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## PLEISTOCENE ERUPTIVE CHRONOLOGY OF THE GÖLCÜK VOLCANO, ISPARTA ANGLE, TURKEY

■  
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### ABSTRACT

In the Eastern Mediterranean region, the Isparta volcanic belongs to the post-collisional alkali-potassic to ultrapotassic magmatism active since the Miocene in this part of the Anatolian peninsula from Afyon to Isparta. In the so-called Isparta Angle (IA) the magmatism is contemporaneous with an extensional regime initiated during Late Miocene and active throughout the Pliocene and Quaternary. Previous K/Ar dating performed on lavas suggested that potassic-ultrapotassic magmatism occurred between 4.7 to 4 Ma. However, a more recent (Quaternary) activity of the Gölcük volcano is evidenced by the present-day morphology and field evidence although it remained undated and poorly studied so far. Field mapping and new radiometric data indicate that the main volcano-forming stages of the Gölcük volcano consist of three main eruptive cycles. (1) Cycle I, represented by more than 200m-thick pyroclastic flow deposits occasionally separated by paleosoils and corresponding to caldera-forming ignimbritic eruptions. (2) Cycle II, consisting of tephriphonolite lava dome-flows extruded throughout the caldera and currently found along the rim of the present crater. (3) Cycle III made up of tuff-ring deposits related to several phreatoplinian eruptions of a maar-type volcanic activity. This youngest cycle ends with trachytic domes protruding within the maar crater. Unspiked <sup>40</sup>K/<sup>40</sup>Ar dating on mesostasis was performed on lavas (tephriphonolites and trachytic domes), and complemented by preliminary <sup>40</sup>Ar/<sup>39</sup>Ar data on tephra deposits (sanidine). Our preliminary results show that the entire activity of Gölcük volcano took place during the Pleistocene and was disconnected from the older Pliocene volcanism. This volcanic activity can be considered as a new volcanic cycle, starting (Cycle I) around 200 ka with major explosive, regional-scale, events represented by at least six ignimbrites sheets. Cycle II occurred between 115 ± 3 ka to 62 ± 2 ka with probably some associated tephra deposits. Tuff-ring of Cycle III formed from 72.7 ± 4.7 ka to 24 ± 2 ka. The associated phreatoplinian eruptions have almost entirely destroyed the previously formed flow-dome. This latest activity corresponds to several volcanic crises as illustrated by the two domes protrusions separated by about 30 ka. The volcanic history of Gölcük ceased around 24 ka ± 2 ka, but the periodicity of eruptive events appears to be long and complex. Currently, the volcano is at rest, but there is no doubt that the Isparta town (more than 120 000 people) built on top of the most recent tephra falls is exposed to a major volcanic hazard in the future.

**Key-words:** alkaline volcanism, tephra, ignimbrite, pyroclastite, <sup>40</sup>Ar/<sup>39</sup>Ar, K/Ar, <sup>14</sup>C dating methods, volcanism hazard, Gölcük, Isparta Angle, Turkey.

### RÉSUMÉ

#### CHRONOLOGIE DES ÉPISODES VOLCANIQUES PLÉISTOCÈNES DU VOLCAN GÖLCÜK, ANGLE D'ISPARTA, TURQUIE

En Méditerranée Orientale, la région active d'Isparta est le siège d'un magmatisme alcalin lié à la distension affectant cette partie de la Péninsule Anatolienne depuis le Miocène supérieur. Le volcanisme Pliocène est alcalin et très potassique, depuis des magmas lamprophyriques à lamproïtiques, jusqu'à des téphriphonolites et des trachytes. La construction du volcan Gölcük au sud d'Isparta marque le début d'un nouveau cycle éruptif après une longue période d'arrêt et d'érosion. L'étude morpho-structurale du volcan couplée aux datations <sup>40</sup>K/<sup>40</sup>Ar sur lave et <sup>39</sup>Ar/<sup>40</sup>Ar sur monograin de feldspath-K indique une histoire éruptive complexe, nettement plus jeune que l'activité antérieure (Pliocène). Ces résultats préliminaires montrent que l'activité volcanique du Gölcük est située dans le Pléistocène supérieur (Paléolithique) entre environ 200 ka et 24 ka. Trois cycles volcaniques majeurs sont reconnus : (1) Cycle I débutant vers 200 ka avec des éruptions ignimbritiques majeures avec un ensemble de coulées pyroclastiques trachytiques comblant les paléo-vallées ouvertes dans les formations sédimentaires et les formations volcaniques d'âge pliocène ; (2) Cycle II avec un épisode effusif de faible importance succède entre 115 ± 3 ka et 62 ± 2 ka à l'activité explosive initiale avec la mise en place d'un édifice central constitué de dômes-coulées téphri-phonolitiques ; (3) Cycle III entre 70 ka et 24 ka, l'activité devient phréatoplinienne et suit de près le cycle précédent. Le dynamisme éruptif phréatomagmatique est celui d'un maar formé d'un large cratère d'explosion entouré d'un anneau de tufs. La dernière crise volcanique se termine par l'extrusion de plusieurs dômes de trachyte dans le cratère et de téphras associés, de nouvelles coulées pyroclastiques se mettent vraisemblablement en place vers le nord-ouest. Les données de terrain et les âges <sup>40</sup>Ar/<sup>39</sup>Ar disponibles indiquent que ces dernières manifestations (construction du maar) sont très récentes et sub-contemporaines du dernier niveau de retombées poncées sous les immeubles de la ville et des dômes de lave intra-caldeira. Cet âge récent est confirmé par un âge <sup>14</sup>C obtenu sur des bois carbonisés. La morphologie du volcan actuel est relativement bien conservée, malgré l'érosion très active qui remodèle déjà partiellement les pentes. La reprise éventuelle de l'activité du volcan constituerait un risque majeur à l'échelle de la région et en particulier pour la ville d'Isparta établie au pied de l'édifice, notamment sur les coulées pyroclastiques et les retombées poncées les plus récentes.

**Mot-clés :** volcanisme alcalin, téphras, ignimbrite, pyroclastite, datations <sup>40</sup>Ar/<sup>39</sup>Ar, K/Ar, <sup>14</sup>C, risque volcanique, Gölcük, Angle d'Isparta, Turquie.

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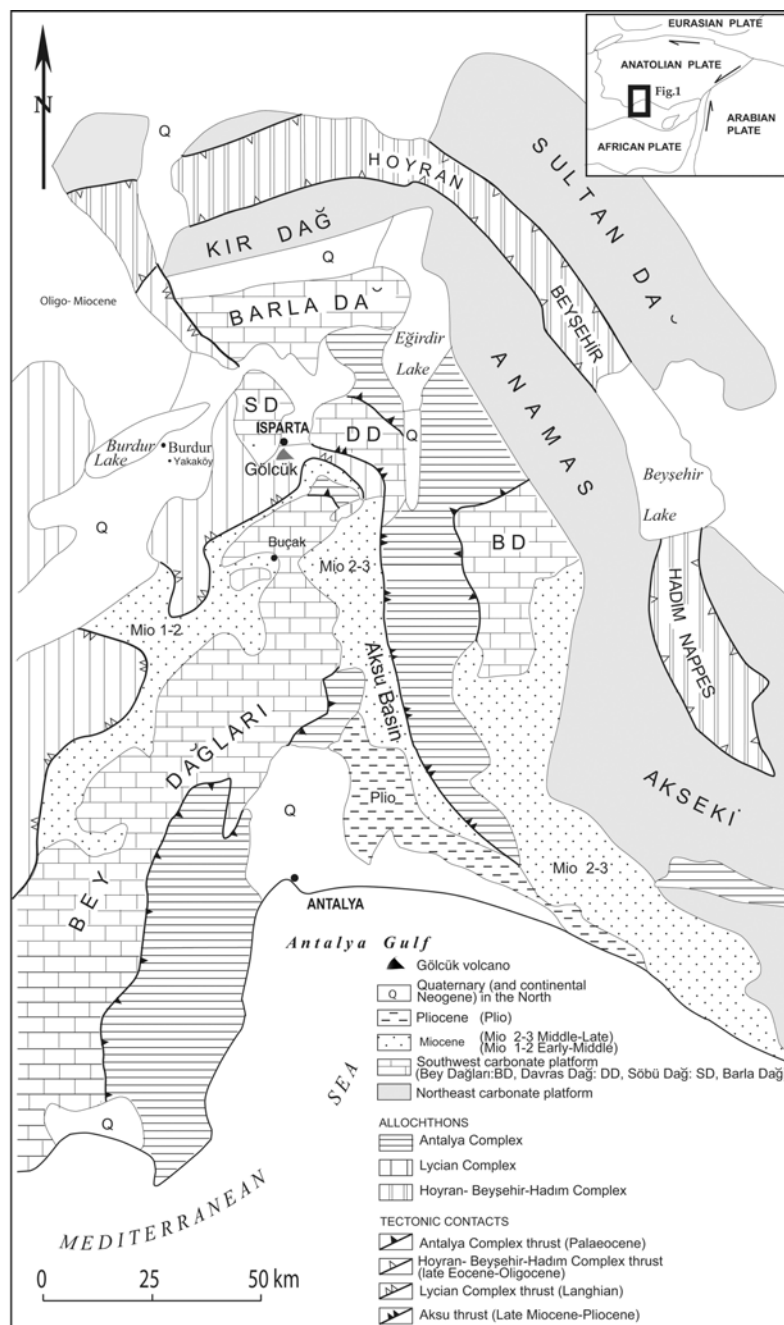
## 1 - INTRODUCTION

In SW Turkey the Isparta volcanism belongs to the post-collisional alkali potassic-ultrapotassic magmatism occurring from Afyon in Central Anatolia to the North, to the Isparta-Bucak area to the South (fig. 1). Previous  $^{40}\text{K}/^{40}\text{Ar}$  dating was performed by Lefèvre *et al.*, (1983) on lavas who showed that the first potassic-ultrapotassic emissions occurred between 4.7 to 4 Ma. However, the recent activity of the Gölcük volcano has never been precisely dated and its age remains controversial (Coban, 2005; Coban & Flower, 2006). The aims of this paper are: i) to present new and more precise geochronological constraints on the recent (Pliocene) Gölcük activity; ii) to delineate the number of

eruptive cycles as well as their respective duration and recurrence time; iii) to evaluate the natural hazard represented by this recent activity for the nearby and populated Isparta region.

### 1.1 - REGIONAL CONTEXT

The Gölcük volcano (Turkey) is located at the apex of the so-called "Isparta Angle". This area corresponds to the junction of the Hellenic and Cyprus arcs. The volcano is built up on a complex pile of allochthonous units thrust onto the relative autochthonous Bey Daglari platform (fig. 1). The Late-Miocene Antalya complex and the mid-Miocene Lycian Complex are two allochthonous units (Poisson *et al.*, 2003a) resulting



**Fig. 1:** Geological map of Isparta-Antalya area, from Poisson (2003a).

*Fig. 1 : Carte géologique du secteur Isparta-Antalya, d'après Poisson (2003a).*

from N-S convergence of Eurasia and Africa starting during Late Cretaceous and ending with the complete closure of the Northern Neotethys located North of the Anatolian micro-plate, and the Southern Pamphylian Basin of the Southern Neotethys. The Lycian Nappes came from the Northern Tethys and achieved their translation during Langhian times. At that time, the Isparta area emerged and the Lycian Nappes were partly eroded to fill the Southern molassic Aksu basin. E-W compression and associated uplift (3000m for the Aksu valley) occurred during Late Miocene and mid-Pliocene (Poisson *et al.*, 2003b) giving way to the Antalya Complex (Robertson, 1993). Farther to the West, in the areas of Burdur and Isparta, extension prevailed, initiated probably during Pliocene and resulting in a complex system of grabens along NW-SE and NE-SW striking normal faults (Temiz *et al.*, 1997; Walkens *et al.*, 2000).

Post-collision potassic-rich magmatism in Southern Turkey started during Miocene in the northern district of Afyon and during Pliocene in Isparta and Burdur areas (Keller, 1982). Extension is associated with important magmatic activity since Early Pliocene in these areas and remains currently active (Lefèvre *et al.*, 1983; Guillou, 1987; Özgür *et al.*, 1990; Yagmurlu *et al.*, 1997; Savaşçın & Oyman, 1998). The Gölcük volcano and associated Pliocene protrusions and dykes determine many circular structures easily seen on satellite views (Cengiz *et al.*, 2005). Numerous dykes and protrusions outcropping around Isparta and Bucak are the remnants of the Pliocene magmatic activity whose surface manifestations and volcanic products have been largely eroded today. The Gölcük volcano is particular in being the only well preserved volcano still observable today and is the youngest witness of the potassic magmatism in this area.

## 1.2 - MORPHOLOGY AND STRUCTURE OF THE GÖLCÜK VOLCANO

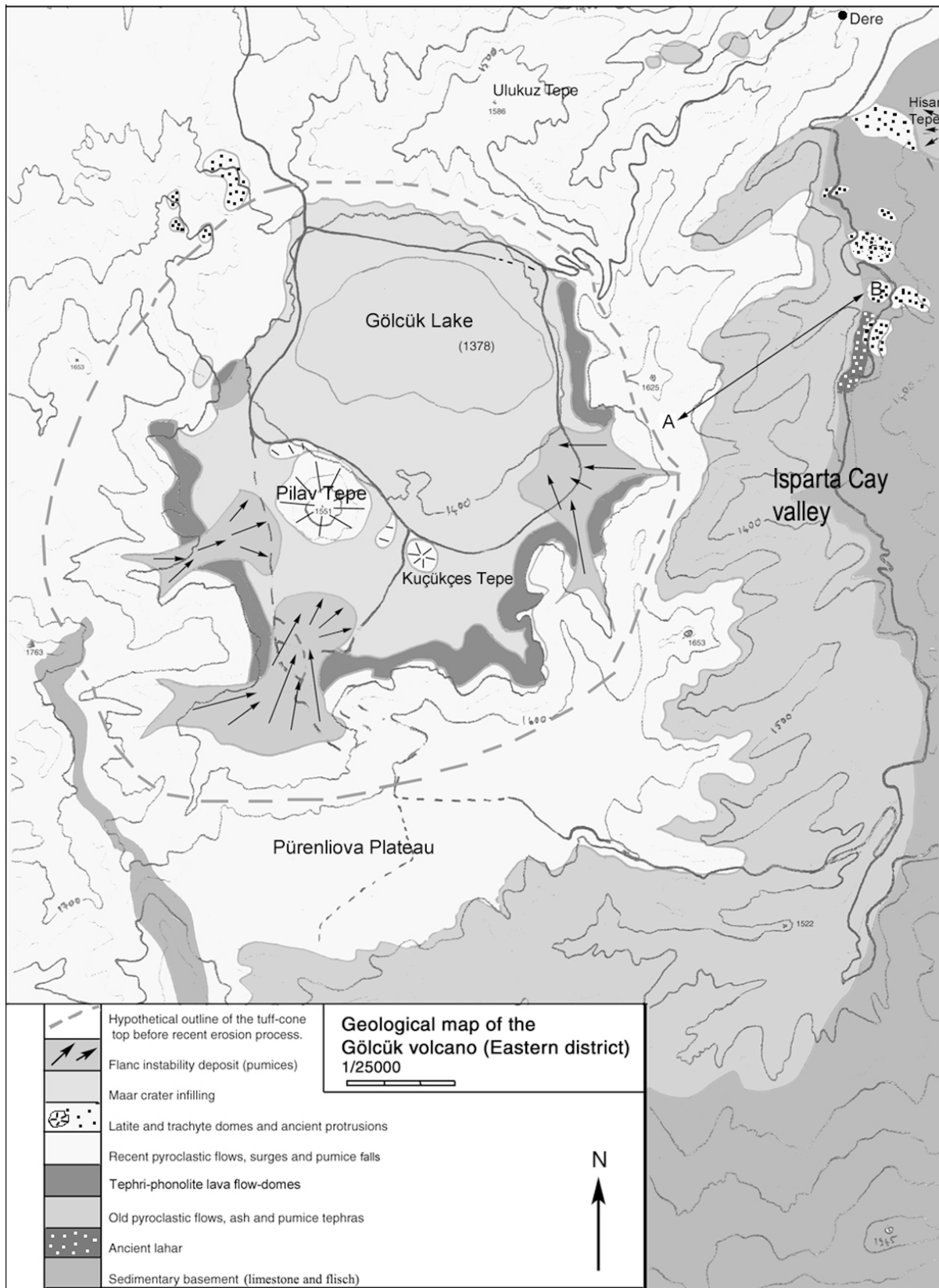
The Gölcük volcano (fig. 2 and 3) is located immediately South of Isparta city. It partially covers the Lycian Nappes and lavas, and older volcano-clastic deposits and trachy-andesitic protrusions belonging to the westernmost part of the Pliocene volcanic cycle. The proper volcanic edifice corresponds to a large maar crater (2.5 km in diameter) partly occupied by a lake and surrounded by a relatively well-preserved 150 m-thick tuff cone (fig. 4 and 5). Morphologically, the crater edge mainly consists of remnants of tephri-phonolitic lava flow-domes rimming the central depression occupied by the Gölcük Lake (fig. 5C), with two recent intracaldera-like trachytic domes protruding through the South-central part of the crater. The bulk (> 90%) of the volcanic edifice is predominantly composed of tephra deposits (pyroclastic flows, air-falls and surges, minor lahars) with subsidiary lava flows and domes. These products were emplaced through a complex eruptive sequence consisting of at

least three successive cycles (fig. 2, 3, 4) herein designated Eruptive Cycles I, II, and III.

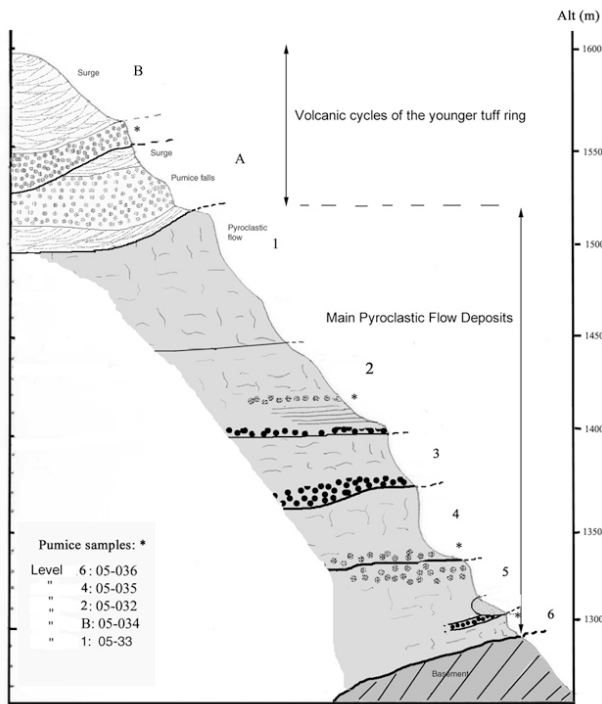
## 2 - ERUPTIVE CYCLE I: MAIN PYROCLASTIC FLOW DEPOSITS (MPFD)

The MPFD correspond to a 200m-thick pile of poorly consolidated pyroclastic flow deposits previously described by Alici *et al.*, (1998). They can be observed next to the southern part of the maar crater (the Pürenliova plateau) and they correspond to a previous caldera filled by pyroclastic flow deposits. This older caldera has been partially destroyed by a subsequent explosive phreatoplinian event. MPFD are also well exposed in the valley running east of the main volcanic edifice (fig. 5B) beneath the recent tuff cone of the later Cycle III. These pyroclastic deposits are also well exposed along the Isparta Cay valley, in the Isparta city basement and in the southern Pürenliova plateau. The best exposures are found in the eastern valley cut where a minimum of six superimposed pyroclastic flows locally separated by paleosoil can be recognized. These pyroclastic flows infilled a paleo-valley carved into the sedimentary basement and older Pliocene volcanic formations (fig. 3 and 5B). Each pyroclastic unit is made of a relatively poorly consolidated, homogeneous, fresh or welded ash matrix enclosing cm to dm-size pumice pyroclasts, associated with lithoclasts of the sedimentary basement and older lavas. A rough discontinuous stratification can be locally seen, with dm-size layers of pumice pyroclasts mixed with lithoclasts, depending on which part of the pyroclastic deposit is exposed. The base of the pyroclastic units can locally display a thick layer of 10 to 50 cm-size lithoclast blocks accumulated and enclosed in a matrix with cm-size old lava fragments and pumice pyroclasts. The products of this cycle are characteristically mildly to strongly weathered, with evidence of post-emplacment alteration associated with dissolution of pumice clasts in the matrix and frequent surface hardening due to late-stage dissolution-precipitation reactions. At least one unit of this cycle displays long cavities with elliptic section (up to 30cm across the long axis) corresponding to transported and preferentially-aligned tree logs with traces of charcoal coating the inner surface of the cavities. The presence of trees indicates that an evolved vegetation cover prevailed, at least locally, at the time of emplacement of this pyroclastic venue of Cycle I.

By their volumetric importance, the MPFD correspond to a regional-scale initial ignimbric episode marking the beginning of the Gölcük activity. As a whole, MPFD are found in topographic depressions including the eastern valley, the Burdur and Isparta depressions and the Lycian Nappes limestone. This topographic system appears to delimit an originally flat trough area centred on the Gölcük volcano that would correspond to the initial caldera of the volcano almost entirely filled by the pyroclastic flows of Cycle I (Alici *et al.*, 1998; Cengiz *et al.*, 2005).



**Fig. 2: Geological map of the central and south-eastern parts of the Gölcük volcano, from Platevoet *et al.*, 2006. A-B crosscut is described in fig. 3.**  
 Fig. 2 : Carte géologique de la partie centrale et sud-est du volcan Gölcük d'après Platevoet *et al.*, 2006. La coupe A-B est décrite fig. 3.



**Fig. 3: Volcanic succession observed along the crosscut section A-B, from the eastern valley road to the top of the recent tuff ring. The two main tephra deposits: the Main Pyroclastic Flow Deposit (M.P.F.D.) made of six successive pyroclastic flow deposits and the younger tuff ring tephra made of two main sequences of tephra.**

*Fig. 3 : Succession des produits volcaniques suivant la section A-B depuis la route de l'est jusqu'à l'anneau de tuf récent. Deux principales formations : les dépôts pyroclastiques majeurs (M.P.F.D.) faites de six coulées pyroclastiques et les téphras de l'anneau de tuf récent fait de deux séquences majeures de téphras.*

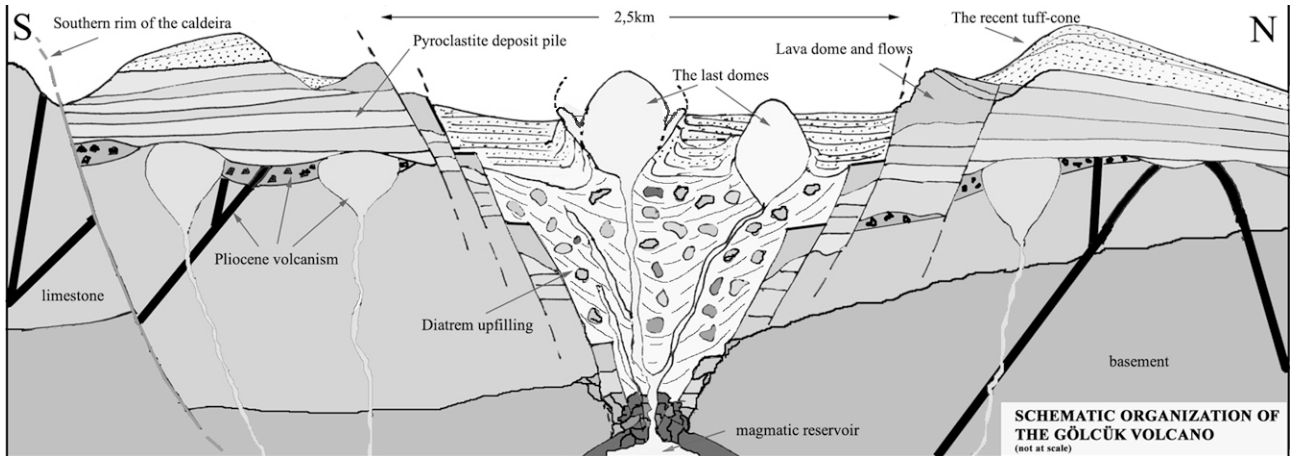
Other thick pyroclastic deposits, situated far from the present volcano are good witnesses of the regional character of the Gölcük activity. On the north-western flank of the Gölcük, four units lying on older lahar deposit(s) can be recognized in a quarry exposing a 40m-thick stratigraphic section across approximately 10m-thick pyroclastic flows, but field relationships are still uncertain as to whether this pile belongs to Cycle I as described above, or to a younger/older event. In the Burdur basin, two thick pyroclastic flow deposits (> 20m-thick) were found interstratified toward the top of the lacustrine deposits, indicating that the Gölcük pyroclastic activity was contemporaneous with the opening and filling of the basin. Two thick, flat-lying pyroclastic deposits are also exposed nearby in quarries cut close to the Yakaköy village (near Burdur). These lie topographically over the tilted lacustrine deposits suggesting that they could represent eruptive events distinct and younger than the interstratified flows, although they have not been observed directly in contact (i.e. discordant) with the underlying sediments.

### 3 - ERUPTIVE CYCLE II: TEPHRIPHONOLITIC DYKES AND LAVA FLOW-DOMES

This cycle represents a volumetrically minor component of the entire eruptive sequence (< 10 %, probably). Cycle-II lava products outcrop along north-eastern, south-eastern and western wall of the maar crater (fig. 5C). At the north-eastern margin, a NW-dipping 10m-thick dyke of tephriphonolite intruded two lava flows displaying basal scoriae and rough columnar jointing. Higher up in the pile, the dike tip is cut by several (at least two) flows of very similar tephriphonolitic composition. At the south-eastern and western margin, the lava formations are massive and very thick (30-50m) and probably correspond to lava-dome remnants preserved from the subsequent Cycle III explosive maar activity. This apparent ring-like structure around the maar crater could be the result of the destruction of earlier domes emplaced inside the caldera and associated with lava flows running on their flanks, rather than a real ring-dyke structure intruding the caldera as recently suggested by Kumral *et al.* (2006). These lava flow-domes, or protrusions, were linked to the same magma chamber and were emplaced not very long after the end of the initial Cycle-I plinian episode. These protrusions could reflect a change in the magma eruptive dynamics of the feeding system with viscous, H<sub>2</sub>O-undersaturated, tephriphonolitic magmas following the more evolved (fluid-saturated and very explosive) trachytic magmas initially extracted during Cycle I from the top of a probably stratified magma chamber.

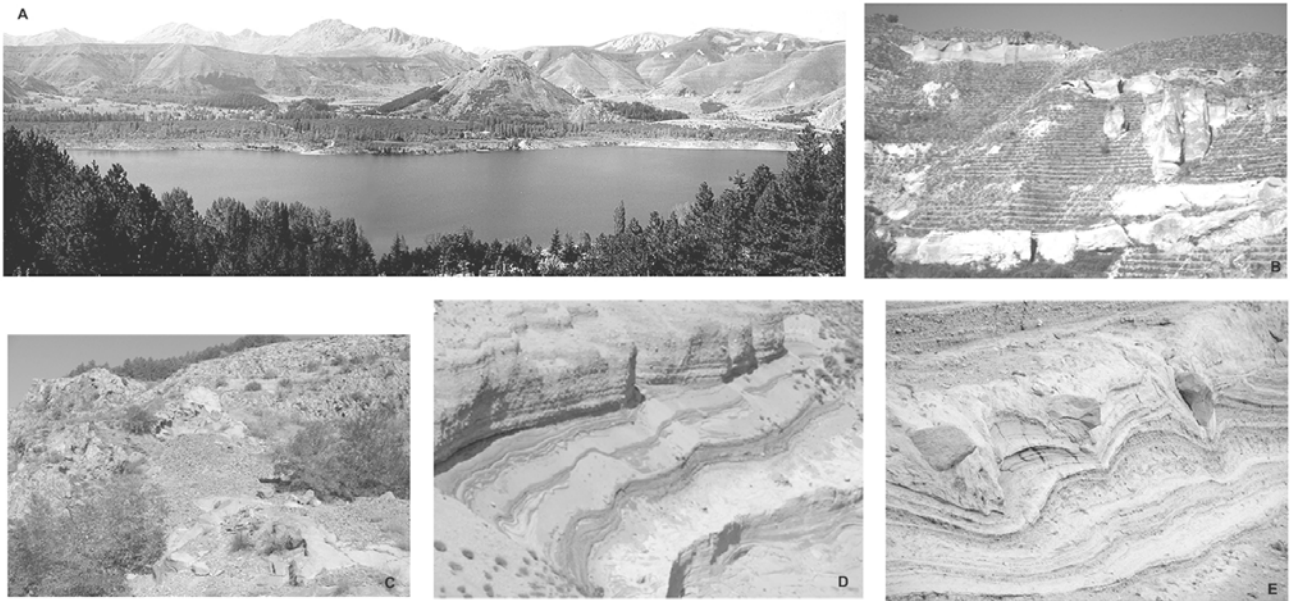
### 4 - ERUPTIVE CYCLE III: LATE TUFF-RING DEPOSITS

A second pile of tephra fallout and surges covers the tephriphonolitic lava sequence and Cycle I to form a large tuff cone centred on the 2.5 km-wide maar crater and extending beyond the central depression rim over the flanks of the volcano. The tephra of the tuff cone cover all earlier Cycle I and II volcanic deposits. The maximum thickness observed ranges between 100-150m. The observed thickness rapidly decreases outside of the maar crater rim with only 30 to 100cm-thick pumice fall deposit in the Isparta and Egirdir grabens. A distinctive tephra marker (consisting of alternative fall and surge members) can be observed on the north-eastern and Eastern flanks of the volcano (Hildenbrand *et al.*, 1999). These layers can be traced uninterruptedly to the north, gently sloping toward the city of Isparta and capping the crest and ridge morphology of the northern slopes of the volcano. To the north-east, the tephra pile is already strongly eroded. The complete Cycle-III sequence consists of successive phreatoplinian eruptions of a maar-type volcano (fig. 5D) ending with trachytic dome extrusion within the maar crater, the cryptic diatrem is probably below the actual lake (fig. 5A) (Schmincke *et al.*, 1973; Lorenz, 2007).



**Fig. 4:** Schematic N-S cross-section of the Gölcük volcano passing through the maar crater, the last trachytic domes, the tuff ring and the M.P.F.D.

*Fig. 4 : Coupe schématique N-S du volcan Gölcük en passant par le cratère du maar, les derniers dômes trachytiques, l'anneau de tuf et les dépôts pyroclastiques majeurs (M.P.F.D.).*



**Fig. 5:** 5A, From north, view of the central part of Gölcük volcano; from front to background: the maar crater partially occupied by a lake; the last trachytic dome (Pilav Tepe), the tephra from the first cycle covered by the tephra building the younger maar tuff ring; the Lycian nappes made of limestone. 5B, the M.P.F.D. with five successive pyroclastic flow deposits (see fig. 3) filling a paleo-valley, contact is at the bottom right. 5C, tephri-phonolitic dyke cutting two small lava flows and covered by new lava flows, north-eastern rim of the maar crater. 5D, the two eruptive sequences building the recent tuff ring of the maar, the cliff is the main pumice fall deposit lying unconformably over base surge deposits. 5E, base surge deposits with meter-size ballistic tephri-phonolitic blocks.

*Fig. 5 : 5A, vue du nord de la partie centrale du volcan Gölcük ; depuis le premier plan vers l'arrière : le cratère du maar occupé en partie par un lac ; le dernier dôme trachytique (Pilav Tepe), les téphras du premier cycle couverts par les téphras du plus récent anneau de tuf du maar ; les nappes lyciennes de calcaire. 5B, les dépôts pyroclastiques majeurs (M.P.F.D.) avec les dépôts de cinq coulées pyroclastiques superposées (voir la fig. 3) remplissant une paléo-vallée, le contact est visible en bas à droite. 5C, un dyke de téphri-phonolite recoupant deux petites coulées et couvert par de nouvelles coulées de lave, bord nord-est du cratère. 5D, les deux séquences éruptives majeures construisant l'anneau de tuf du maar, la falaise est constituée par le principal niveau de retombées poncées discordant sur des dépôts de déferlantes. 5E, dépôts de déferlantes impactés par des blocs balistiques de téphri-phonolite de taille métrique.*

The tuff ring is composed of two superposed volcanic sequences separated by a paleosoil horizon and one erosion cycle manifested by at least one intraformational discordance. A basal fall out sequence is composed of 5 to 10m-thick pumice fall deposits divided into 4-5 cycles of relatively well calibrated pumice lapilli (1-5cm) at the base, capped by coarser deposits with 20 to 30cm pumice blocks (fig. 5D) corresponding to successive paroxysmal and strength-decreasing phreato-plinian eruptions. Pumice lapilli are always mingled with abundant lithoclasts lava lapilli. Ultramafic, mafic, and felsic plutonic blocks are locally observed in the fall deposits and were probably tapped from the crystallized top of the magma chamber during the raising of magma. The fall out sequence is followed by the accumulation of 5 to 10m-thick base surge deposits consisting of typical dune-antidune structures and composed of fine ash layers alternating with layers or lenses of mingled pumice and lava lithoclast lapilli. All the layers can be locally impacted by huge ballistic lava blocks (fig. 5E). The ballistic blocks are derived from the pre-existing tephriphonolite flow-domes destroyed during the maar activity. A last minor tephra deposit discordant at the top of the maar forms the last fall out blanketing the flanks of the volcano, reaching down the foothills and the plain where the city of Isparta is now constructed. The deposit is composed of a single 30cm to 1m-thick layer of pumice lapilli fall. Possible far-reaching equivalents of this last eruptive episode can be found away from the Gölcük itself in the Egirdir graben (25 km) to the East and around Bucak (15 km) to the South-West. This last event is probably related to the growth of the last trachytic domes preserved within the maar crater including notably the Pilav Tepe, a well-preserved dome about 150 m high built up by two successive trachytic venues (fig. 5A).

## 5 - DATING TECHNIQUES AND PRELIMINARY AGE RESULTS

In order to place age constraints on the different eruptive cycles recognized above, the unspiked  $^{40}\text{K}/^{40}\text{Ar}$  dating technique was applied on samples selected from pre-Cycle I trachytic domes, the Cycle-II trachy-andesites and tephriphonolites flow-dome and dyke, and the late Cycle-III central trachytic domes. We analyzed the separated mesostasis of lava flows and domes following procedures described in Guillou *et al.*, (1998). Preliminary  $^{40}\text{Ar}/^{39}\text{Ar}$  analyses were also performed on K-feldspar (anorthoclase-sanidine) separated from a few pyroclastic units of Cycle I for a reconnaissance study using the procedures described in Nomade *et al.*, (2005).

Isotopic results are reported in table 1. An eroded trachy-andesitic dome (05-019b) predating Cycle I gave an age of  $2.77 \pm 0.06$  Ma, indicating that early trachy-andesitic dome-like activity dates back as far as the Mid-Pliocene (Piacenzian) in the Gölcük area. Such activity is notably younger than the Lower Pliocene leucitite lavas from Bucak, including also a few dykes and protrusion from the Isparta area, that were previously K-Ar dated between  $4.0 \pm 0.2$  Ma and  $4.7 \pm 0.2$  Ma by Lefèvre *et al.*, (1983). Two tephriphonolitic lavas from Cycle-II collected at the margin of the Gölcük maar crater give an age of  $115 \pm 3$  ka (sample 005-08) and  $62 \pm 2$  ka (sample 005-11) respectively. These data indicate that the recent Gölcük volcano activity is considerably younger than the early (Pliocene) activity recognized regionally and probably totally disconnected from it. The two late trachytic domes of Cycle-III extruded inside the maar crater give an age of  $52 \pm 2$  ka (sample 005-12) and  $24 \pm 2$  ka (sample 005-14), respectively, placing the first age constraints on the very recent activity of the Gölcük volcano.

Sample ID	Experiment #	Weight molten (g)	K* (wt.%)	$^{40}\text{Ar}^*$ (%)	$^{40}\text{Ar}^*$ ( $10^{-13}$ mol/g)	$^{40}\text{Ar}^*$ weighted mean ( $\pm 1\sigma$ )	Age $\pm 2\sigma$ ka
005-14	7208	0.90213	$4.674 \pm 0.047$	1.327	$1.753 \pm 0.123$		
005-14	7272	1.47871	"....."	1.740	$1.990 \pm 0.064$	$1.939 \pm 0.057$	$24 \pm 2$
005-12	7197	0.96924	$4.724 \pm 0.047$	6.503	$4.133 \pm 0.125$		
005-12	7212	1.36758	"....."	10.143	$4.283 \pm 0.065$	$4.251 \pm 0.058$	$52 \pm 2$
005-11	7160	1.02303	$5.230 \pm 0.052$	1.287	$5.805 \pm 0.118$		
005-11	7192	1.03662	"....."	1.061	$5.403 \pm 0.117$	$5.603 \pm 0.083$	$62 \pm 2$
005-08	7159	0.99451	$5.819 \pm 0.058$	11.722	$11.658 \pm 0.013$		
005-08	7175	1.06733	"....."	10.411	$11.553 \pm 0.013$	$11.605 \pm 0.009$	$115 \pm 3$

Sample ID	Experiment #	Weight molten (g)	K* (wt.%)	$^{40}\text{Ar}^*$ (%)	$^{40}\text{Ar}^*$ ( $10^{-11}$ mol/g)	$^{40}\text{Ar}^*$ weighted mean ( $\pm 1\sigma$ )	Age $\pm 2\sigma$ Ma
005-19b	7183	1.13575	$4.831 \pm 0.048$	23.322	$2.337 \pm 0.012$		
005-19b	7207	0.50320	"....."	21.816	$2.313 \pm 0.012$	$2.325 \pm 0.008$	$2.77 \pm 0.06$

**Tab. 1: K-Ar ages of samples from the Gölcük volcano. Age calculations are based on the decay and abundance constants from Steiger & Jäger (1977).**

*Tab. 1 : Ages K/Ar sur les laves du volcan Gölcük. Le calcul de l'âge est réalisé en utilisant les constantes de Steiger & Jäger (1977).*



The preliminary  $^{40}\text{Ar}/^{39}\text{Ar}$  data on the first (basal) and fifth (near-top) pyroclastic units of Cycle I outcropping in the Eastern valley revealed complex results with mixed ages on single grains that probably reflect xenocrystic contamination during eruption. Multimodal  $^{40}\text{Ar}/^{39}\text{Ar}$  age populations (tab. 2, fig. 6) were obtained in all cases with apparent total fusion ages ranging between 73-190 Ma and 173-660 Ma (samples 05-034 and 05-032, respectively). This precluded clearcut age assignment to these units but clearly indicate an age distribution consistent with the timespan bracketed between 115-24 ka by the K-Ar data from pre-Cycle I and late-stage Cycle-III eruptive products. Correspondingly, younger ages spreading around 68-77 ka and 56-50 ka were obtained on a younger Cycle-III tuff-ring fallout (sample 005-034) and a pumice fall (sample 005-030) found beneath the soil of the southern suburb of Isparta. These data again consist of multimodal age distributions with mixed ages indicating a maximum age for the respective deposits around 50 ka and 77 ka, respectively. These maximum ages are broadly consistent with the K-Ar ages of the late intracaldera domes (50-25 ka). Further laser probe  $^{40}\text{Ar}/^{39}\text{Ar}$  work is underway to clarify the exact (i.e., unbiased and xenocrystic-free) age relationships between these and other pyroclastics units of Cycles I and III.

The  $^{14}\text{C}$  dating method was applied on one of the few charcoals found during this study at the base of a pyroclastic flow in the upper Burdur lacustrine sequence. The  $^{14}\text{C}$  concentration is measured by accelerator mass spectrometry ARTEMIS Facility UMS LMC 14, Saclay, France, in the framework of INSU Service using Fe graphite targets prepared at UMR IDES, Orsay. The sample yielded an uncalibrated age of  $38.6 \pm 1.3$  ka BP. Such a young age would indicate that the pyroclastic flow capping the lacustrine deposits of the Burdur basin belongs to the youngest Cycle III of Gölcük volcano. This age awaits confirmation, however, via cross-checking against the  $^{40}\text{Ar}/^{39}\text{Ar}$  age of the enclosing pyroclastic flow (work underway). Such a confirmation is needed before any genetic link can be firmly established between this unit and the last phreato-plinian event of Cycle-III marked by the trachytic domes protruding inside the Gölcük maar crater.

Sample ID	Age of tephra Relative probability ka	MSWD	bracket Age of xenocrysts
005-36	$206,1 \pm 9,8\text{ka}$	0.39	-
005-32	$173,0 \pm 7,4\text{ka}$	0.19	350-660 ka
005-34	$72,7 \pm 4,7\text{ka}$	1.5	150-190 ka
005-30	$53,5 \pm 2,7\text{ka}$	0.73	70-80 ka

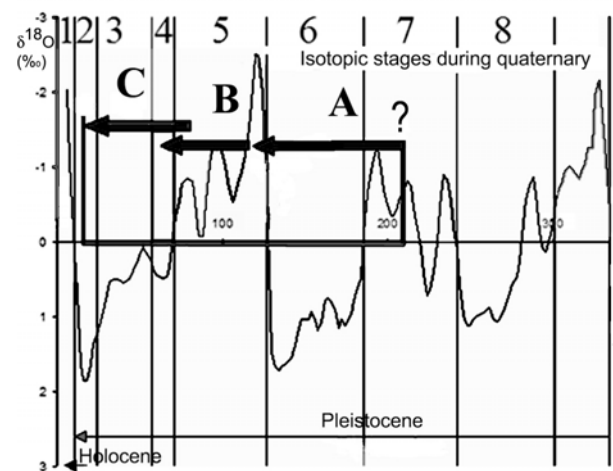
**Tab. 2: Preliminary  $^{40}\text{Ar}/^{39}\text{Ar}$  data on Cycle I and III tephra. The main relative probability age is only indicative and needs further investigation.**

Tab. 2 : Données  $^{40}\text{Ar}/^{39}\text{Ar}$  préliminaires sur les cycles de téphras I et III. L'âge donné par la probabilité relative est indicatif uniquement et demande d'autres études.

## 6 - SUMMARY AND CONCLUSIONS: GÖLCÜK VOLCANO ACTIVITY DURING THE LAST 200 KA

Based on newly acquired K-Ar and  $^{14}\text{C}$  data and detailed field mapping, the recent activity of Gölcük volcano appears to be quite young, taking place from the 7<sup>th</sup> to 2<sup>nd</sup> isotopic stages (Bassino *et al.*, 1994) during Pleistocene (fig. 6). Such a young activity is unrelated to the much older dyke and dome-forming Pliocene volcanic activity previously dated in the region by Lefèvre *et al.* (1983), a fact also testified by the much better preservation of the volcanic structure and eruptive sequence recognized all around the Gölcük edifice.

The volcanic activity started with major caldera-forming episode (Eruptive Cycle I) responsible for the outpouring of a thick (> 200m) ignimbritic eruptive sequence comprising at least six ignimbrite flows extending regionally as far as 10-15km away from a central (or diffuse) vent probably located close the centre of the modern edifice (Gölcük lake). The great majority of extra-caldera deposits has been substantially eroded since then, and is preserved mainly in subsiding areas like the Gölcük caldera, the Isparta and Burdur grabens. Although the geochronologic data for this cycle are only preliminar, the age of Cycle-I is constrained to be younger than older dome-forming protrusions dated by K-Ar at  $2.77 \pm 0.06$  Ma, and more probably around 200 ka (fig. 6) based on preliminary  $^{40}\text{Ar}/^{39}\text{Ar}$  data that need to be confirmed by further work (in progress). This episode probably lasted about 50 ka, the timespan revealed by the available  $^{40}\text{Ar}/^{39}\text{Ar}$  age distribution, although the precise duration of this stage need to be confirmed by further  $^{40}\text{Ar}/^{39}\text{Ar}$  analyses. A second volcanic episode (Eruptive Cycle II), consisting of intra-caldera lava dykes and flow-domes of tephri-phonolite composition occurred between 115 to 62 ka based on new unspiked K-Ar data. Magmas



**Fig. 6: The main volcanic events of the Gölcük volcano during Pleistocene and referenced to the successive marine isotopic stages during quaternary (Bassinot *et al.*, 94).**

Fig. 6 : Principaux événements volcaniques pendant le Pléistocène reportés sur la succession des stades isotopiques du quaternaire (Bassinot *et al.*, 94).

erupted at this stage are slightly less evolved compared to the trachytic composition of Cycle-I Plinian products. They could represent resident magmas tapped after the most evolved magmas of Cycle I drained from the top of a stratified magma chamber, without necessarily implying a significant break in time between both cycles. A third and last volcanic episode (Eruptive Cycle III) ensued with the building of a tuff-ring from 72 to 24 ka as a result of multiple maar-type eruptions. The phreatoplinian eruptions of this last cycle almost entirely destroyed the previous lava flow-domes, which only subsist at the rim of the crater. This phreatoplinian crisis ended with a trachytic dome protruding the caldera floor. As a whole, the complete Cycle-I through Cycle-III sequence lasted for about 200 ka with periods of quiescence, as illustrated by erosion, soil development, and several discordances between the successive eruptions. The last two dome extrusions closing Cycle III are separated by 30 ka, each dome probably ending a short sub-cycle. At last, our preliminary results show that Gölcük is presently enjoying a repose period uninterrupted since at least 22 ka.

## 7 - CONCLUDING REMARKS

The entire volcanic history of Gölcük volcano appears to be quite young (Pleistocene) with recurrent eruptive cycles of major explosive events episodically marked by thick, far-travelled ignimbrite units. The periodicity of the eruptive cycles appears to be long with repose periods on the order of several tens of thousands of years. Major pyroclastic events associated with the lacustrine deposits of the nearby Burdur graben show that the volcanism activity and the graben formation are probably coupled. The presence of pumice or ash fall deposits as far as 30km around the volcano show that the volcanic activity of Gölcük regionally impacted the area with unexpectedly violent, major caldera-forming eruptions. The high explosivity and relatively far-travelled ignimbrite flows produced during Cycle I (and possibly Cycle III) must have been associated with volcanic ash cloud whose manifestation in the sedimentary record must be sought for inland (in nearby extensional basins like Burdur and Egirdir), and possibly as far as within the southeastern Mediterranean realm in marine sediments younger than 200 ka. Currently, the volcanic system is at rest since around 22 ka. However, given the revealed cyclicality of the eruptive history, explosive events cannot be excluded in the near future, with major regional consequences with ash/pumice falls, and especially for the nearby urban area including ash/pumice falls, and also highly destructive ash flows, and/or localized landslides, mudflows or lahars. Channelized ash flow transport – even from minor eruptions – through the valleys opened on the northern flank of the volcano is potentially a major cause of highly destructive events for the populated city of Isparta.

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