette et al., 2018). The pre-Miocene sequences and the records of the Messinian salinity crisis (Hsü et al., 1973), holding an important place in the Tertiary geology of the Mediterranean, are almost absent in southwestern Anatolia (e.g., Şenel, 1997, 2002). This situation was first noted in the northern Aegean and Marmara seas (Sakınç et al., 1999; 2000; Sakınç and Yaltırak, 2005; Snel et al., 2006), where Pliocene carbonate sequences do not exist and terrestrial conglomerates and alluvial fan sediments unconformably rest on the Miocene sequences. Based on the presence of Mediterranean fauna and the ages of cross-cutting basalts, Sakınç and Yaltırak (2005) suggested that the lower part of the limestones in the Alçıtepe Formation (northwestern Anatolia) were deposited during the Tortonian. These authors also suggested that the upper parts of the Alçıtepe Formation, including the brackish species, were deposited during the Messinian and that they can be considered as evidence for the inflow from the Paratethys to the Northern Aegean region during the Messinian.

The new radiometric ages provided in this study allowed a more reliable comparison between the northern Aegean

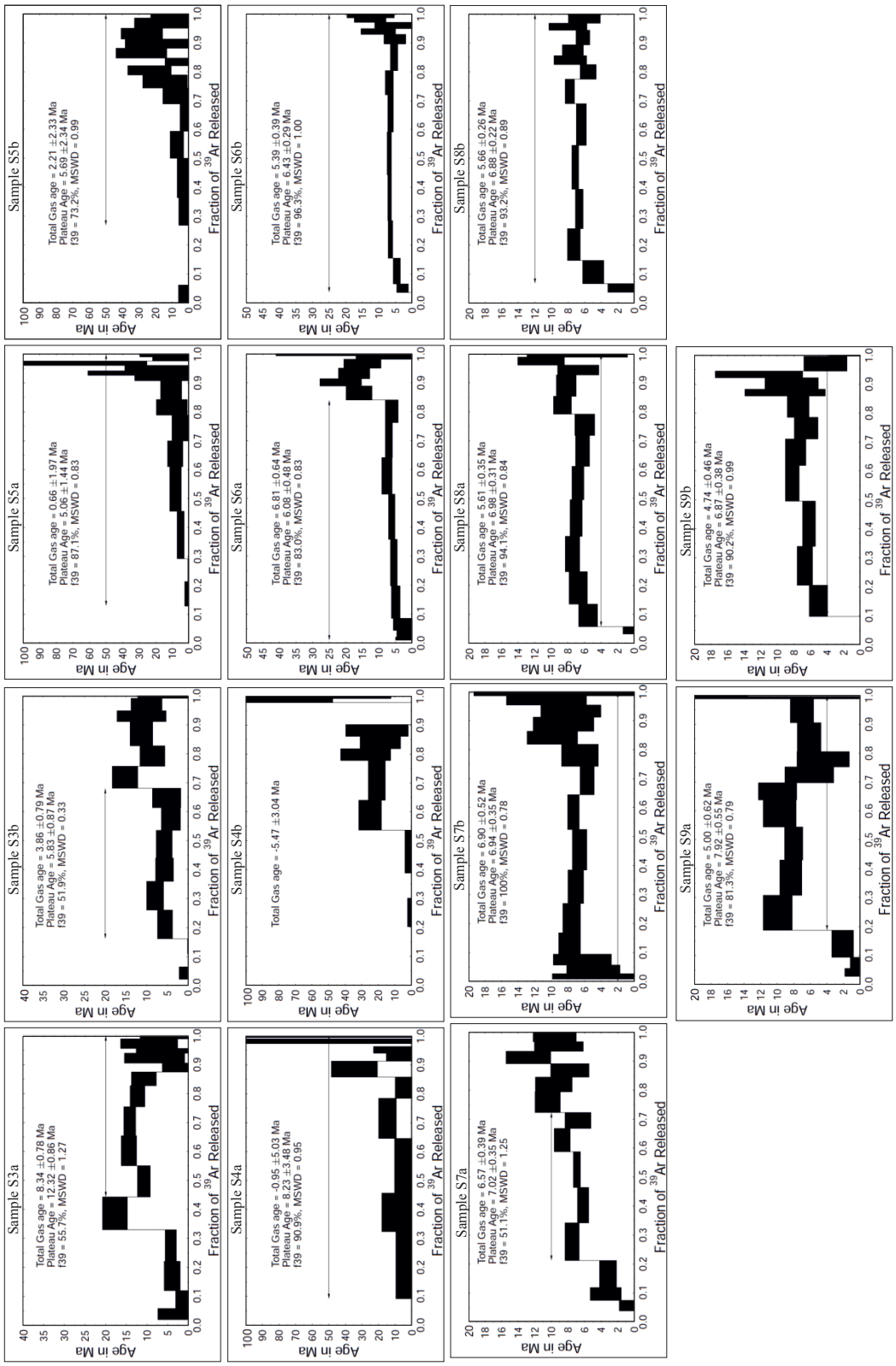


**Figure 6.** Diagrams of plateau ages obtained from biotites of lamproites samples. Ar isotopes were measured in the Argon Geochronology Laboratory, University of Michigan, Ann Arbor, MI, USA (analyst: Chris Hall).

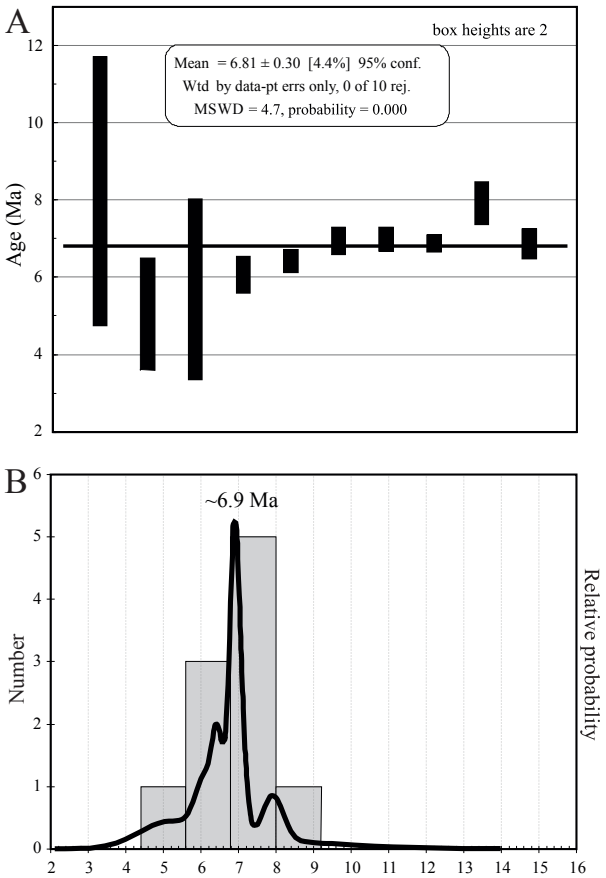


**Figure 7.** $^{40}Ar/^{39}Ar$ age range plots of the individual samples except tuff sample. A) Mean age calculation of the ages (Ludwig, 2003). B) Relative probability distribution of the ages.

region (i.e. northwestern Anatolia) and southwestern Anatolia. The carbonate deposition (i.e. the Alçıtepe Formation) in northwestern Anatolia and the Sea of Marmara has a time-equivalent deposition in southwestern Anatolia (i.e. the İbecik Formation). Likewise, the Dirmil Formation is similar in terms of sedimentary characteristics to the late Pliocene-early Quaternary Conkbayırı Formation (Şentürk and Karaköse, 1987; Yaltırak, 2002) in the Gelibolu Peninsula, the Samanlıdağ Formation in the Armutlu Peninsula (Alpar and Yaltırak, 2002), and the Karacabey Formation in the Manyas Plain (Yaltırak and Alpar, 2002). Accordingly, this sequence is time-equivalent to the Neogene sequence along the middle section of the Burdur-Fethiye Shear Zone. This left-lateral transtensional shear system created various basins. Today, these basins include the remnants of larger carbonate lakes. In previous studies, these lacustrine deposits were assigned to the Pliocene, except for the Acıpayam Basin (e.g., Şenel, 2002; Alçiçek et al., 2004, 2005, 2006, 2008; Kazancı et al., 2012). Paton (1992) dated the basaltic dykes cutting limestones

**Table 1.** Brief characterization of samples and their ages.

| Sample | Locality | Rock | Mineral | Age, Ma |
|---|---|---|---|---|
| S3a*<br>S3b* | 37°2′14.60″N,<br>29°4′48.29″E | Tuff | Biotite | 12.32 ± 0.86<br>5.83 ± 0.87 |
| S4a*<br>S4b* | 37°40′2.71″N,<br>29°21′53.05″E | Lamproite | Biotite | 8.23 ± 3.48<br>- |
| S5a*<br>S5b* | 37°39′52.63″N,<br>29°22′32.92″E | Lamproite | Biotite | 5.06 ± 1.44<br>5.69 ± 2.34 |
| S6a*<br>S6b* | 37°36′12.49″N,<br>29°27′21.85″E | Lamproite | Biotite | 6.08 ± 0.48<br>6.43 ± 0.29 |
| S7a*<br>S7b* | 37°37′21.07″N,<br>29°28′28.45″E | Lamproite | Biotite | 7.02 ± 0.35<br>6.94 ± 0.35 |
| S8a*<br>S8b* | 37°35′18.78″N,<br>29°26′20.69″E | Lamproite | Biotite | 6.98 ± 0.31<br>6.88 ± 0.22 |
| S9a*<br>S9b* | 37°37′2.42″N,<br>29°27′18.40″E | Lamproite | Biotite | 7.92 ± 0.55<br>6.87 ± 0.38 |
| S3** | 37°2′14.60″N,<br>29°4′48.29″E | Tuff | Zircon | 6.933 ± 0.041 |

*$^{40}Ar/^{39}Ar$ dating; **U-Pb dating.

as upper Miocene in the north of Acıpayam Basin. This interpretation led to the separation of the same unit into two different formations (e.g., Şenel, 2002). The different age assignments for the same rocks at two different sides of the same basin created great confusion in the literature and led to misinterpretation of the geological history of the region.

Paton (1992) studied the Denizli lamproites and dated them using the $^{40}Ar/^{39}Ar$ whole-rock method with radiometric ages of 4.59 ± 0.57, 5.66 ± 0.63, 5.89 ± 0.41, 6.52 ± 0.33, 6.28 ± 0.48, and 6 ± 1.54 Ma (i.e. Tortonian–early Pliocene). At the same time, some researchers reported mammal fossils located in the south of the Acıpayam Basin and gave an age interval between 10.8 and 1.8 Ma (e.g., Saraç, 2003; Alçiçek et al., 2005; van den Hoek Ostende et al., 2015b). Elitez et al. (2016) and Elitez and Yaltırak (2018) claimed that the geographic locations of these samples and positions of the fossils are not reliable. Therefore, stratigraphic relationships remain ambiguous. Across the northern part of the Acıpayam Basin at elevations of ~1500–1600 m, the volcanic rocks cut and/or overlie lacustrine sediments of the İbecik Formation (Figure 3). In this study, we dated biotites from seven samples of these volcanics using the $^{40}Ar$-$^{39}Ar$ method. However, some of the samples yielded bad results, most probably due to alteration of the samples. Furthermore, we could constrain the age range of the volcanics. The $^{40}Ar$-

**Table 2.** Zircon LA-ICP-MS data of sample S3.

| | | | | | Isotopic ratios | | | | | | | Apparent ages (Ma) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spot | Th (ppm) | U (ppm) | Pb (ppm) | Th/U | $^{207}Pb/^{206}Pb$ | ± 1σ | $^{207}Pb/^{235}U$ | ± 1σ | $^{206}Pb/^{238}U$ | ± 1σ | Rho | $^{206}Pb/^{238}U$ | ± 2σ | $^{207}Pb/^{235}U$ | ± 2σ | Concordance |
| 1 | 933.13 | 1173.52 | 1.34 | 0.80 | 0.04859 | 0.03344 | 0.00685 | 0.00465 | 0.00102 | 0.00005 | 0.51669 | 6.58 | 0.64 | 6.93 | 9.36 | 95% |
| 2 | 1548.03 | 2579.09 | 2.99 | 0.60 | 0.04607 | 0.01395 | 0.00663 | 0.00198 | 0.00104 | 0.00003 | 0.52244 | 6.72 | 0.39 | 6.71 | 3.99 | 100% |
| 3 | 3174.95 | 3293.75 | 3.95 | 0.96 | 0.04298 | 0.01159 | 0.00629 | 0.00165 | 0.00106 | 0.00004 | 0.53016 | 6.83 | 0.52 | 6.36 | 3.33 | 107% |
| 4 | 2846.23 | 2223.47 | 2.93 | 1.28 | 0.04592 | 0.01248 | 0.00677 | 0.00182 | 0.00107 | 0.00003 | 0.52369 | 6.89 | 0.39 | 6.85 | 3.67 | 101% |
| 5 | 2464.87 | 2183.70 | 2.81 | 1.13 | 0.04608 | 0.00894 | 0.00680 | 0.00130 | 0.00107 | 0.00003 | 0.53256 | 6.89 | 0.39 | 6.88 | 2.62 | 100% |
| 6 | 1909.99 | 2053.28 | 2.50 | 0.93 | 0.04575 | 0.01430 | 0.00676 | 0.00208 | 0.00107 | 0.00003 | 0.52041 | 6.90 | 0.39 | 6.84 | 4.19 | 101% |
| 7 | 759.53 | 1219.00 | 1.38 | 0.62 | 0.04587 | 0.02033 | 0.00679 | 0.00298 | 0.00107 | 0.00004 | 0.52002 | 6.91 | 0.52 | 6.87 | 6.00 | 101% |
| 8 | 628.52 | 1058.23 | 1.18 | 0.59 | 0.04633 | 0.01482 | 0.00686 | 0.00215 | 0.00107 | 0.00003 | 0.51995 | 6.91 | 0.39 | 6.94 | 4.33 | 100% |
| 9 | 2898.74 | 2211.67 | 2.91 | 1.31 | 0.04571 | 0.00994 | 0.00680 | 0.00146 | 0.00108 | 0.00003 | 0.52948 | 6.95 | 0.39 | 6.88 | 2.94 | 101% |
| 10 | 1995.09 | 1541.33 | 2.09 | 1.29 | 0.04732 | 0.02662 | 0.00704 | 0.00392 | 0.00108 | 0.00004 | 0.51540 | 6.95 | 0.52 | 7.12 | 7.89 | 98% |
| 11* | 1196.98 | 1229.28 | 1.54 | 0.97 | 0.05246 | 0.01510 | 0.00782 | 0.00222 | 0.00108 | 0.00003 | 0.52215 | 6.96 | 0.39 | 7.91 | 4.47 | 88% |
| 12 | 1655.50 | 1782.37 | 2.22 | 0.93 | 0.04627 | 0.01018 | 0.00690 | 0.00150 | 0.00108 | 0.00003 | 0.52864 | 6.96 | 0.39 | 6.98 | 3.02 | 100% |
| 13 | 1378.51 | 1709.69 | 2.03 | 0.81 | 0.04550 | 0.01079 | 0.00679 | 0.00158 | 0.00108 | 0.00003 | 0.52616 | 6.97 | 0.39 | 6.87 | 3.18 | 101% |
| 14* | 2354.34 | 3038.96 | 3.70 | 0.77 | 0.05849 | 0.00871 | 0.00873 | 0.00128 | 0.00108 | 0.00002 | 0.52804 | 6.97 | 0.26 | 8.82 | 2.58 | 79% |
| 15 | 1863.29 | 2827.69 | 3.35 | 0.66 | 0.05135 | 0.01154 | 0.00767 | 0.00170 | 0.00108 | 0.00003 | 0.52876 | 6.98 | 0.39 | 7.75 | 3.42 | 90% |
| 16 | 1132.48 | 2033.75 | 2.29 | 0.56 | 0.04603 | 0.01480 | 0.00688 | 0.00217 | 0.00108 | 0.00003 | 0.51999 | 6.98 | 0.39 | 6.96 | 4.37 | 100% |
| 17 | 3093.72 | 2312.65 | 3.13 | 1.34 | 0.04629 | 0.00995 | 0.00695 | 0.00147 | 0.00109 | 0.00003 | 0.52962 | 7.01 | 0.39 | 7.03 | 2.96 | 100% |
| 18 | 1809.53 | 1496.46 | 2.00 | 1.21 | 0.04459 | 0.00979 | 0.00670 | 0.00145 | 0.00109 | 0.00003 | 0.52783 | 7.02 | 0.39 | 6.78 | 2.92 | 104% |
| 19 | 1436.70 | 1597.15 | 2.04 | 0.90 | 0.04588 | 0.01632 | 0.00697 | 0.00244 | 0.00110 | 0.00005 | 0.52840 | 7.09 | 0.64 | 7.05 | 4.91 | 101% |
| 20 | 1181.09 | 1086.60 | 1.43 | 1.09 | 0.04487 | 0.02206 | 0.00687 | 0.00333 | 0.00111 | 0.00004 | 0.51729 | 7.15 | 0.52 | 6.95 | 6.71 | 103% |
| 21* | 1317.21 | 1329.23 | 1.59 | 0.99 | 0.01226 | 0.01416 | 0.00183 | 0.00208 | 0.00108 | 0.00004 | 0.50813 | 6.96 | 0.52 | 1.85 | 4.21 | 376% |
| 22* | 7374.26 | 6693.73 | 9.19 | 1.10 | 0.09434 | 0.00637 | 0.01392 | 0.00090 | 0.00107 | 0.00002 | 0.55468 | 6.89 | 0.26 | 14.03 | 1.80 | 49% |
| 23* | 2477.10 | 2162.38 | 2.78 | 1.15 | 0.06162 | 0.00969 | 0.00909 | 0.00141 | 0.00107 | 0.00002 | 0.52700 | 6.89 | 0.26 | 9.18 | 2.84 | 75% |
| 24* | 3895.93 | 3659.24 | 4.80 | 1.06 | 0.08341 | 0.01098 | 0.01231 | 0.00156 | 0.00107 | 0.00003 | 0.54393 | 6.89 | 0.39 | 12.42 | 3.13 | 56% |
| 25* | 1083.17 | 1900.45 | 2.60 | 0.57 | 0.13619 | 0.01353 | 0.02016 | 0.00192 | 0.00107 | 0.00003 | 0.55619 | 6.92 | 0.39 | 20.26 | 3.82 | 34% |
| 26* | 834.13 | 954.61 | 1.24 | 0.87 | 0.11212 | 0.01787 | 0.01672 | 0.00259 | 0.00108 | 0.00004 | 0.54866 | 6.97 | 0.52 | 16.83 | 5.17 | 41% |
| 27* | 2201.48 | 1651.83 | 2.57 | 1.33 | 0.13287 | 0.01632 | 0.01994 | 0.00235 | 0.00109 | 0.00004 | 0.55896 | 7.01 | 0.52 | 20.04 | 4.67 | 35% |
| 28* | 1029.26 | 1121.67 | 1.67 | 0.92 | 0.14675 | 0.02497 | 0.02208 | 0.00359 | 0.00109 | 0.00005 | 0.55246 | 7.03 | 0.64 | 22.17 | 7.12 | 32% |
| 29* | 1832.31 | 2009.34 | 2.66 | 0.91 | 0.09232 | 0.01782 | 0.01402 | 0.00262 | 0.00110 | 0.00005 | 0.54854 | 7.09 | 0.64 | 14.13 | 5.24 | 50% |
| 30* | 1856.05 | 1951.93 | 2.82 | 0.95 | 0.11241 | 0.01223 | 0.01753 | 0.00183 | 0.00113 | 0.00003 | 0.54906 | 7.29 | 0.39 | 17.64 | 3.65 | 41% |
| 31* | 1113.52 | 1340.18 | 3.74 | 0.83 | 0.36478 | 0.03775 | 0.07754 | 0.00697 | 0.00154 | 0.00008 | 0.58120 | 9.93 | 1.03 | 75.83 | 13.09 | 13% |

*Highly discordant analyses.

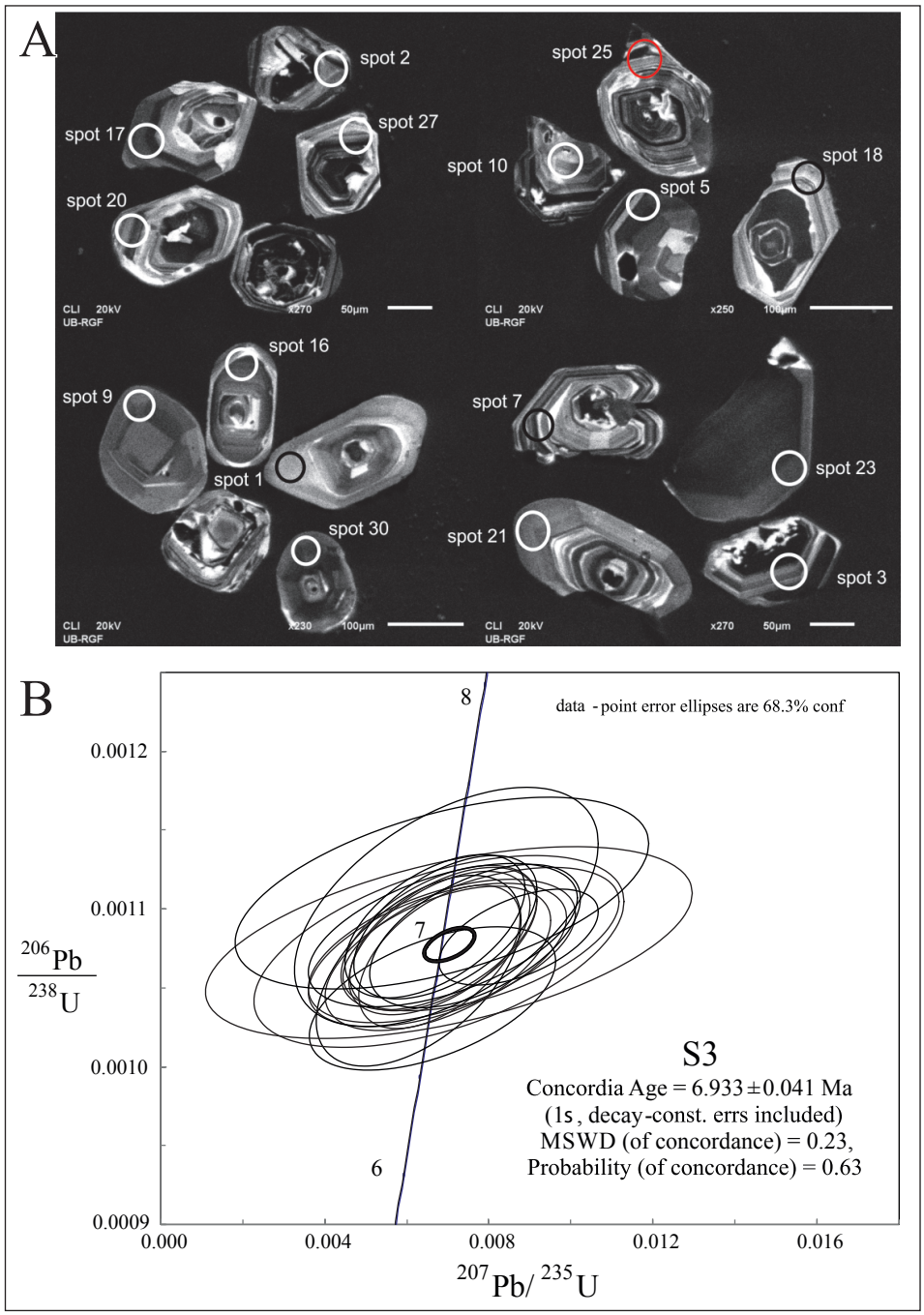


**Figure 8.** A) Cathodoluminescence images of zircon crystals from sample S3. B) U-Pb LA-ICP-MS data for zircons from the tuff level in the İbecik Formation.

$^{39}$Ar data yielded ages of 5.06 ± 1.44, 6.08 ± 0.48, 6.43 ± 0.29, 6.98 ± 0.31, 6.88 ± 0.22, and 6.87 ± 0.38 Ma (6.81 ± 0.30 Ma weighted average; Figures 6 and 7). In addition, we obtained two important age data: 1) biotites from a lamproite dyke cutting the conglomerates of the Gölhisar Formation (Figure 4c) yielded the $^{40}$Ar/$^{39}$Ar age of 6.94 ± 0.35 Ma, and 2) the zircon age from a tuff level intercalated with the lacustrine deposits of the İbecik Formation (Figures 4d and 4e) yielded a precise U-Pb age of 6.93 ± 0.041 Ma (Figure 7; Tables 1 and 2). The same sample also gave a 5.83 ± 0.87 Ma biotite $^{40}$Ar-$^{39}$Ar age (Sample S3b; Figure 7 and Table 1).

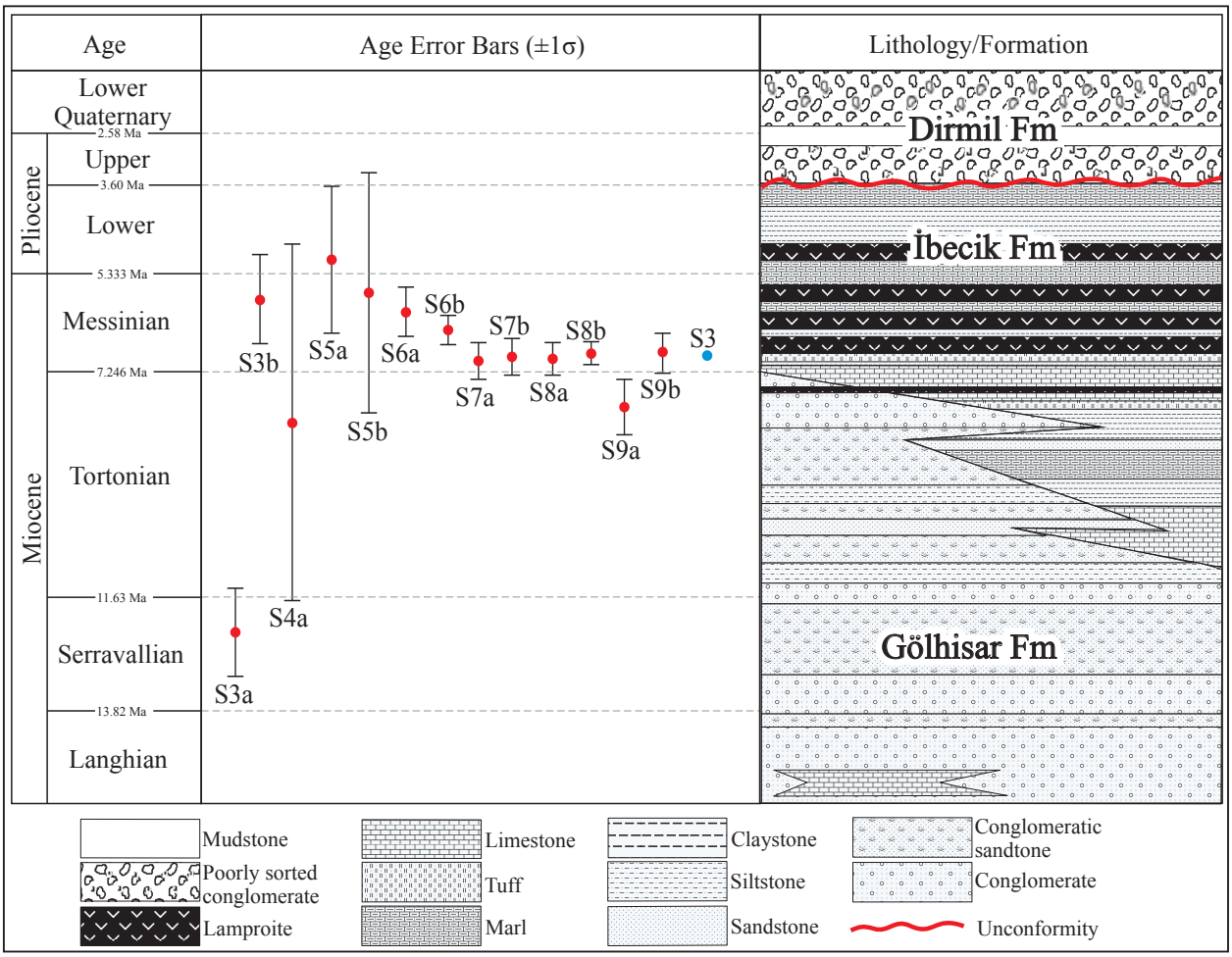


**Figure 9.** Generalized stratigraphic sequence of the Gölhisar, İbecik, and Dirmil formations, and age distributions of the dated samples in the sequence.

The İbecik Formation grades laterally and vertically into the Gölhisar Formation at its base. This uppermost part of the river deposits of the Gölhisar Formation indicates a lower Messinian age (Figure 9). The red wine-colored beds at the top of the İbecik Formation indicate a period of aridity, probably related to the Messinian salinity crisis, and imply intense evaporation during the Messinian (Elitez and Yaltırak, 2016). The $^{40}Ar/^{39}Ar$ and U-Pb ages demonstrated that the Burdur-Fethiye Shear Zone has been active since the middle Miocene. According to the results presented in this paper, it is well established that there was a lamproite upwelling related to the evolution of the Burdur-Fethiye Shear Zone during the Messinian. New $^{40}Ar/^{39}Ar$ and U-Pb dates unequivocally demonstrate that the lacustrine sediments located both along the northern and southern sectors of the study area are upper Miocene-lower Pliocene in age (Table 1) and that the widespread exposures of the lacustrine sediments indicate the presence of an extensive late Miocene warm lake. This lake intensively evaporated during the Messinian salinity crisis. After the Messinian, the lake began to break up into smaller lakes associated with the evolution of the Burdur-Fethiye Shear Zone. The Acıpayam, Çameli, and Gölhisar basins were the parts of this large pre-Messinian lake.

In conclusion, the Pliocene age indicated for the lacustrine sediments in previous studies should be revised in the light of these new radiometric ages. These new ages strongly suggest that the 1.2-km-thick river facies of the Gölhisar Formation located under the lacustrine sediments of the İbecik Formation were deposited during the middle-upper Miocene. The volcanic and volcanosedimentary sequences grade laterally into the river sediments around Şuhut in the northern part of the Burdur-Fethiye Shear Zone (Figure 1). The river sediments in that region are equivalent to the sediments of the Gölhisar Formation and the ages of the volcanic

and volcanosedimentary sequences are between 15 and 8 Ma (Akal et al., 2013; Prelević et al., 2015). The decreasing radiometric ages of the volcanic rocks from north to south indicate that the Burdur-Fethiye Shear Zone is a deep tear zone between the western Anatolian extensional and the western Taurides compressional regimes since 15 Ma (Elitez et al., 2016). This study clearly documented that the lamproites in the north and the tuffs in the southernmost part of the Gölhisar-Çameli-Acıpayam basin are of the same age as the limestones in the north. Thus, the northern limestones bearing lamproite intrusions and the southern limestones including tuff layers are the same age (Figure 2 and 3). These ages indicate that the lacustrine basins on the Burdur-Fethiye Shear Zone and the timing of sedimentation are older.

The new data presented here show that the Burdur-Fethiye Shear Zone initiated during the middle Miocene in an area where there were carbonate lakes of late Tortonian-early Pliocene age. New radiometric ages are in stark contrast with the late Pliocene-early Pleistocene age for these deposits claimed by previous studies and geological maps. Finally, our results allow correlations to be established between the lacustrine sediments in the middle part of the Burdur-Fethiye Shear Zone with sedimentary sequences of the other basins in southwestern Turkey (e.g., lacustrine sediments at ~200 m in the northern part of the Eşen Basin and at ~1200 m around Acıgöl and Burdur basins).

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**Appendix.** The measured Ar gas fractions released by laser-step heating for each of the 5 Ar isotopes in units of $1 \times 10^{-13}$ ccSTP. Also included are the "J" factors and calculated ages. Measured volumes have been corrected for K, Ca AND Cl interference. All errors ARE ±1 sigma.

| Sample S3a | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248795 ± 0.0000173571 | | | | Tot. gas. age = 8/337 ± 0.777 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.02025 | 100 | 0.02842 | 0.00159 | 0.10052 | 0.00681 | 0.09193 | 0.00316 | 0.24300 | 0.00259 | 6.36919 | 0.04684 | –37.890 | 8.908 |
| 0.05817 | 200 | 0.04155 | 0.00146 | 0.10462 | 0.00473 | 0.12313 | 0.00268 | 0.45502 | 0.00286 | 12.59601 | 0.00978 | 3.146 | 4.263 |
| 0.11972 | 300 | 0.05718 | 0.00108 | 0.16099 | 0.00548 | 0.17260 | 0.00196 | 0.73858 | 0.00526 | 17.07755 | 0.02187 | 1.107 | 1.942 |
| 0.22140 | 400 | 0.06735 | 0.00179 | 0.25043 | 0.01100 | 0.26836 | 0.00424 | 1.22016 | 0.00592 | 20.96459 | 0.02116 | 3.906 | 1.941 |
| 0.32971 | 600 | 0.05200 | 0.00132 | 0.27981 | 0.00706 | 0.26373 | 0.00306 | 1.29961 | 0.00419 | 16.60624 | 0.02011 | 4.274 | 1.343 |
| 0.44346 | 800 | 0.03374 | 0.00285 | 0.24544 | 0.00549 | 0.26749 | 0.00263 | 1.36502 | 0.00627 | 15.40010 | 0.38362 | 17.769 | 3.012 |
| 0.55109 | 1000 | 0.03199 | 0.00151 | 0.28796 | 0.00576 | 0.24860 | 0.00190 | 1.29154 | 0.00516 | 12.56504 | 0.03725 | 10.779 | 1.550 |
| 0.65461 | 1200 | 0.02279 | 0.00175 | 0.29086 | 0.00495 | 0.23436 | 0.00240 | 1.24221 | 0.00548 | 10.72605 | 0.01647 | 14.371 | 1.854 |
| 0.75473 | 1400 | 0.01641 | 0.00129 | 0.26183 | 0.00786 | 0.22148 | 0.00297 | 1.20140 | 0.00515 | 8.66212 | 0.01438 | 14.187 | 1.421 |
| 0.82701 | 1600 | 0.01106 | 0.00116 | 0.27352 | 0.00475 | 0.16756 | 0.00355 | 0.86733 | 0.00516 | 5.66096 | 0.01736 | 12.347 | 1.765 |
| 0.87461 | 1800 | 0.00781 | 0.00129 | 0.23938 | 0.00929 | 0.11195 | 0.00218 | 0.57113 | 0.00394 | 3.68310 | 0.00990 | 10.782 | 2.988 |
| 0.90550 | 2000 | 0.00706 | 0.00142 | 0.21434 | 0.00750 | 0.10273 | 0.00230 | 0.37068 | 0.00360 | 2.19168 | 0.00935 | 1.275 | 5.072 |
| 0.93867 | 2400 | 0.00621 | 0.00219 | 0.15730 | 0.00697 | 0.08544 | 0.00154 | 0.39807 | 0.00455 | 2.56304 | 0.00835 | 8.183 | 7.266 |
| 0.95568 | 2800 | 0.00393 | 0.00154 | 0.08731 | 0.00785 | 0.04526 | 0.00108 | 0.20404 | 0.00300 | 1.28093 | 0.00869 | 2.637 | 10.020 |
| 0.98886 | 3200 | 0.00482 | 0.00207 | 0.08091 | 0.00586 | 0.07412 | 0.00156 | 0.39815 | 0.00406 | 2.26753 | 0.01084 | 9.492 | 6.868 |
| 1.00000 | 4000 | 0.00396 | 0.00234 | 0.06579 | 0.00620 | 0.02592 | 0.00147 | 0.13369 | 0.00222 | 0.82271 | 0.00662 | –11.657 | 23.362 |

**Appendix.** (Contunied).

| Sample S3b | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248795 ± 0.0000173571 | | | | Tot. gas. age = 3.859 ± 0.786 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.02173 | 100 | 0.03266 | 0.00172 | 0.16236 | 0.00778 | 0.10198 | 0.00370 | 0.26276 | 0.00731 | 3.79217 | 0.05952 | –102.962 | 9.713 |
| 0.06521 | 200 | 0.03320 | 0.00193 | 0.17192 | 0.00670 | 0.13791 | 0.00311 | 0.52583 | 0.00799 | 9.49052 | 0.02141 | –2.726 | 4.886 |
| 0.11013 | 300 | 0.02749 | 0.00161 | 0.14973 | 0.00695 | 0.12304 | 0.00346 | 0.54317 | 0.00453 | 7.55646 | 0.02283 | –4.698 | 3.946 |
| 0.16175 | 400 | 0.02529 | 0.00180 | 0.14221 | 0.00430 | 0.14006 | 0.00301 | 0.62414 | 0.00629 | 6.96282 | 0.01483 | –3.666 | 3.832 |
| 0.26078 | 600 | 0.03487 | 0.00162 | 0.24053 | 0.00554 | 0.25432 | 0.00427 | 1.19753 | 0.00559 | 11.79238 | 0.04327 | 5.572 | 1.796 |
| 0.35941 | 800 | 0.03088 | 0.00183 | 0.24613 | 0.00802 | 0.23787 | 0.00389 | 1.19268 | 0.00689 | 11.23947 | 0.01622 | 7.940 | 2.032 |
| 0.43979 | 1000 | 0.02071 | 0.00159 | 0.19211 | 0.00481 | 0.18766 | 0.00367 | 0.97187 | 0.00876 | 7.35037 | 0.01917 | 5.674 | 2.168 |
| 0.53614 | 1200 | 0.02295 | 0.00168 | 0.24099 | 0.00979 | 0.22902 | 0.00317 | 1.16508 | 0.00601 | 8.27714 | 0.01591 | 5.753 | 1.907 |
| 0.61355 | 1400 | 0.01670 | 0.00162 | 0.20414 | 0.00828 | 0.18411 | 0.00353 | 0.93613 | 0.00519 | 5.80183 | 0.01741 | 4.152 | 2.291 |
| 0.68072 | 1600 | 0.01256 | 0.00209 | 0.16093 | 0.00661 | 0.15700 | 0.00363 | 0.81219 | 0.00629 | 4.65461 | 0.01928 | 5.212 | 3.411 |
| 0.75634 | 1800 | 0.00762 | 0.00213 | 0.23933 | 0.00663 | 0.16890 | 0.00245 | 0.91444 | 0.00431 | 5.36612 | 0.01232 | 15.226 | 3.061 |
| 0.82733 | 2000 | 0.01029 | 0.00194 | 0.25457 | 0.00492 | 0.17120 | 0.00210 | 0.85842 | 0.00647 | 4.69518 | 0.01207 | 8.629 | 2.977 |
| 0.91023 | 2400 | 0.00680 | 0.00205 | 0.32422 | 0.00652 | 0.20293 | 0.00306 | 1.00251 | 0.00563 | 4.53599 | 0.02036 | 11.276 | 2.696 |
| 0.94792 | 2800 | 0.00259 | 0.00205 | 0.20344 | 0.00627 | 0.09469 | 0.00190 | 0.45573 | 0.00495 | 1.90643 | 0.01107 | 11.211 | 5.935 |
| 0.99119 | 3200 | 0.00227 | 0.00148 | 0.18228 | 0.00485 | 0.10021 | 0.00230 | 0.52320 | 0.00300 | 1.84692 | 0.01350 | 10.056 | 3.726 |
| 1.00000 | 4000 | 0.00188 | 0.00129 | 0.03854 | 0.00500 | 0.02195 | 0.00169 | 0.10654 | 0.00338 | 0.46366 | 0.01040 | –3.867 | 16.062 |

**Appendix.** (Contunied).

| Sample S4a | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248894 ± 0.0000172331 | | | | Tot. gas. age = –0.946 ± 5.34 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.09114 | 100 | 0.00759 | 0.00219 | 0.04828 | 0.00475 | 0.02527 | 0.00172 | 0.15718 | 0.00428 | 0.79967 | 0.00952 | –41.665 | 18.933 |
| 0.19220 | 200 | 0.00639 | 0.00164 | 0.03792 | 0.00603 | 0.01476 | 0.00199 | 0.17430 | 0.00289 | 1.77666 | 0.00922 | –2.887 | 12.540 |
| 0.32345 | 300 | 0.01467 | 0.00190 | 0.02892 | 0.00619 | 0.01440 | 0.00156 | 0.22636 | 0.00338 | 4.26287 | 0.01288 | –1.455 | 11.125 |
| 0.45677 | 400 | 0.01566 | 0.00202 | 0.04044 | 0.00617 | 0.01720 | 0.00181 | 0.22992 | 0.00435 | 4.95954 | 0.01335 | 6.466 | 11.604 |
| 0.64593 | 600 | 0.02126 | 0.00238 | 0.06343 | 0.00745 | 0.02320 | 0.00153 | 0.32624 | 0.00420 | 6.33433 | 0.01059 | 0.701 | 9.660 |
| 0.78398 | 800 | 0.01289 | 0.00096 | 0.05314 | 0.00739 | 0.01629 | 0.00212 | 0.23811 | 0.00397 | 4.59308 | 0.01275 | 14.720 | 5.307 |
| 0.85758 | 1000 | 0.00637 | 0.00106 | 0.09343 | 0.00806 | 0.01022 | 0.00196 | 0.12693 | 0.00338 | 1.85274 | 0.01454 | –1.067 | 11.068 |
| 0.91240 | 1200 | 0.00180 | 0.00101 | 0.08292 | 0.00678 | 0.01033 | 0.00175 | 0.09455 | 0.00327 | 1.26738 | 0.00846 | 34.631 | 13.918 |
| 0.93978 | 1400 | 0.00319 | 0.00148 | 0.04453 | 0.00661 | 0.00571 | 0.00147 | 0.04721 | 0.00373 | 0.66046 | 0.00777 | –26.965 | 42.373 |
| 0.96300 | 1600 | 0.00213 | 0.00132 | 0.03252 | 0.00659 | 0.00567 | 0.00147 | 0.04006 | 0.00321 | 0.44219 | 0.01042 | –21.111 | 44.245 |
| 0.97303 | 1800 | 0.00198 | 0.00127 | 0.03239 | 0.00409 | –0.00209 | 0.00146 | 0.01729 | 0.00267 | 0.16530 | 0.00995 | –112.170 | 105.607 |
| 0.98489 | 2000 | –0.00010 | 0.00162 | 0.05031 | 0.00730 | 0.00136 | 0.00122 | 0.02045 | 0.00163 | 0.14003 | 0.00809 | 36.868 | 103.012 |
| 0.98645 | 2400 | 0.00278 | 0.00138 | 0.01584 | 0.00496 | –0.00173 | 0.00127 | 0.00270 | 0.00211 | 0.09018 | 0.00627 | –1978.395 | 3576.32 |
| 0.98995 | 2800 | –0.00024 | 0.00140 | 0.01144 | 0.00310 | –0.00048 | 0.00096 | 0.00603 | 0.00209 | 0.09064 | 0.00753 | 115.844 | 290.589 |
| 0.99385 | 3200 | –0.00224 | 0.00157 | –0.00327 | 0.00568 | –0.00162 | 0.00208 | 0.00672 | 0.00304 | 0.05269 | 0.00717 | 424.259 | 298.444 |
| 1.00000 | 4000 | 0.00054 | 0.00210 | 0.02384 | 0.00739 | –0.00018 | 0.00206 | 0.01061 | 0.00328 | 0.12257 | 0.00647 | –16.107 | 264.884 |

**Appendix.** (Contunied).

| Sample S4b | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248894 ± 0.0000172331 | | | | Tot. gas. age = –5.47 ± 3.038 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.06800 | 100 | 0.01353 | 0.00256 | 0.09157 | 0.00666 | 0.06111 | 0.00263 | 0.22330 | 0.00339 | 1.73803 | 0.01794 | –46.013 | 15.643 |
| 0.20278 | 200 | 0.01997 | 0.00158 | 0.11823 | 0.00604 | 0.05842 | 0.00275 | 0.44258 | 0.00552 | 3.17033 | 0.01165 | –27.909 | 4.839 |
| 0.30200 | 300 | 0.03719 | 0.00184 | 0.05873 | 0.00648 | 0.03725 | 0.00162 | 0.32584 | 0.00249 | 10.60892 | 0.01809 | –5.248 | 7.523 |
| 0.38828 | 400 | 0.03237 | 0.00188 | 0.05745 | 0.00522 | 0.03187 | 0.00165 | 0.28332 | 0.00347 | 8.75266 | 0.00976 | –12.937 | 8.878 |
| 0.53688 | 600 | 0.04616 | 0.00184 | 0.09359 | 0.00799 | 0.04277 | 0.00174 | 0.48798 | 0.00506 | 13.50567 | 0.01822 | –1.231 | 5.018 |
| 0.63961 | 800 | 0.02702 | 0.00177 | 0.06628 | 0.00464 | 0.01845 | 0.00206 | 0.33735 | 0.00556 | 9.86915 | 0.02506 | 24.913 | 6.897 |
| 0.77717 | 1000 | 0.03156 | 0.00176 | 0.16539 | 0.00585 | 0.02627 | 0.00209 | 0.45173 | 0.00487 | 11.43020 | 0.01698 | 20.800 | 5.110 |
| 0.81880 | 1200 | 0.00906 | 0.00158 | 0.15889 | 0.00385 | 0.01635 | 0.00213 | 0.13669 | 0.00430 | 3.52496 | 0.01256 | 27.635 | 15.134 |
| 0.86092 | 1400 | 0.00875 | 0.00129 | 0.07173 | 0.00414 | 0.00781 | 0.00193 | 0.13833 | 0.00422 | 3.16834 | 0.01196 | 18.775 | 12.260 |
| 0.90193 | 1600 | 0.00756 | 0.00193 | 0.05365 | 0.00404 | 0.00485 | 0.00219 | 0.13467 | 0.00380 | 2.85938 | 0.00810 | 20.744 | 18.826 |
| 0.92104 | 1800 | 0.01158 | 0.00257 | 0.04106 | 0.00944 | 0.00601 | 0.00220 | 0.06276 | 0.00358 | 1.46827 | 0.00924 | –145.591 | 59.558 |
| 0.94208 | 2000 | 0.00768 | 0.00176 | 0.06695 | 0.00639 | 0.00528 | 0.00189 | 0.06906 | 0.00214 | 1.49953 | 0.00917 | –50.780 | 34.773 |
| 0.96402 | 2400 | 0.00886 | 0.00186 | 0.04415 | 0.00724 | 0.00664 | 0.00185 | 0.07205 | 0.00335 | 1.19748 | 0.01003 | –90.810 | 36.314 |
| 0.97733 | 2800 | 0.00633 | 0.00189 | 0.08254 | 0.00898 | 0.00408 | 0.00166 | 0.04373 | 0.00251 | 0.70892 | 0.00766 | –123.364 | 61.791 |
| 0.99180 | 3200 | –0.00095 | 0.00172 | 0.07915 | 0.00655 | 0.00075 | 0.00202 | 0.04753 | 0.00262 | 0.73516 | 0.00422 | 93.546 | 45.990 |
| 1.00000 | 4000 | –0.00068 | 0.00170 | 0.07036 | 0.00597 | 0.00101 | 0.00192 | 0.02691 | 0.00225 | 0.36883 | 0.00824 | 92.507 | 80.184 |

**Appendix.** (Contunied).

| Sample S5a | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248692 ± 0.0000174758 | | | | Tot. gas. age = 0.658 ± 1.973 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.04385 | 100 | 0.01841 | 0.00104 | 0.11001 | 0.00728 | 0.05717 | 0.00186 | 0.24656 | 0.00430 | 2.17042 | 0.02569 | –60.481 | 5.919 |
| 0.12928 | 200 | 0.02144 | 0.00169 | 0.09825 | 0.00867 | 0.03828 | 0.00253 | 0.48038 | 0.00413 | 4.30591 | 0.02578 | –19.062 | 4.727 |
| 0.21384 | 300 | 0.03953 | 0.00246 | 0.06926 | 0.00771 | 0.03225 | 0.00269 | 0.47545 | 0.00379 | 11.21024 | 0.03061 | –4.459 | 6.880 |
| 0.29282 | 400 | 0.04427 | 0.00165 | 0.06136 | 0.01139 | 0.03114 | 0.00211 | 0.44409 | 0.00158 | 12.65572 | 0.01795 | –4.305 | 4.941 |
| 0.45667 | 600 | 0.09465 | 0.00148 | 0.17339 | 0.00855 | 0.05606 | 0.00203 | 0.92135 | 0.00428 | 29.00108 | 0.02086 | 5.022 | 2.125 |
| 0.61038 | 800 | 0.07586 | 0.00228 | 0.29347 | 0.00681 | 0.04458 | 0.00211 | 0.86429 | 0.00794 | 23.96498 | 0.03172 | 8.024 | 3.492 |
| 0.69961 | 1000 | 0.04024 | 0.00173 | 0.34649 | 0.01318 | 0.02565 | 0.00141 | 0.50173 | 0.00391 | 12.81227 | 0.02414 | 8.231 | 4.568 |
| 0.78868 | 1200 | 0.03409 | 0.00228 | 0.54066 | 0.01324 | 0.02636 | 0.00204 | 0.50086 | 0.00346 | 10.54705 | 0.02041 | 4.223 | 6.032 |
| 0.84277 | 1400 | 0.01779 | 0.00215 | 0.33288 | 0.00522 | 0.01687 | 0.00181 | 0.30414 | 0.00352 | 5.95274 | 0.01803 | 10.247 | 9.306 |
| 0.90777 | 1600 | 0.02206 | 0.00175 | 0.74540 | 0.01065 | 0.02292 | 0.00144 | 0.36546 | 0.00415 | 7.40402 | 0.01561 | 10.819 | 6.317 |
| 0.92595 | 1800 | 0.00501 | 0.00245 | 0.29071 | 0.00628 | 0.00766 | 0.00134 | 0.10223 | 0.00329 | 1.50555 | 0.00931 | 1.055 | 31.727 |
| 0.94171 | 2000 | 0.00384 | 0.00274 | 0.30733 | 0.00572 | 0.00457 | 0.00171 | 0.08862 | 0.00350 | 1.54001 | 0.00840 | 20.388 | 40.565 |
| 0.95997 | 2400 | 0.00479 | 0.00242 | 0.29906 | 0.00480 | 0.01003 | 0.00216 | 0.10267 | 0.00301 | 1.58970 | 0.00916 | 7.545 | 31.107 |
| 0.97531 | 2800 | 0.00158 | 0.00257 | 0.22488 | 0.00672 | 0.00869 | 0.00181 | 0.08623 | 0.00320 | 1.71116 | 0.01293 | 63.652 | 38.232 |
| 0.98986 | 3200 | 0.00515 | 0.00238 | 0.28923 | 0.00563 | 0.00479 | 0.00197 | 0.08183 | 0.00225 | 1.21398 | 0.00705 | –17.019 | 38.954 |
| 1.00000 | 4000 | 0.00301 | 0.00153 | 0.10112 | 0.00619 | 0.00200 | 0.00145 | 0.05702 | 0.00256 | 0.81570 | 0.00664 | –5.897 | 35.587 |

**Appendix.** (Contunied).

| Sample S5b | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248692 ± 0.0000174758 | | | | Tot. gas. age = 2.21 ± 2.33 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.06139 | 100 | 0.00704 | 0.00286 | 0.09061 | 0.00450 | 0.04372 | 0.00174 | 0.28550 | 0.00541 | 1.62124 | 0.01239 | –7.207 | 13.335 |
| 0.16449 | 200 | 0.01727 | 0.00116 | 0.07994 | 0.00416 | 0.03490 | 0.00175 | 0.47944 | 0.00729 | 3.80321 | 0.01920 | –12.204 | 3.232 |
| 0.26845 | 300 | 0.02695 | 0.00188 | 0.06398 | 0.00451 | 0.02503 | 0.00297 | 0.48342 | 0.00431 | 6.74932 | 0.01067 | –11.317 | 5.200 |
| 0.36378 | 400 | 0.02457 | 0.00197 | 0.06074 | 0.00576 | 0.02459 | 0.00119 | 0.44334 | 0.00429 | 7.26544 | 0.01826 | 0.040 | 5.901 |
| 0.50005 | 600 | 0.04401 | 0.00272 | 0.12280 | 0.00534 | 0.03092 | 0.00199 | 0.63370 | 0.00562 | 13.17008 | 0.01867 | 1.171 | 5.696 |
| 0.59413 | 800 | 0.02073 | 0.00136 | 0.18397 | 0.00663 | 0.02248 | 0.00270 | 0.43748 | 0.00442 | 6.82154 | 0.01772 | 7.109 | 4.106 |
| 0.68895 | 1000 | 0.02740 | 0.00210 | 0.41227 | 0.00710 | 0.02538 | 0.00194 | 0.44096 | 0.00525 | 7.99224 | 0.01491 | –1.072 | 6.323 |
| 0.74393 | 1200 | 0.01263 | 0.00221 | 0.31471 | 0.00976 | 0.01322 | 0.00200 | 0.25566 | 0.00372 | 3.96954 | 0.01423 | 4.171 | 11.412 |
| 0.78826 | 1400 | 0.00825 | 0.00211 | 0.53469 | 0.00726 | 0.01273 | 0.00148 | 0.20617 | 0.00404 | 3.09435 | 0.01042 | 14.237 | 13.484 |
| 0.82094 | 1600 | 0.00843 | 0.00151 | 0.22004 | 0.00590 | 0.00623 | 0.00166 | 0.15195 | 0.00314 | 3.29740 | 0.01429 | 23.663 | 13.039 |
| 0.84638 | 1800 | 0.00974 | 0.00168 | 0.22625 | 0.00712 | 0.01114 | 0.00167 | 0.11831 | 0.00374 | 2.75835 | 0.01379 | –4.590 | 18.896 |
| 0.88139 | 2000 | 0.00923 | 0.00190 | 0.29104 | 0.00920 | 0.01166 | 0.00144 | 0.16282 | 0.00321 | 3.77431 | 0.01082 | 28.585 | 15.220 |
| 0.91289 | 2400 | 0.00977 | 0.00216 | 0.25788 | 0.00892 | 0.00853 | 0.00192 | 0.14649 | 0.00358 | 3.50422 | 0.01043 | 18.801 | 19.398 |
| 0.95016 | 2800 | 0.01102 | 0.00166 | 0.23290 | 0.00759 | 0.01029 | 0.00174 | 0.17331 | 0.00280 | 4.35740 | 0.00835 | 28.282 | 12.488 |
| 0.98485 | 3200 | 0.01309 | 0.00239 | 0.24878 | 0.00815 | 0.01211 | 0.00232 | 0.16131 | 0.00301 | 4.34253 | 0.01885 | 13.151 | 19.547 |
| 1.00000 | 4000 | 0.00690 | 0.00226 | 0.17674 | 0.00361 | 0.00483 | 0.00180 | 0.07047 | 0.00251 | 1.72517 | 0.00997 | –20.014 | 42.965 |

**Appendix.** (Contunied).

| Sample S6a | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248239 ± 0.0000178951 | | | | Tot. gas. age = 6.811 ± 0.644 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.00974 | 100 | 0.01033 | 0.00134 | 0.02368 | 0.00386 | 0.01705 | 0.00223 | 0.14672 | 0.00415 | 1.67162 | 0.01168 | –42.675 | 12.419 |
| 0.02098 | 200 | 0.00436 | 0.00144 | 0.00825 | 0.00359 | 0.00433 | 0.00294 | 0.16938 | 0.00434 | 1.04970 | 0.00908 | –6.309 | 11.266 |
| 0.04466 | 300 | 0.00591 | 0.00215 | 0.00614 | 0.00427 | 0.00614 | 0.00191 | 0.35687 | 0.00495 | 1.48186 | 0.01107 | –3.337 | 7.976 |
| 0.08593 | 400 | 0.00614 | 0.00194 | 0.00017 | 0.00358 | 0.00888 | 0.00183 | 0.62189 | 0.00570 | 2.02789 | 0.01328 | 1.533 | 4.118 |
| 0.19804 | 600 | 0.00991 | 0.00168 | 0.03260 | 0.00316 | 0.01744 | 0.00235 | 1.68929 | 0.00687 | 4.80708 | 0.01223 | 4.972 | 1.314 |
| 0.35876 | 800 | 0.00914 | 0.00184 | 0.03723 | 0.00715 | 0.02155 | 0.00242 | 2.42173 | 0.00876 | 5.70205 | 0.01643 | 5.543 | 1.005 |
| 0.51498 | 1000 | 0.00687 | 0.00171 | 0.05972 | 0.01048 | 0.02188 | 0.00183 | 2.35392 | 0.00809 | 5.28793 | 0.00952 | 6.189 | 0.959 |
| 0.64162 | 1200 | 0.00305 | 0.00222 | 0.03206 | 0.00433 | 0.01650 | 0.00159 | 1.90826 | 0.00798 | 4.14478 | 0.01390 | 7.596 | 1.534 |
| 0.76213 | 1400 | 0.00354 | 0.00140 | 0.04577 | 0.00645 | 0.01568 | 0.00221 | 1.81589 | 0.00825 | 3.89824 | 0.01119 | 7.018 | 1.020 |
| 0.84009 | 1600 | 0.00283 | 0.00169 | 0.02179 | 0.00454 | 0.00913 | 0.00152 | 1.17465 | 0.00644 | 2.44947 | 0.01337 | 6.140 | 1.895 |
| 0.88893 | 1800 | –0.00384 | 0.00219 | 0.01164 | 0.00555 | 0.00422 | 0.00185 | 0.73604 | 0.00447 | 1.51402 | 0.00898 | 16.048 | 3.900 |
| 0.91388 | 2000 | –0.00319 | 0.00179 | -0.01129 | 0.00694 | –0.00043 | 0.00275 | 0.37588 | 0.00383 | 0.87767 | 0.00963 | 21.565 | 6.225 |
| 0.95036 | 2400 | –0.00293 | 0.00198 | 0.00056 | 0.00506 | 0.00521 | 0.00188 | 0.54973 | 0.00534 | 1.29324 | 0.01042 | 17.492 | 4.714 |
| 0.98104 | 2800 | –0.00156 | 0.00197 | 0.00118 | 0.00634 | –0.00071 | 0.00201 | 0.46232 | 0.00332 | 1.09860 | 0.00741 | 15.043 | 5.585 |
| 0.99280 | 3200 | 0.00073 | 0.00141 | 0.00265 | 0.00610 | –0.00213 | 0.00276 | 0.17714 | 0.00270 | 0.47255 | 0.00765 | 6.490 | 10.481 |
| 1.00000 | 4000 | 0.00012 | 0.00223 | 0.00374 | 0.00633 | –0.00181 | 0.00197 | 0.10850 | 0.00290 | 0.37968 | 0.00737 | 14.117 | 26.966 |

**Appendix.** (Contunied).

| Sample S6b | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248239 ± 0.0000178951 | | | | Tot. gas. age = 5.393 ± 0.391 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.01024 | 100 | 0.01990 | 0.00226 | 0.07949 | 0.00372 | 0.04316 | 0.00296 | 0.29216 | 0.00386 | 2.51488 | 0.03195 | –52.351 | 10.567 |
| 0.01994 | 200 | 0.01038 | 0.00169 | 0.03018 | 0.00562 | 0.01161 | 0.00249 | 0.27670 | 0.00540 | 1.96030 | 0.02081 | –18.024 | 8.189 |
| 0.03689 | 300 | 0.01159 | 0.00253 | 0.02931 | 0.00455 | 0.00808 | 0.00251 | 0.48367 | 0.00488 | 2.56540 | 0.01649 | –7.985 | 6.959 |
| 0.06658 | 400 | 0.01045 | 0.00113 | 0.01908 | 0.00307 | 0.00782 | 0.00280 | 0.84726 | 0.00475 | 3.63272 | 0.01507 | 2.872 | 1.764 |
| 0.15483 | 600 | 0.02131 | 0.00203 | 0.04165 | 0.00477 | 0.02239 | 0.00255 | 2.51795 | 0.00826 | 8.91181 | 0.01695 | 4.647 | 1.063 |
| 0.28470 | 800 | 0.01288 | 0.00190 | 0.09266 | 0.00452 | 0.03362 | 0.00254 | 3.70573 | 0.01024 | 9.23562 | 0.01359 | 6.551 | 0.676 |
| 0.44367 | 1000 | 0.01031 | 0.00190 | 0.11585 | 0.00391 | 0.04121 | 0.00237 | 4.53578 | 0.01337 | 9.93347 | 0.01248 | 6.787 | 0.551 |
| 0.59133 | 1200 | 0.00789 | 0.00196 | 0.13032 | 0.00677 | 0.03305 | 0.00234 | 4.21330 | 0.00871 | 8.82856 | 0.01868 | 6.893 | 0.613 |
| 0.72082 | 1400 | 0.01059 | 0.00233 | 0.16463 | 0.00425 | 0.03013 | 0.00234 | 3.69451 | 0.01161 | 8.48808 | 0.01671 | 6.485 | 0.833 |
| 0.80385 | 1600 | 0.00453 | 0.00217 | 0.06591 | 0.00476 | 0.02153 | 0.00253 | 2.36906 | 0.00755 | 5.00627 | 0.01372 | 6.918 | 1.206 |
| 0.89683 | 1800 | 0.00847 | 0.00227 | 0.06119 | 0.00778 | 0.02141 | 0.00206 | 2.65320 | 0.01125 | 5.72534 | 0.01543 | 5.430 | 1.129 |
| 0.92886 | 2000 | 0.00266 | 0.00228 | 0.01224 | 0.00642 | 0.00620 | 0.00233 | 0.91390 | 0.00593 | 1.85241 | 0.00684 | 5.219 | 3.287 |
| 0.94949 | 2400 | 0.00013 | 0.00233 | 0.01706 | 0.00599 | 0.00318 | 0.00196 | 0.58871 | 0.00557 | 1.38313 | 0.00945 | 10.207 | 5.220 |
| 0.97064 | 2800 | 0.00207 | 0.00261 | 0.01048 | 0.00679 | 0.00619 | 0.00152 | 0.60345 | 0.00546 | 1.36373 | 0.01037 | 5.575 | 5.708 |
| 0.98637 | 3200 | –0.00089 | 0.00162 | 0.01225 | 0.00592 | 0.00349 | 0.00147 | 0.44872 | 0.00430 | 1.00699 | 0.00731 | 12.643 | 4.748 |
| 1.00000 | 4000 | –0.00055 | 0.00211 | 0.01377 | 0.00487 | 0.00286 | 0.00123 | 0.38890 | 0.00359 | 0.92633 | 0.00523 | 12.500 | 7.125 |

**Appendix.** (Contunied).

| Sample S7a | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248358 ± 0.0000177989 | | | | Tot. gas. age = 6.569 ± 0.385 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.01125 | 100 | 0.01092 | 0.00126 | 0.04225 | 0.00542 | 0.04114 | 0.00226 | 0.20583 | 0.00522 | 2.82187 | 0.01061 | –8.824 | 8.139 |
| 0.03889 | 200 | 0.01080 | 0.00125 | 0.03945 | 0.00596 | 0.05523 | 0.00252 | 0.50585 | 0.00526 | 2.55703 | 0.01348 | –5.640 | 3.291 |
| 0.07501 | 300 | 0.01040 | 0.00153 | 0.02260 | 0.00552 | 0.03896 | 0.00243 | 0.66087 | 0.00608 | 2.88584 | 0.01180 | –1.269 | 3.075 |
| 0.11891 | 400 | 0.00821 | 0.00114 | 0.01625 | 0.00519 | 0.02846 | 0.00199 | 0.80325 | 0.00701 | 3.04435 | 0.00586 | 3.445 | 1.870 |
| 0.21232 | 600 | 0.01219 | 0.00134 | 0.05045 | 0.00620 | 0.04098 | 0.00230 | 1.70930 | 0.00551 | 4.81325 | 0.01002 | 3.175 | 1.035 |
| 0.34269 | 800 | 0.00578 | 0.00156 | 0.22288 | 0.00951 | 0.03446 | 0.00187 | 2.38552 | 0.00886 | 5.71021 | 0.01907 | 7.503 | 0.864 |
| 0.46367 | 1000 | 0.00658 | 0.00112 | 0.40742 | 0.00695 | 0.02933 | 0.00209 | 2.21376 | 0.00791 | 4.99859 | 0.01291 | 6.170 | 0.670 |
| 0.58757 | 1200 | 0.00555 | 0.00074 | 0.52504 | 0.00885 | 0.02934 | 0.00219 | 2.26708 | 0.00990 | 5.15150 | 0.01041 | 6.927 | 0.434 |
| 0.66793 | 1400 | 0.00236 | 0.00107 | 0.58554 | 0.01138 | 0.02007 | 0.00157 | 1.47049 | 0.00715 | 3.55455 | 0.01211 | 8.686 | 0.959 |
| 0.72304 | 1600 | 0.00257 | 0.00119 | 0.43110 | 0.00582 | 0.01410 | 0.00124 | 1.00852 | 0.00608 | 2.29099 | 0.01236 | 6.792 | 1.561 |
| 0.79389 | 1800 | –0.00036 | 0.00149 | 0.38770 | 0.00790 | 0.01611 | 0.00136 | 1.29636 | 0.00540 | 2.92897 | 0.00652 | 10.461 | 1.515 |
| 0.84428 | 2000 | 0.00015 | 0.00155 | 0.34688 | 0.01035 | 0.00864 | 0.00103 | 0.92202 | 0.00368 | 2.05179 | 0.01322 | 9.734 | 2.212 |
| 0.89030 | 2400 | 0.00200 | 0.00148 | 0.34708 | 0.00913 | 0.01054 | 0.00200 | 0.84219 | 0.00533 | 2.05363 | 0.00919 | 7.769 | 2.310 |
| 0.93336 | 2800 | –0.00090 | 0.00161 | 0.56610 | 0.00760 | 0.01269 | 0.00178 | 0.78795 | 0.00508 | 1.98713 | 0.00706 | 12.770 | 2.686 |
| 0.96691 | 3200 | 0.00106 | 0.00137 | 0.33978 | 0.00491 | 0.00710 | 0.00206 | 0.61376 | 0.00389 | 1.56344 | 0.00854 | 9.111 | 2.941 |
| 1.00000 | 4000 | 0.00033 | 0.00119 | 0.54501 | 0.00788 | 0.00580 | 0.00215 | 0.60557 | 0.00594 | 1.39968 | 0.00645 | 9.607 | 2.598 |

**Appendix.** (Contunied).

| Sample S7b | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00248358 ± 0.0000177989 | | | | Tot. gas. age = 6.895 ± 0.52 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.00926 | 100 | 0.01038 | 0.00170 | 0.06561 | 0.00900 | 0.05481 | 0.00221 | 0.19468 | 0.00474 | 2.15019 | 0.01428 | –21.241 | 11.718 |
| 0.02729 | 200 | 0.00619 | 0.00179 | 0.03882 | 0.00557 | 0.07701 | 0.00277 | 0.37916 | 0.00396 | 2.13562 | 0.01228 | 3.628 | 6.255 |
| 0.05777 | 300 | 0.00591 | 0.00156 | 0.02804 | 0.00506 | 0.07608 | 0.00307 | 0.64071 | 0.00448 | 2.45246 | 0.01019 | 4.938 | 3.225 |
| 0.09530 | 400 | 0.00565 | 0.00209 | 0.02378 | 0.00538 | 0.04774 | 0.00291 | 0.78917 | 0.00601 | 2.77701 | 0.01688 | 6.283 | 3.500 |
| 0.16889 | 600 | 0.00916 | 0.00154 | 0.04443 | 0.00616 | 0.04242 | 0.00260 | 1.54736 | 0.00766 | 5.41124 | 0.01933 | 7.810 | 1.310 |
| 0.26990 | 800 | 0.01135 | 0.00171 | 0.10314 | 0.00589 | 0.03429 | 0.00260 | 2.12365 | 0.00535 | 6.95088 | 0.01550 | 7.575 | 1.064 |
| 0.38524 | 1000 | 0.01279 | 0.00172 | 0.17279 | 0.00535 | 0.03068 | 0.00251 | 2.42519 | 0.00683 | 7.61642 | 0.01365 | 7.076 | 0.938 |
| 0.52464 | 1200 | 0.01344 | 0.00192 | 0.49707 | 0.01284 | 0.03295 | 0.00192 | 2.93099 | 0.01166 | 8.30516 | 0.01200 | 6.613 | 0.865 |
| 0.64477 | 1400 | 0.01037 | 0.00133 | 0.65991 | 0.00875 | 0.02783 | 0.00222 | 2.52582 | 0.00890 | 7.21846 | 0.01418 | 7.356 | 0.695 |
| 0.74291 | 1600 | 0.00879 | 0.00133 | 0.93747 | 0.00786 | 0.02259 | 0.00187 | 2.06346 | 0.00427 | 5.22803 | 0.01155 | 5.705 | 0.850 |
| 0.81853 | 1800 | 0.00423 | 0.00268 | 0.81742 | 0.00608 | 0.01859 | 0.00150 | 1.59004 | 0.00777 | 3.58599 | 0.01305 | 6.570 | 2.220 |
| 0.86285 | 2000 | 0.00063 | 0.00216 | 0.51591 | 0.00867 | 0.01444 | 0.00196 | 0.93181 | 0.00403 | 2.24735 | 0.00706 | 9.888 | 3.047 |
| 0.91199 | 2400 | 0.00198 | 0.00288 | 0.61531 | 0.01229 | 0.01369 | 0.00158 | 1.03308 | 0.00582 | 2.56089 | 0.00761 | 8.545 | 3.671 |
| 0.95393 | 2800 | 0.00832 | 0.00242 | 0.66728 | 0.00424 | 0.01482 | 0.00141 | 0.88185 | 0.00408 | 3.96486 | 0.01086 | 7.643 | 3.616 |
| 0.98541 | 3200 | 0.00020 | 0.00243 | 0.31256 | 0.00722 | 0.01020 | 0.00229 | 0.66200 | 0.00454 | 1.62812 | 0.01032 | 10.587 | 4.828 |
| 1.00000 | 4000 | 0.00085 | 0.00280 | 0.15808 | 0.00899 | 0.00495 | 0.00254 | 0.30669 | 0.00296 | 0.75465 | 0.00825 | 7.344 | 12.027 |

**Appendix.** (Contunied).

| Sample S8a | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00247437 ± 0.0000183505 | | | | Tot. gas. age = 5.613 ± 0.354 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.00781 | 100 | 0.02574 | 0.00277 | 0.10535 | 0.00751 | 0.05699 | 0.00263 | 0.24668 | 0.00748 | 3.03087 | 0.02227 | –84.734 | 15.768 |
| 0.01720 | 200 | 0.02543 | 0.00150 | 0.05493 | 0.00993 | 0.07175 | 0.00293 | 0.29697 | 0.00508 | 6.20635 | 0.01263 | –19.782 | 6.761 |
| 0.03193 | 300 | 0.04577 | 0.00191 | 0.04715 | 0.00825 | 0.08604 | 0.00395 | 0.46534 | 0.00365 | 12.38070 | 0.02155 | –11.024 | 5.445 |
| 0.05753 | 400 | 0.06665 | 0.00160 | 0.03904 | 0.00588 | 0.07377 | 0.00267 | 0.80880 | 0.00341 | 19.47035 | 0.01766 | –1.247 | 2.607 |
| 0.13590 | 600 | 0.12690 | 0.00213 | 0.08682 | 0.00916 | 0.09318 | 0.00265 | 2.47659 | 0.00865 | 40.59625 | 0.03377 | 5.573 | 1.131 |
| 0.24732 | 800 | 0.10390 | 0.00298 | 0.20080 | 0.00668 | 0.07447 | 0.00237 | 3.52061 | 0.01305 | 36.03903 | 0.02983 | 6.756 | 1.115 |
| 0.36994 | 1000 | 0.06600 | 0.00256 | 0.18749 | 0.00709 | 0.05924 | 0.00240 | 3.87479 | 0.00781 | 25.97611 | 0.03072 | 7.443 | 0.868 |
| 0.49619 | 1200 | 0.05076 | 0.00222 | 0.25662 | 0.00473 | 0.05143 | 0.00223 | 3.98936 | 0.00480 | 21.26503 | 0.02090 | 6.997 | 0.732 |
| 0.61189 | 1400 | 0.03134 | 0.00199 | 0.42178 | 0.00623 | 0.03740 | 0.00205 | 3.65606 | 0.01097 | 14.83634 | 0.02225 | 6.794 | 0.715 |
| 0.71835 | 1600 | 0.03132 | 0.00213 | 0.44904 | 0.00556 | 0.03618 | 0.00346 | 3.36391 | 0.01047 | 13.96267 | 0.01296 | 6.238 | 0.831 |
| 0.79138 | 1800 | 0.01697 | 0.00209 | 0.37652 | 0.00887 | 0.02481 | 0.00178 | 2.30782 | 0.01066 | 8.10903 | 0.02122 | 5.978 | 1.190 |
| 0.85321 | 2000 | 0.00861 | 0.00161 | 0.30717 | 0.00523 | 0.02120 | 0.00158 | 1.95364 | 0.00814 | 6.34306 | 0.01106 | 8.660 | 1.081 |
| 0.92728 | 2400 | 0.01210 | 0.00212 | 0.41828 | 0.00894 | 0.02317 | 0.00206 | 2.34066 | 0.00440 | 7.88701 | 0.01817 | 8.206 | 1.188 |
| 0.96095 | 2800 | 0.00483 | 0.00200 | 0.25110 | 0.00828 | 0.01075 | 0.00207 | 1.06383 | 0.00431 | 3.03910 | 0.00967 | 6.754 | 2.473 |
| 0.98894 | 3200 | 0.00040 | 0.00190 | 0.19419 | 0.00494 | 0.00516 | 0.00293 | 0.88447 | 0.00584 | 2.35095 | 0.00675 | 11.234 | 2.811 |
| 1.00000 | 4000 | 0.00083 | 0.00161 | 0.05403 | 0.00417 | 0.00135 | 0.00196 | 0.34942 | 0.00387 | 0.78419 | 0.00622 | 6.881 | 6.068 |

**Appendix.** (Contunied).

| Sample S8b | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00247437 ± 0.0000183505 | | | | Tot. gas. age = 5.659 ± 0.256 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.00717 | 100 | 0.02504 | 0.00145 | 0.12848 | 0.00835 | 0.06980 | 0.00210 | 0.34563 | 0.00652 | 3.22217 | 0.02731 | –54.762 | 5.824 |
| 0.01847 | 200 | 0.03577 | 0.00176 | 0.10082 | 0.00514 | 0.07187 | 0.00208 | 0.54465 | 0.00267 | 8.77567 | 0.02157 | –14.775 | 4.309 |
| 0.03767 | 300 | 0.09585 | 0.00237 | 0.06283 | 0.00464 | 0.07008 | 0.00297 | 0.92558 | 0.00425 | 27.17320 | 0.02219 | –5.561 | 3.391 |
| 0.06764 | 400 | 0.13053 | 0.00212 | 0.07048 | 0.00822 | 0.06818 | 0.00173 | 1.44431 | 0.00563 | 38.97860 | 0.04104 | 1.254 | 1.943 |
| 0.14761 | 600 | 0.22014 | 0.00374 | 0.14190 | 0.01033 | 0.09817 | 0.00144 | 3.85469 | 0.00790 | 69.33984 | 0.04608 | 4.958 | 1.278 |
| 0.25772 | 800 | 0.15290 | 0.00309 | 0.23168 | 0.00487 | 0.08857 | 0.00293 | 5.30706 | 0.01513 | 53.89163 | 0.04146 | 7.310 | 0.765 |
| 0.39393 | 1000 | 0.11340 | 0.00229 | 0.42027 | 0.00403 | 0.09038 | 0.00357 | 6.56547 | 0.01077 | 43.33723 | 0.03616 | 6.670 | 0.460 |
| 0.54610 | 1200 | 0.09070 | 0.00231 | 0.57351 | 0.01237 | 0.08936 | 0.00243 | 7.33496 | 0.01619 | 38.56216 | 0.02442 | 7.144 | 0.414 |
| 0.68940 | 1400 | 0.06832 | 0.00316 | 0.78026 | 0.01223 | 0.08218 | 0.00217 | 6.90700 | 0.00865 | 30.13114 | 0.03450 | 6.415 | 0.602 |
| 0.77391 | 1600 | 0.03546 | 0.00173 | 0.49788 | 0.01031 | 0.03951 | 0.00236 | 4.07318 | 0.01232 | 17.60110 | 0.01898 | 7.789 | 0.559 |
| 0.82515 | 1800 | 0.02051 | 0.00179 | 0.36979 | 0.00904 | 0.02931 | 0.00233 | 2.46983 | 0.00997 | 9.15164 | 0.01600 | 5.577 | 0.952 |
| 0.85605 | 2000 | 0.00686 | 0.00223 | 0.13949 | 0.00443 | 0.01589 | 0.00226 | 1.48931 | 0.00796 | 4.61399 | 0.01184 | 7.737 | 1.972 |
| 0.89287 | 2400 | 0.00770 | 0.00171 | 0.20794 | 0.00902 | 0.01910 | 0.00287 | 1.77492 | 0.00822 | 5.23426 | 0.00977 | 7.425 | 1.270 |
| 0.94319 | 2800 | 0.01203 | 0.00154 | 0.59010 | 0.00705 | 0.02356 | 0.00251 | 2.42525 | 0.00890 | 6.94055 | 0.01409 | 6.222 | 0.837 |
| 0.96764 | 3200 | 0.00342 | 0.00205 | 0.19048 | 0.00693 | 0.00962 | 0.00151 | 1.17878 | 0.00757 | 3.13803 | 0.00712 | 8.037 | 2.284 |
| 1.00000 | 4000 | 0.00907 | 0.00227 | 0.16855 | 0.00566 | 0.01483 | 0.00193 | 1.55958 | 0.00686 | 4.79543 | 0.00892 | 6.042 | 1.912 |

**Appendix.** (Contunied).

| Sample S9a | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00246143 ± 0.0000186481 | | | | Tot. gas. age = 5.001 ± 0.619 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.01055 | 100 | 0.01590 | 0.00231 | 0.10339 | 0.00458 | 0.05062 | 0.00164 | 0.17011 | 0.00640 | 1.48755 | 0.03255 | –85.811 | 19.019 |
| 0.02730 | 200 | 0.01604 | 0.00212 | 0.07875 | 0.00340 | 0.05654 | 0.00241 | 0.27003 | 0.00352 | 1.73918 | 0.01296 | –50.013 | 10.621 |
| 0.05465 | 300 | 0.00954 | 0.00171 | 0.03480 | 0.00649 | 0.04695 | 0.00145 | 0.44086 | 0.00530 | 2.49570 | 0.01578 | –3.267 | 5.103 |
| 0.09407 | 400 | 0.01258 | 0.00160 | 0.03636 | 0.00586 | 0.04724 | 0.00246 | 0.63550 | 0.00593 | 3.41572 | 0.00980 | –2.109 | 3.315 |
| 0.18659 | 600 | 0.02415 | 0.00150 | 0.05125 | 0.00625 | 0.05645 | 0.00150 | 1.49156 | 0.00508 | 7.84528 | 0.01629 | 2.106 | 1.315 |
| 0.30821 | 800 | 0.01275 | 0.00263 | 0.12391 | 0.00528 | 0.05386 | 0.00175 | 1.96079 | 0.00705 | 8.17777 | 0.00945 | 9.957 | 1.751 |
| 0.43019 | 1000 | 0.01234 | 0.00199 | 0.46618 | 0.00601 | 0.04740 | 0.00096 | 1.96657 | 0.00834 | 7.36302 | 0.01826 | 8.370 | 1.326 |
| 0.54421 | 1200 | 0.00771 | 0.00153 | 0.93935 | 0.00749 | 0.04108 | 0.00140 | 1.83811 | 0.00450 | 5.61167 | 0.01174 | 8.033 | 1.086 |
| 0.63744 | 1400 | 0.00353 | 0.00228 | 1.40348 | 0.00953 | 0.03643 | 0.00217 | 1.50294 | 0.00875 | 4.34339 | 0.01534 | 9.727 | 1.982 |
| 0.69712 | 1600 | 0.00177 | 0.00171 | 0.80845 | 0.01270 | 0.02639 | 0.00116 | 0.96227 | 0.00581 | 2.68915 | 0.01418 | 9.964 | 2.316 |
| 0.75195 | 1800 | 0.00440 | 0.00198 | 0.82498 | 0.00934 | 0.02268 | 0.00188 | 0.88393 | 0.00733 | 2.52168 | 0.01113 | 6.133 | 2.934 |
| 0.80526 | 2000 | 0.00474 | 0.00207 | 1.18480 | 0.01040 | 0.01436 | 0.00167 | 0.85938 | 0.00671 | 2.26812 | 0.01174 | 4.474 | 3.159 |
| 0.90551 | 2400 | 0.00676 | 0.00174 | 3.27346 | 0.01475 | 0.03422 | 0.00245 | 1.61621 | 0.00785 | 4.24405 | 0.01219 | 6.161 | 1.411 |
| 0.98735 | 2800 | 0.00304 | 0.00143 | 2.52515 | 0.01201 | 0.02052 | 0.00170 | 1.31932 | 0.00495 | 2.98673 | 0.00768 | 7.020 | 1.417 |
| 0.99670 | 3200 | 0.00018 | 0.00170 | 0.59908 | 0.01043 | 0.00492 | 0.00243 | 0.15080 | 0.00241 | 0.36749 | 0.00645 | 9.205 | 14.721 |
| 1.00000 | 4000 | –0.00160 | 0.00165 | 0.27930 | 0.00770 | 0.00288 | 0.00192 | 0.05321 | 0.00294 | 0.17520 | 0.00689 | 53.243 | 39.717 |

**Appendix.** (Contunied).

| Sample S9b | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass = 1 | | J = 0.00246143 ± 0.0000186481 | | | | Tot. gas. age = 5.001 ± 0.619 | | | | | | | |
| Fraction 39Ar released | LP (mW) | Vol36 | Err36 | Vol37 | Err37 | Vol38 | Err38 | Vol39 | Err39 | Vol40 | Err40 | Age (Ma) | AgeErr |
| 0.00955 | 100 | 0.01385 | 0.00111 | 0.12735 | 0.01255 | 0.05966 | 0.00222 | 0.18903 | 0.00320 | 1.74904 | 0.02844 | –55.910 | 8.022 |
| 0.02660 | 200 | 0.01647 | 0.00210 | 0.10181 | 0.01087 | 0.08471 | 0.00301 | 0.33758 | 0.00345 | 2.84931 | 0.02262 | –26.745 | 8.304 |
| 0.05520 | 300 | 0.01597 | 0.00173 | 0.07850 | 0.01073 | 0.08812 | 0.00226 | 0.56621 | 0.00442 | 3.53398 | 0.00948 | –9.314 | 4.025 |
| 0.09816 | 400 | 0.02169 | 0.00196 | 0.04739 | 0.01151 | 0.07978 | 0.00177 | 0.85043 | 0.00506 | 5.56622 | 0.00806 | –4.403 | 3.031 |
| 0.20607 | 600 | 0.03126 | 0.00180 | 0.12227 | 0.01102 | 0.09008 | 0.00237 | 2.13628 | 0.00624 | 11.67378 | 0.01732 | 5.058 | 1.106 |
| 0.34004 | 800 | 0.02012 | 0.00188 | 0.55291 | 0.00671 | 0.07991 | 0.00323 | 2.65210 | 0.00877 | 9.95475 | 0.01153 | 6.698 | 0.925 |
| 0.49628 | 1000 | 0.01997 | 0.00181 | 1.02736 | 0.00982 | 0.08229 | 0.00139 | 3.09309 | 0.00880 | 10.23043 | 0.01187 | 6.205 | 0.766 |
| 0.61884 | 1200 | 0.00733 | 0.00153 | 1.49518 | 0.01468 | 0.06553 | 0.00243 | 2.42641 | 0.00509 | 6.67376 | 0.02052 | 8.228 | 0.825 |
| 0.71075 | 1400 | 0.00482 | 0.00169 | 1.63944 | 0.01146 | 0.03705 | 0.00275 | 1.81958 | 0.00862 | 4.63361 | 0.01043 | 7.815 | 1.216 |
| 0.78558 | 1600 | 0.00479 | 0.00159 | 1.76636 | 0.01008 | 0.03090 | 0.00210 | 1.48135 | 0.00812 | 3.60325 | 0.01083 | 6.545 | 1.408 |
| 0.85871 | 1800 | 0.00309 | 0.00146 | 2.71298 | 0.01359 | 0.02615 | 0.00190 | 1.44761 | 0.00657 | 3.36523 | 0.00833 | 7.503 | 1.316 |
| 0.88250 | 2000 | 0.00053 | 0.00175 | 0.68587 | 0.00961 | 0.01567 | 0.00246 | 0.47101 | 0.00538 | 1.12042 | 0.00682 | 9.074 | 4.847 |
| 0.92119 | 2400 | 0.00109 | 0.00188 | 2.09052 | 0.01465 | 0.01590 | 0.00255 | 0.76607 | 0.00485 | 1.75434 | 0.01124 | 8.279 | 3.210 |
| 0.94516 | 2800 | –0.00073 | 0.00192 | 1.29965 | 0.01300 | 0.01211 | 0.00229 | 0.47441 | 0.00400 | 1.09573 | 0.00691 | 12.234 | 5.283 |
| 0.99602 | 3200 | 0.00449 | 0.00200 | 3.02462 | 0.01962 | 0.02442 | 0.00226 | 1.00685 | 0.00554 | 2.28657 | 0.00857 | 4.226 | 2.604 |
| 1.00000 | 4000 | 0.00151 | 0.00104 | 0.19102 | 0.00700 | –0.00096 | 0.00165 | 0.07885 | 0.00333 | 0.20557 | 0.00670 | –13.599 | 17.424 |