FAIRY CHIMNEY DEVELOPMENT
IN CAPPADOCIAN IGNIMBRITES
(CENTRAL ANATOLIA, TURKEY)

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**FAIRY CHIMNEY DEVELOPMENT
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ABSTRACT

FAIRY CHIMNEY DEVELOPMENT
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The purpose of this study is to evaluate systematic fairy chimney development within Cappadocian ignimbrites. The first step in the sudy is to identify fairy chimney producing ignimbrites. Accordingly the fairy chimneys are formed within Kavak ignimbrite, at Kavak-Zelve transition, and within Zelve and Cemilköy ignimbrites. Field measurements are taken from the fairy chimneys to quantify the shape and the size. Slope of the selected areas are identified to investigate the most suitable topography.

Analysis have shown that fairy chimneys have basal diameters ranging from 9.7 to 13.7 m, with heights in the range from 8.41 to 21.73 m. The slopes of fairy chimneys are 60 to 70 degrees with a slight asymmetry towards the upslope. The chimneys are sligthy rounded due to the erosion in the slope direction. Distances between the fairy chimneys change from a minimum of 5.45 m for Zelve and 42.72 m for Kavak chimneys.

Fairy chimneys are developed in two stages. The first stage is the generation of topography suitable for the formation of fairy chimneys. Three main factors in this stage are degree of welding, thickness of ignimbrite and topographic slope. In the second stage, several local features contribute for the final shaping of the chimneys.

Keywords: fairy chimney, ignimbrite, Cappadocia

ÖZ

KAPADOKYA İGNİMBRİTLERİNDE PERİBACALARININ GELİŞİMİ (ORTA ANADOLU, TÜRKİYE)

Sayın, M. Naci
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Bu çalışmanın amacı Kapadokya ignimbritlerinde sistematik peribacası gelişimini değerlendirmektir. Çalışmanın ilk adımı peribacası üreten ignimbritleri tanımlamaktır. Peribacaları Kavak ignimbriti içarisinde, Kavak-Zelve geçişinde, Zelve ve Cemilköy ignimbritleri içerisinde oluşmuştur. Peribacalarının şeklini ve boyutlarını tanımlamak için arazi ölçümleri alınmıştır. En uygun olan topoğrafyayı belirlemek amacıyla seçilmiş alanlarda eğim hesaplanmıştır.

Analizler peribacalarının çaplarının 9.7 m den 13.7 m ye ve yüksekliklerinin 8.41m den 21.73 m ye değiştiğini göstermiştir. Peribacalarının eğimleri 60 ıle 70 derece arasında değişmektedir ve eğim-yukarı yönde biraz asimetriktir. Peribacaları eğim yönünde erozyondan dolayı biraz yuvarlaklaşmıştır. Peribacaları arasındaki uzaklıklar Zelve' de minimum 5.45 m den Kavak'ta 42.72 m ye değişmektedir.

Peribacaları iki safhada gelişmiştir. İlk safha peribacalarının oluşması için uygun topografyanın üretilmesidir. Bu safhadanın üç önemli faktörü kaynaşma derecesi, ignimbritlerin kalınlığı ve topoğrafik eğimdir. İkinci safhada pekçok lokal özellik peribacasının şekillenmesinde katkıda bulunur.

Anahtar kelimeler: peribacası, ignimbrit, Kapadokya

To My Father and My Family

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I am greatly indepted to Vedat Toprak for his patience, guidance and helpful suggestions during preparation of this thesis.

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INTRODUCTION

1.1. Purpose and Scope

Cappadocian Volcanic Province (CVP) is characterized by several ignimbritic eruptions that extend large areas with different properties such as thickness and welding. One of the most distinguished features of these ignimbrites is the development of fairy chimneys which are erosional landforms of ignimbrites developed in certain localities within the CVP. Although there are 8 extensive ignimbrites within CVP, the fairy chimneys are systematically formed only within the three of these ignimbrites.

Fairy chimneys formed at different ignimbrites have different shape and size. There is no, however, enough information in the literature attempting to quantify the differences between the fairy chimneys formed in different ignimbrites. Furthermore, there is no enough information on the factors that control the development of the fairy chimneys.

The main purpose of this study, therefore, was to focus on the development of the fairy chimneys in order to answer following two questions:

1) What are typical forms of fairy chimneys in different ignimbrites?
2) What factors play a role in their formations?

To answer the first question, necessary field data were measured both from the fairy chimneys and from the area they develop. For the second question, available information on various aspects of the fairy chimneys such as geochemical characteristics and engineering properties were compiled.

1.2. Study area

Study area is located east of Nevşehir (Figure 1.1) and includes within 1/25.000 scale topographic sheets of K33-c1, c2, c3, c4 and L33-b2. The area includes most of the fairy chimney developed regions of Cappadocia around Ürgüp visited by great number of tourists. Therefore, almost all parts of the area are accessible by paved roads.

Study area is drained mainly by the Damsa river and its tributaries which join the Kızılırmak river of south of Avanos. Most of the ignimbrites are exposed in the valleys carved by the tributaries of Kızılırmak river. Average altitude of the area is 1100 m.

Continental climate is dominant in the region. The summer is hot and dry and the winter is cold and rainy.

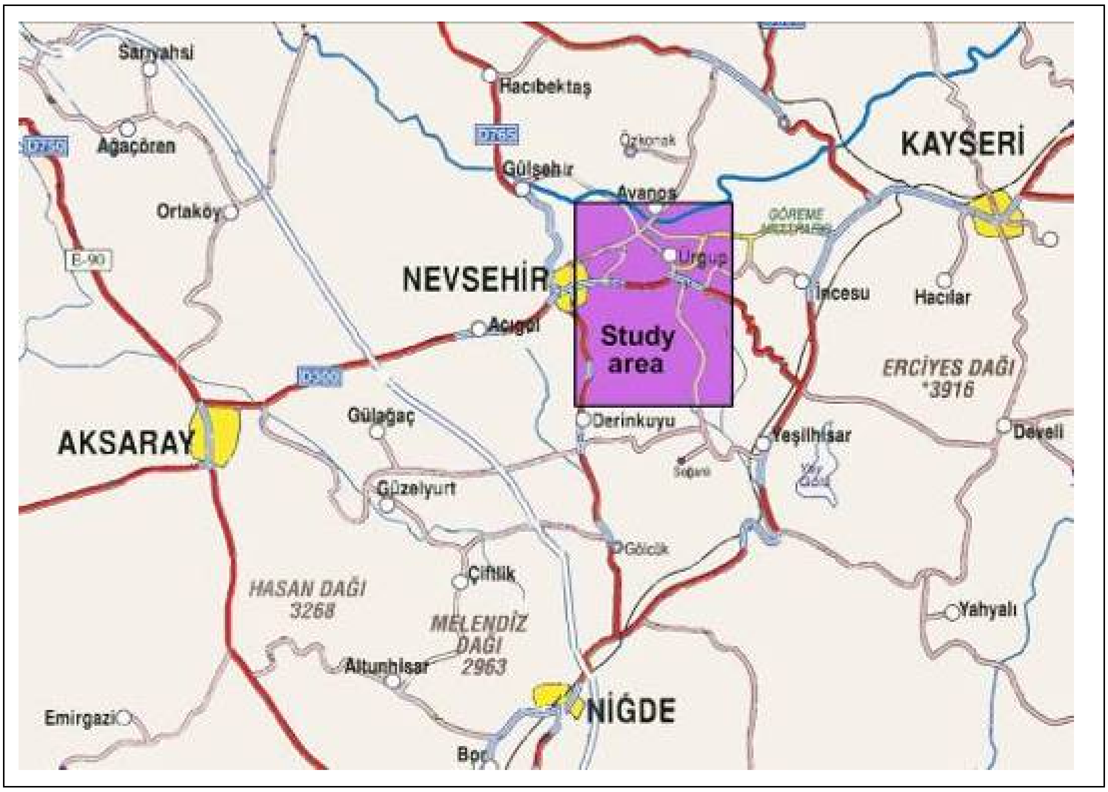


Figure 1.1. Location map of the study area.

1.3. Previous works

CVP is one of the areas in Turkey where numerous geological studies were carried out in various aspects. A geological syntesis of the area, made in the next section, is based on the information given in the literature. Here, available literature is tabulated to avaoid lengthy descriptions, that are not linked directly to the subject of the study (Table 1.1).

The literature on the fairy chimneys, on the other hand, is explained separately in the next chapter.

Table 1.1. Previous works dealing with various subjects around the study area.

	Main Interest	**Interest Area**	**Study**
Regional Geology - Tectonics	Stratigraphy	Tuzgölü-Haymana	Görür, 1981
	Geological evolution	Tuzgölü basin	Görür et al., 1984
	Tectonics	Ecemiş fault zone	Yetiş and Demirkol, 1984
	Stratigraphy	Tuzgölü basin	Atabey et al., 1987
	Volcanism	Central Anatolia	Pasquaré et al., 1988
	Tectonics	CVP	Göncüoğlu and Toprak, 1992
	Neotectonics	CVP	Toprak and Göncüoğlu, 1993a
	Neotectonics	Keçib.-Melendiz fault	Toprak and Göncüoğlu, 1993b
	Neotectonics	Tuzgölü fault zone	Leventoğlu, 1994
	Tectonics	CVP	Lyberis et al., 1994
	Stratigraphy	Ecemiş fault zone	Beyhan, 1994
	Neotectonics	C. Kızılırmak fault	Toprak, 1994
	Slip analysis	Derinkuyu fault	Toprak and Kaymakçı, 1995
	Neotectonics	Central Anatolia	Dirik and Göncüoğlu, 1996
	Plio-Quaternary basins	CVP	Toprak, 1996
	Vent distribution	CVP	Toprak, 1998
	Tectonics	CVP	Dhont et al., 1998
	Neotectonics	Ecemiş fault zone	Koçyiğit and Beyhan, 1998
	Neotectonics	Ecemiş fault zone	Koçyiğit and Beyhan, 1999
	Stratigraphy	Central Anatolia	Göncüoğlu et al., 1992
	Stratigraphy	Kırşehir-Nevşehir	Göncüoğlu et al., 1993
	Tectonism	Tuzgölü basin	Çemen et al., 1999
	Neotectonics	Ecemiş fault zone	Westaway, 1999
	Neotectonics	Ecemiş fault zone	Jaffey and Robertson, 2001
	Neotectonics	Ecemiş fault zone	Dirik, 2001
	Basin development	CVP	Ocakoğlu, 2004
	Volcanism	Central -eastern Anatolia	Şen et al., 2004

Table 1.1 (continued)

	Main Interest	Interest Area	Study
General volcanism	Volcanism	Aksaray-Konya	Lahn, 1941
	Volcanism	Central Anatolia	Tromp, 1942
	Volcanism	Central Anatolia	Lahn, 1945
	Volcanism	Central Anatolia	Lahn, 1949
	Volcanism	Nevşehir-Kayseri	Lebküchner, 1957
	Volcanism	Central Anatolia	Westervald, 1957
	Volcanism	Nevşehir-Kayseri	Pisoni, 1961
	Volcanism	Kayseri	Beekman, 1963
	Volcanism	Aksaray-Niğde	Beekman, 1966
	Volcanism	Acıgöl	Sassano, 1964
	Volcanism	Nevşehir-Kayseri	Pasquaré, 1968
	Volcanism	Karapınar	Keller, 1974
	Caldera	Nevşehir	Öngür, 1978
	Volcanism	Central Anatolia	Amini et al., 1986
	Volcanism	Central Anatolia	Ercan, 1986
	Volcanism	Central Anatolia	Ercan et al., 1987a
	Volcanism	Anatolia-NW Iran	Innocenti et al., 1982
	Gas emission	Central Anatolia	Ercan et al., 1987b
Volcanism and Geochemistry	Geochemistry	Erciyes volcano	Baş et al., 1986
	Petrography	Acıgöl-Göllüdağ	Batum, 1978a
	Petrology	Acıgöl-Göllüdağ	Batum, 1978b
	Petrology	Hasandağ-Karacadağ	Tokel et al., 1988
	Volcanism	Hasandağ-Karacadağ	Ercan et al., 1990a
	Obsidian	Central Anatolia	Ercan et al., 1990b
	Geochemistry	Erciyes volcano	Ayrancı, 1991
	Geochemistry	CVP	Temel, 1992
	Volcanism	Central Anatolia	Olanca et al., 1992
	Geochronology	Hasandağ-Karacadağ	Ercan et al., 1992
	Alteration	Göreme	Ünlü, 1993
	Geochronology	CVP	Ercan et al., 1994
	Geochemistry	Erciyes volcano	Kürkçüoğlu, 1994
	Petrology	CVP	Aydar et al., 1994
	Geochemistry	CVP	Aydar et al., 1995
	Volcanism	Acıgöl	Druitt et al., 1995
	Maar	Acıgöl	Kazancı et al., 1995
	Volcanism	Hasandağ	Deniel et al., 1998
	Geochemistry	Erciyes volcano	Kürkçüoğlu et al., 1998
	Volcanism	Narköy maar	Gevrek and Kazancı, 2000
	Zeolite	Central Anatolia	Birsoy, 2002
	Stratigraphy	CVP	Viereck-Goette et al., 2006
	Clay mineralogy	CVP	Gürel and Kadir, 2006
Ignimbrite	Stratigraphy	CVP	Le Pennec et al., 1991
	Stratigraphy	Nevşehir plateau	Le Pennec et al., 1994
	All ignimbrites	CVP	Schumacher et al., 1991
	Kızılkaya ignimbrite	CVP	Schumacher and Mues-Sch., 1996
	Akdağ-Zelve	CVP	Schumacher and Mues-Sch., 1997
	Emplacement	CVP	Schumacher Keller, 1990
	Geochemistry	CVP	Temel et al., 1998
	Incesu ignimbrite	CVP	Mues-Schumacher et al., 2004
	Geochronology	CVP	Kuzucuoğlu et al., 1998
	Ignimbrites	CVP	Le Pennec et al., 2005

Table 1.1 (continued)

	Main Interest	Interest Area	Study
Geochronology-Palinology	Mammalian	Kayseri	İzbırak and Yalçınlar, 1951
	Mammalians	Kayseri	Şenyürek, 1953
	Ignimbrites	CVP	Innocenti et al., 1975
	Ignimbrites	Central Anatolia	Besang et al., 1977
	Petrology	Acıgöl	Ercan et al., 1991
	Ignimbrites	Central Anatolia	Bigazzi et al., 1993
	Palinology	Kırşehir-Nevşehir	Akgün et al., 1995
	Ignimbrites	CVP	Mues-Sch.and Sch., 1996
Engineering Geology and Conservation	Environment	Ortahisar	Doyuran, 1976
	Underground openings	CVP	Erguvanlı and Yüzer, 1977
	Conservation	Göreme	Bowen, 1982
	Conservation	Göreme	Lizzi, 1982
	Construction	Nevşehir-Ürgüp	Erdoğan, 1986
	Hydrogeology	Göreme	Yılmazer, 1986
	Consolidation	Göreme	Malliet and Rossi, 1986
	Conservation	Göreme	De Witte, 1987
	Conservation	Göreme	De Witte, 1988
	Conservation	Göreme	Bowen, 1988
	Deterioration	Göreme	Caner et al., 1988
	Construction	Nevşehir	Erdoğan, 1989
	Deterioration	Göreme	Erdoğan, 1991
	Deterioration	Göreme	Türkmenoğlu et al., 1991
	Color	Göreme	Ünlü, 1993
	Deterioration	Göreme	Yılmazer, 1993
	Restoration	Göreme	Roselli, 1994
	Deterioration	Ürgüp-Göreme	Topal, 1995
	Fairy Chimney	Ürgüp-Göreme	Topal and Doyuran, 1995
	Conservation	Ürgüp-Göreme	Topal and Doyuran, 1996
	Durability	Ürgüp-Göreme	Topal and Doyuran, 1997
	Deterioration	Ürgüp-Göreme	Topal and Doyuran, 1998
	Underground cities	CVP	Aydan and Ulusay, 2003
	Fairy chimneys	CVP	Baba et al., 2005
	Underground cities	Ürgüp	Ulusay et al., 2005
Geomorphology	Geomorphology	Nevşehir-Ürgüp	Sür, Ö., 1966
	Volcanism	Central Anatolia	Sür, Ö., 1972
	Caldera	Acıgöl	Yıldırım and Özgür, 1979
	Geomorphology	Avanos	Arık, 1981
	Geomorphology	Nevşehir	Emre and Güner, 1985
	Geomorphology	Ürgüp	Emre and Güner, 1988
	Geomorphology	Hasandağ-Keçiboyduran	Emre, 1991

Table 1.1 (continued)

	Main Interest	Interest Area	Study
Geophysics and Paleomagnetism	Caldera	Acıgöl	Yıldırım and Özgür, 1981
	Gravity	Acıgöl	Ekingen and Güven, 1978
	Geophys. Prospection	Nevşehir	Ekingen, 1982
	Resistivity	Acıgöl	Toksöz and Bilginer, 1980
	Caldera	CVP	Froger, et al., 1998
	Gravity-Magnetizm	Central Anatolia	Aydemir and Ateş, 2005
	Paleomagnetizm	Central Anatolia	Plazman et al., 1998
	Paleomagnetizm	Erciyes volcano	Tatar et al., 2000
	Magnetic properties	Central Anatolia	Piper et al., 2002
	Paleomagnetizm	CVP	Büyüksaraç et al., 2005
Medical Geol.	Zeolite	CVP	Ataman, 1978
	Zeolite	CVP	Ataman, 1980
	Zeolite	CVP	Temel and Gündoğdu, 1996
	Zeolite	CVP	Doğan, 2003
Others	Remote sensing	CVP	Arcasoy et al., 2000
	Lineament analysis	CVP	Arcasoy, 2001
	Remote sensing	Hasandağ-Melendiz	Yetkin, 2003
	Remote sensing	Hasandağ-Melendiz	Yetkin et al., 2004
	Lineament analysis	CVP	Arcasoy et al., 2004
	Geothermal	Acıgöl	Kazancı and Gevrek, 1996
	Paleosols	CVP	Lepetit et al., 2006
	Rock settlements	CVP	Sevindi, 2003
	Obsidian	Anatolia	Keller and Seifried, 1990
	CBS	CVP	Ayhan, 2004

Available literature is grouped into ten categories based on the purpose of the study. The first group comprises studies related to the regional geology and tectonics of the region. In this group, major sedimentary basins, fault zones or stratigraphic problems are the main purposes. These studies were carried out either within the volcanic field or within the regions surrounding the area. Among this list, the study made by Pasquare et al (1988) focuses on the major structural features of the CVP.

Studies carried out on the general volcanic properties of the CVP can be categorized into two groups. The first group, chronologically from Lahn (1941) to Keller (1974), are the initial studies on the volcanic products of the CVP based on field relations. Among these studies, the one that was carried out by Pasquare (1968) is the first extensive work in which several ignimbrites within the CVP was distinguished. Compilation of volcanic data at regional scale is main characteristic of some studies in this group.

Geochemical properties of volcanic products were the main concern in the area in the last 20 years. The studies listed in this group are about petrology, mineralogy, and geochemistry of volcanic rocks from different parts of the CVP. In these studies, it was claimed that the CVP volcanic rocks are of calc-alkaline type and the formation of the CVP was attributed to the convergence in the Eastern Mediterranean area.

The next group studies are about stratigraphy, source determination and geochemical characteristics of ignimbrites. Some studies dealt with individual ignimbrites while some others attempted to solve stratigraphic problems and to determine age of ignimbrites.

Age of both volcanic products and sedimentary rocks intercalated with these volcanics is the topic of the next group studies. Three of these studies (İzbırak and Yalçınlar, 1951; Şenyürek, 1953; Akgün et al, 1995) assigned ages to sedimentary intercalations using mammalian fossils and palinologic determinations.

The other group studies are about engineerng aspects of volcanic rocks in the area. Most of the studies were carried out for the conservation of cultural heritage in the vicinity of Ürgüp-Göreme area. Among this group at studies, engineering properties of the ignimbrites in which the fairy chimneys were developed constitute an important input data for this study. The properties dry unit weight, effective porosity and dry uniaxial compressive strength of the ignimbrites were studied in these works. These properties is dealt in the DISCUSSION chapter due to the fact they may have an effect on the formation of the fairy chimneys. Therefore, available published data on this property were compiled and listed in Table 1.2. This compilation includes only fairy chimney bearing ignimbrites (Kavak, Zelve and Cemilköy). The data are available only for Kavak and Zelve Ignimbrites. The data of Kavak Ignimbrite were published by Erguvanlı and Yüzer (1977), Erdoğan (1986), Topal (1995) and Aydan and Ulusay (2003). The data of Zelve Ignimbrite are published by Erdoğan (1986) and Aydan and Ulusay (3003).

Studies carried out on the geomorphological aspects of the area can be grouped into two topics: 1) general morphological features of volcanic rocks and 2) formation of fairy chimneys.

Table 1.2. Engineering properties of fairy chimney bearing ignimbrites

Tests	Erguvanlı and Yüzer (1977)	Erdoğan (1986)		Erguvanlı et al. (1989)	Topal (1995)	Aydan and Ulusay (2003)	
	Kavak	Kavak	Zelve	Kavak	Kavak	Kavak	Zelve
Dry unit weigth (kN/m3)	11,50	15,10	15,30	15,90	13,60	14.25	13.0
Effective Porosity (%)	28,00	28,76	31,11	28,76	38,29	32.8	35.2
Dry uniaxial compressive strength vertical (Mpa)	5,50	6,50	15,00	6,50	6,53	6,45	4,00

Other group of studies is geophysical studies which tend to locate buried calderas exist in the area (Yıldırım and Öngür, 1981; Ekingen and Güven, 1978; Ekingen, 1982; Toksöz and Bilginer, 1980) or paleomagnetism related studies that contribute on block rotations in the area (Plazman et al., 1998; Tatar et al., 2000; Piper et al., 2002; Büyüksaraç et al., 2005).

Effect of the volcanic rocks on human health (medical geology) is the topic for the other group studies. Zeolite is the main focus in all of these studies.

The last group studies are categorized as mixed type dealing with various topics such as remote sensing and/or GIS, geoarchaeology, geothermal and identification of the paleosols in the area.

1.4. Regional Setting

The study area is located within Cappadocian Volcanic Province (CVP) (Figure 1.2). The subject of the study is closely related to the evolution and volcanic products of the CVP. Therefore, in this section the CVP is briefly explained and the major rock units of the province are introduced.

CVP is volcanic field that extends as a belt in NEE-SWW direction for a length of more than 250 km and width of 40-60 km. It is bounded by Central Kızılırmak Fault zone (CKFZ) and Niğde Fault zone (NFZ) (Toprak, 1994) at the north and south, respectively. It is dominantly composed of calc-alkaline rocks whose formation is attributed to the convergence between Eurasian and Afro-Arabian plates (Beekman, 1966; Pasquare, 1968; Keller, 1974; Innocenti et al., 1975; Besang et al., 1977; Batum, 1978 a, b; Pasquare et al., 1998, Ercan et al., 1990, 1992, 1994; Aydar et al., 1994).

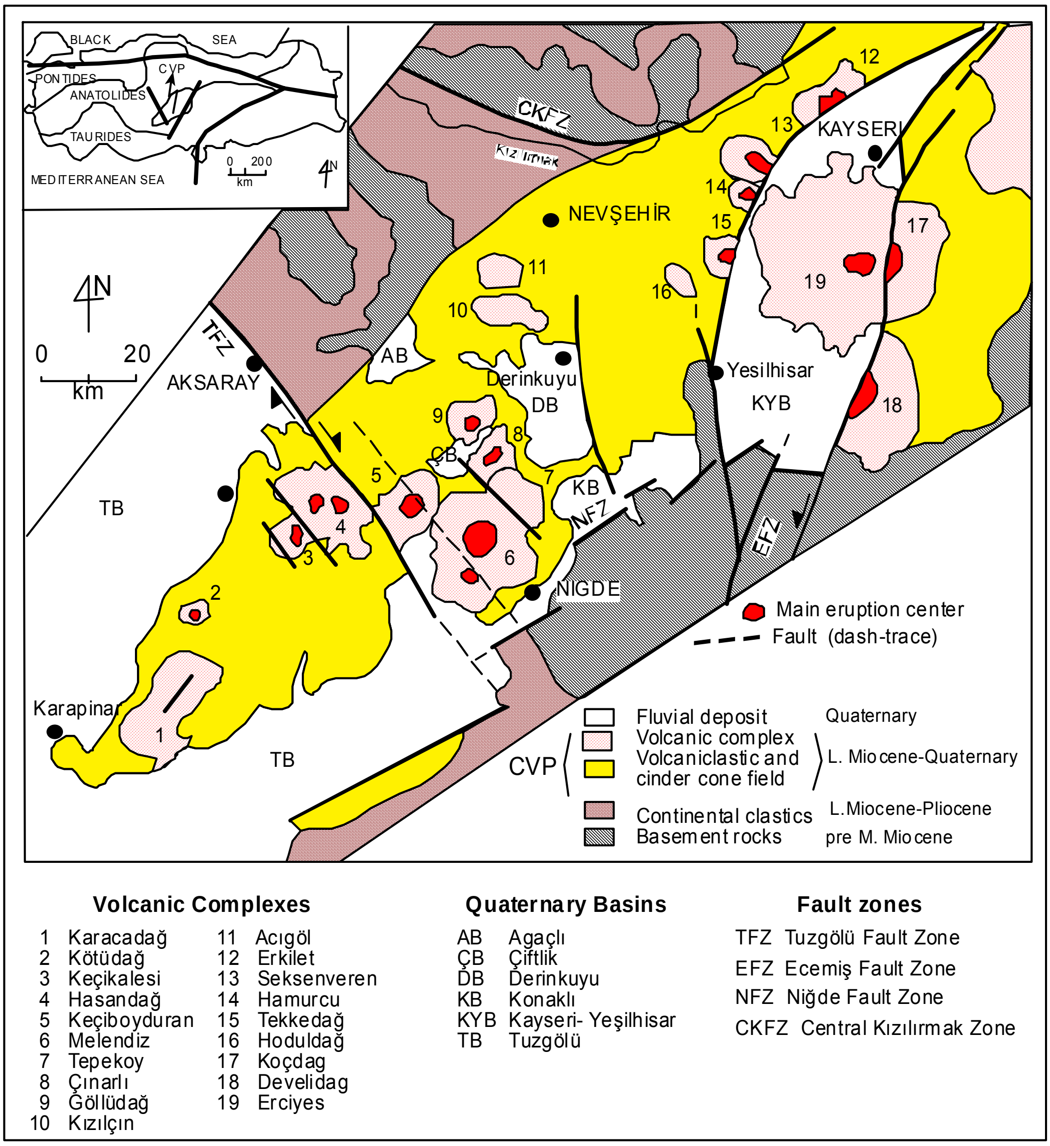


Figure 1.2. Geological map of Cappadocian Volcanic Province (CVP) (Toprak, 1998).

One of the most striking features of the CVP is the presence of eruption centers distributed over the volcanic field. Toprak (1988) identified 19 major eruption centers in the forms of strato-volcano or caldera (Figure 1.2). Each of these centers is characterized by multiple eruptions causing an alternation of lava flows and volcanoclastics. Erciyes and Hasandağ volcanoes are examples of these polygenetic erution centers formed during the Quaternary. Around these major centers, there are numerous monogenetic volcanoes formed by single eruptions. These volcanoes exist in the area mostly in the form of cinder cones although other forms such as maars and domes also exist. Arcasoy (2001) identified 549 of these volcanoes.

Rest of the CVP is covered by a volcano-sedimentary sequence deposited in the main depression of the CVP. Evolution of the CVP in relation to this main depression is illustrated in Figure 1.3 (Toprak and Göncüoğlu, 1993a). Two fault sytems, namely, Tuzgölü and Ecemiş, have been active in the area since pre-Miocene. These faults are the products of N-S compression and have right-lateral and left-lateral strike slip components, respectively. During Middle Miocene-Early Pliocene, two fault zones (CKFZ and NFZ) were activate forming a depression in between. This depression was filled with continental sediments and pyroclastics material erupted from the major centers.

The volcanosedimentary sequence of the CVP is best observed in the vicinity of Ürgüp and is named as Ürgüp formation by Pasquare (1968). The sequence has a thickness of about 430 m which is characterized by thick ignimbrites interbedded with fluvial to lacustrine sediments.

The sedimentary part of this sequence is called Bayramhacılı and Mustafapaşa by Pasquare (1968) and Çökek Member by Temel (1992). Most of the studies carried out in this sequence, however, were concentrated on the ignimbritic levels for various reasons such as geochemical, geochronological and source determination investigations (Le Pennec, 1991, 1994, 2005; Schumacher and Keller, 1990; Schumacher et al, 1991; Schumacher and Mues-Schumacher, 1996, 1997; Temel, 1998).

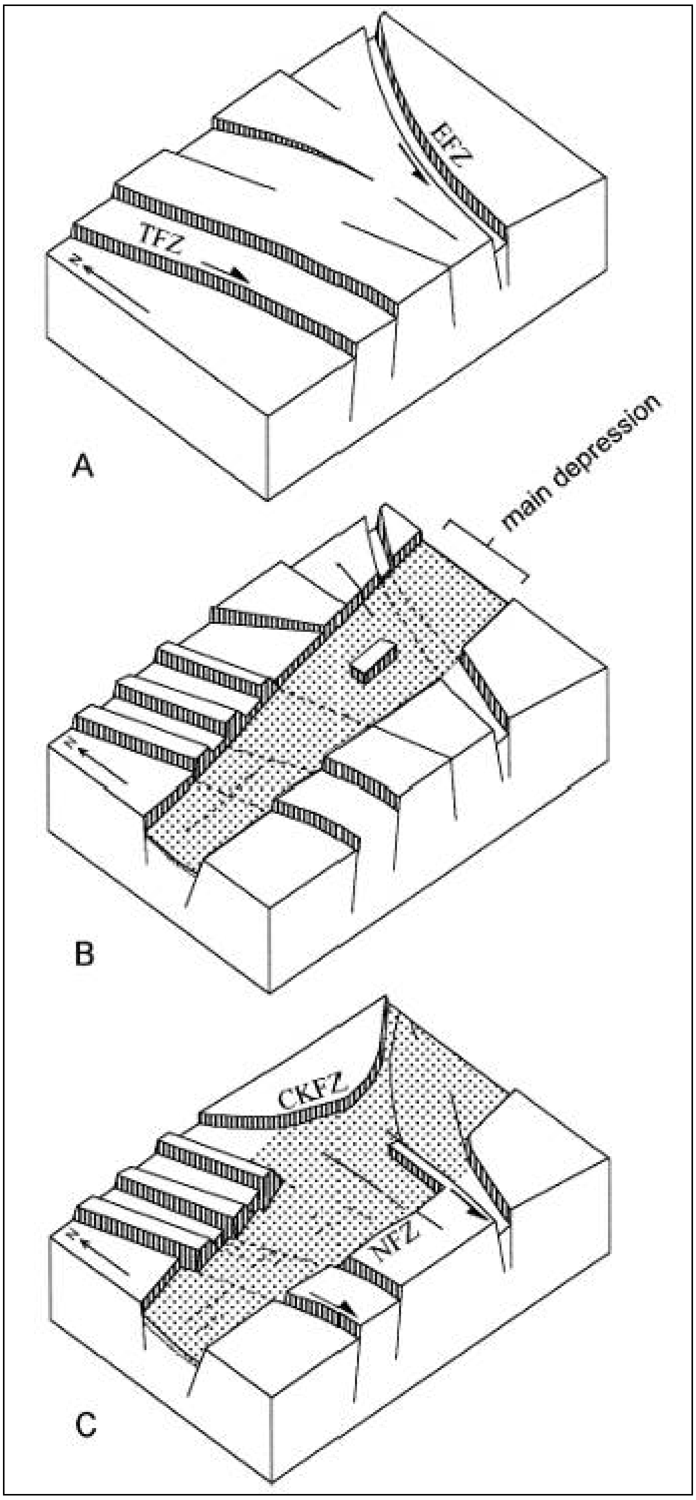


Figure 1.3. Block diagrams illustrating behavior of Tuzgölü and Ecemiş fault systems for Mio-Quaternary period and formation of the CVP main depression (from Toprak and Göncüoğlu, 1993a) TFZ: Tuzgolu fault zone, EFZ: Ecemis¸ fault zone, CKFZ: Central Kızılırmak fault zone, NFZ: Nigde fault zone.

A: Pre-Middle Miocene only Tuzgolu fault system activates, N–S compression;

B: Middle-Miocene–Early Pliocene both fault systems are active, all normal faults .

C: Late Pliocene—Recent only Tuzgolu fault system activates, N–S compression .

The fairy chimneys which are the main topic of this study were formed within the ignimbrites of this sequence. A correlation chart of these ignimbrites is given in Table 1.3 that shows different names used for the ignimbrites. In this study, the nomeclature used by Le Pennec et al. (2005) is used.

Generalized columnar section of the Ürgüp formation suggested by Le Pennec et al (2005) is given in Figure 1.4. There are eight widespread ignimbrites which are, from bottom to top, Kavak, Zelve, Sarımaden Tepe, Cemilköy, Tahar, Gördeles, Kızılkaya and Valibaba Tepe Ignimbrites.

Absolute age determinations of these ignimbrites (first column in the figure) suggest that they have been erupted in the interval from 9-14 Ma to 2.6-3.0 Ma. The mammalian fossil assemblage identified within the sedimentary section of the sequence (last column in the figure) is consistent with these ages.

Published literature on the geochemical characteristics of these ignimbrites suggests that the ignimbrites are rhyolitic in composition (Temel et al. 1992). All the ignimbrites plot in the high-K calc-alkaline field in relation to the collision of Arabian and Eurasian plates.

Table 1.3. Correlation chart of the names used for ignimbrites (Le Pennec et al., 2005)

Stratigraphic level	LITHOLOGY	Unit name in Pasquaré 1968	Name in Innocenti et al. 1975	Age Ma (+/- error)	Name in Besang et al. 1977	Age Ma (+/- error)	Age in Temel 1992	Name in Le Pennec et al. 1994	Age in Notsu et al. 1995	Name in Mues-Schumacher and Schumacher 1996	Age in Ma (+/- error)	Name in this study	most probable age range in Ma
13	LAVAS LAVAS	Erciyes Erciyes							2.5 +/- 0.3 2.6 +/- 0.1				2.2 - 2.8
12	IGNIMBRITE	Valibaba Tepe	Valibaba Tepe	2.7 +/- 0.1 2.8 +/- 0.1 3.0 +/- 0.1				Valibaba Tepe		Valibaba-Sofular Incesu	1.1 +/- 0.1 2.8 +/- 0.1	Valibaba Tepe	2.6 - 3.0
11	IGNIMBRITE	Incesu	Karahöyük Başköy	4.4 +/- 0.1 5.4 +/- 1.1	Kizilkaya	4.9 +/- 0.2 5.5 +/- 0.2		Kizilkaya		Kizilkaya	4.3 +/- 0.2 4.3 +/- 0.2 4.5 +/- 0.2	Kizilkaya	4.5 - 5.5
10	LAVAS	Topuz dag					7.0 +/- 0.2					Topuz dag	6.8 - 7.2
9	IGNIMBRITE	Sofular	Sofular	6.8 +/- 1.4				Sofular		Valibaba-Sofular	1.1 +/- 0.1	Gördeles	6.8 - 7.6
8	IGNIMBRITE	Gördeles	Gördeles	7.8 +/- 1.6				Gördeles		Gördeles	4.0 +/- 0.2		
7	IGNIMBRITE	Tahar	Tahar					Tahar		Tahar		Tahar	7.2 - 7.8
6	IGNIMBRITE	Cemilköy	Cemilköy					Cemilköy		Cemilköy	6.5 +/- 0.2 6.8 +/- 0.2	Cemilköy	7.6 - 8.4
5	LAVAS	Damsa					8.2 +/- 0.2					Damsa	8.0 - 8.4
4	IGNIMBRITE	Sarimaden Tepe	Sarimaden Tepe	8.0 +/- 1.6 8.6 +/- 1.7				Sarimaden		Sarimaden		Sarimaden Tepe	8.3 - 8.7
3	IGNIMBRITE	(not identified)	(not identified)					Zelve		Akdag-Zelve	7.5 +/- 0.2 7.7 +/- 0.2	Zelve	8.5 - 9.0
2	GROUP OF IGNIMBRITES	Kavak	Kavak	8.6 +/- 1.7			11.2 +/- 2.5	Kavak		Upper Göreme Lower Göreme	6.9 +/- 0.2 7.3 +/- 0.2 8.7 +/- 0.2 9.2 +/- 0.2	Kavak ignimbrites	9.0 - 14
1	IGNIMBRITE	Akköy		8.5 +/- 0.2									

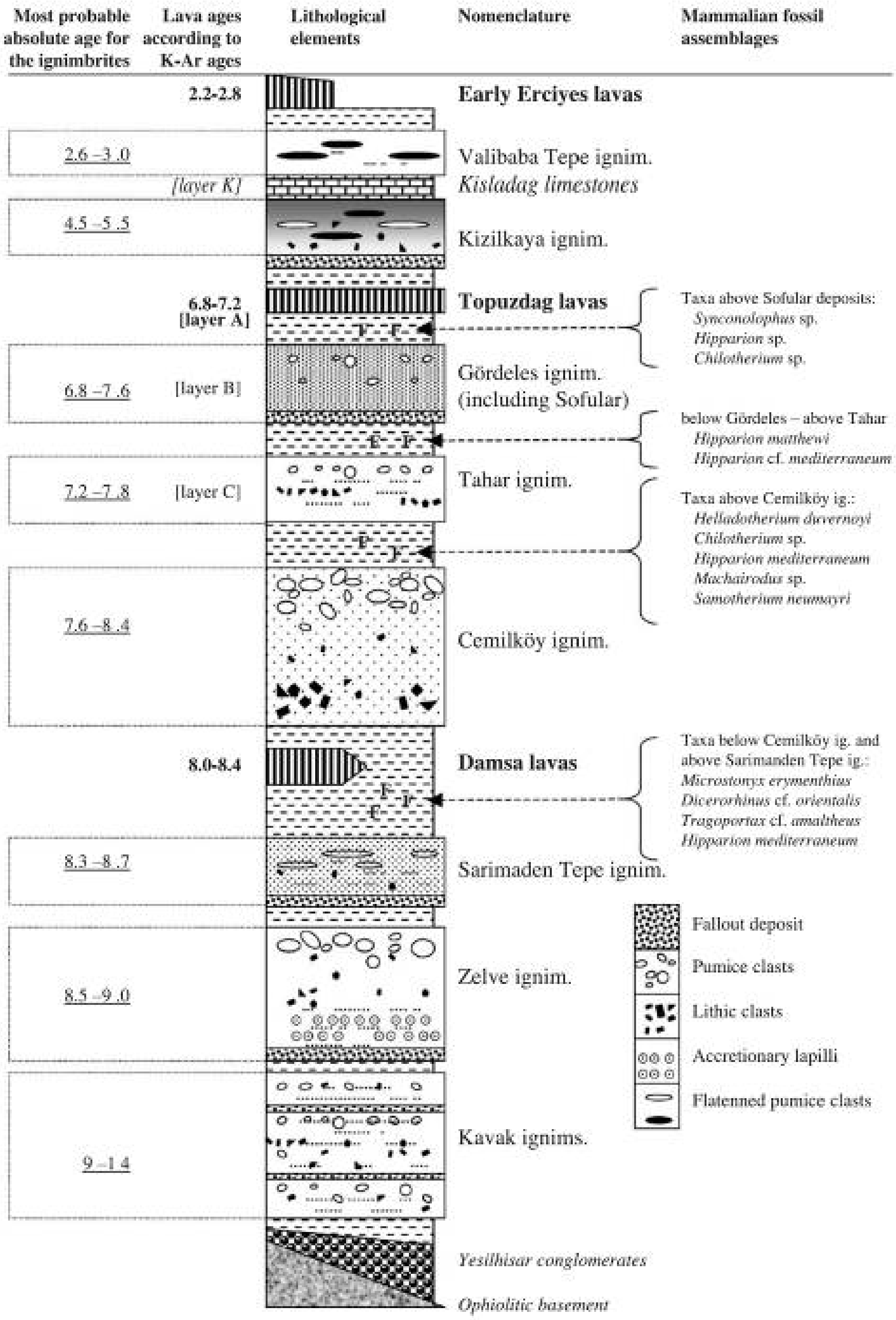


Figure 1.4. Generalized columnar section of the Ürgüp formation with a particular emphasis on the ignimbrites (Le Pennec et al., 2005).

CHAPTER 2

LITERATURE ON FAIRY CHIMNEYS AND IGNIMBRITES

Fairy chimneys of the Cappadocian Volcanic Province (CVP) have always been a wonder and attractive site for visitors. The earliest descriptions of the fairy chimneys were made by western travelers. Among these, Lucas (1712) and Texier (1882) are the famous ones. Lucas (1712) was shocked by the panorama of Avanos-Ürgüp area when he saw these erosional landforms. He depicted the fairy chimneys in the form of ideal cones at tops of which Virgin Mary was illustrated (Figure 2.1).

Tromp (1942) noted that the fairy chimneys (earth pyramids) were formed within a tuff series of Pleistocene age. According to him, there are two reasons for the origin of these pyramids; (1), the tuffs were covered by the recent terrace conglomerates including large igneous boulders. (2), the igneous boulders contain large amount of manganese minerals forming thick coatings over the tuffs. The boulders including coatings protected the underlying beds from erosion.

Chaput (1947) studied the formation of the fairy chimneys around Ürgup-Göreme area. He claimed that the cap rock of the fairy chimneys consists of basalt. He indicated that fairy chimneys were formed as a result of erosion.

Sür (1966 and 1972) carried out geomorphologic studies around Nevşehir-Ürgüp area. Morphologic development in the area produced present landscape occurred in a semi-arid climate mainly during Quaternary. The fairy chimneys were formed due to erosion in homogenous volcanic tuff. The cap rock of the fairy chimneys consists of basaltic and andesitic lava flows. The maximum height of the fairy chimneys was indicated to be around 25-30 m. According to him, thickness of the volcanic tuff, erodibility, steepness of the topography and climate are the main reasons for the formation of fairy chimneys.

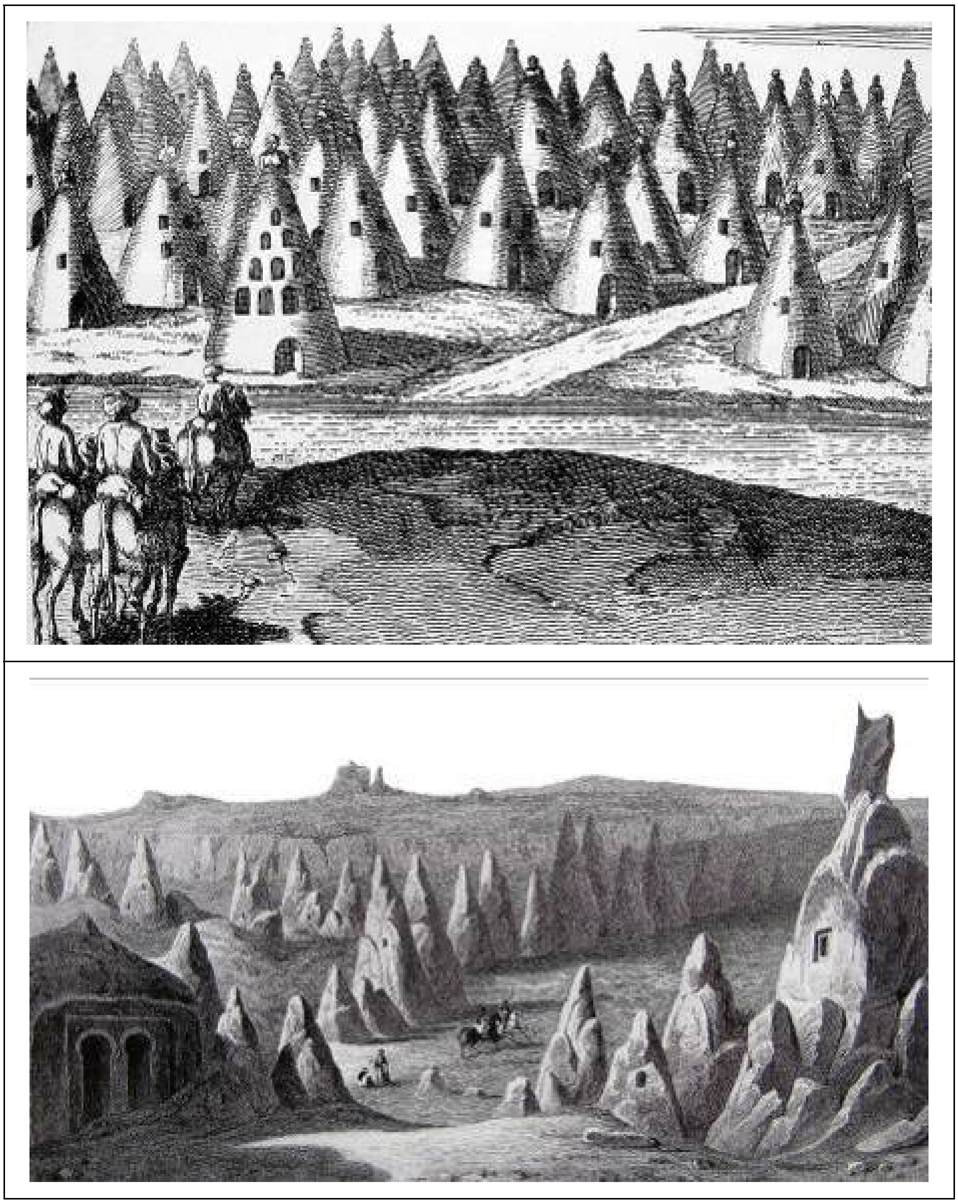


Figure 2.1. Earliest illustrations of fairy chimneys as depicted by Lucas, 1712 (above) and by Texier, 1882 (below).

Giovanni (1971) published a book that comprises several cultural and historical aspects of the Cappadocian region. This study includes a section that also deals with the development of the chimneys (Figure 2.2). According to him, new chimneys were formed at the slopes and the older ones were eroded towards the center of the valley. A detailed section of an ideal fairy chimney was illustrated with a particular reference to the relationship between the rock structure and erosion (Figure 2.3).

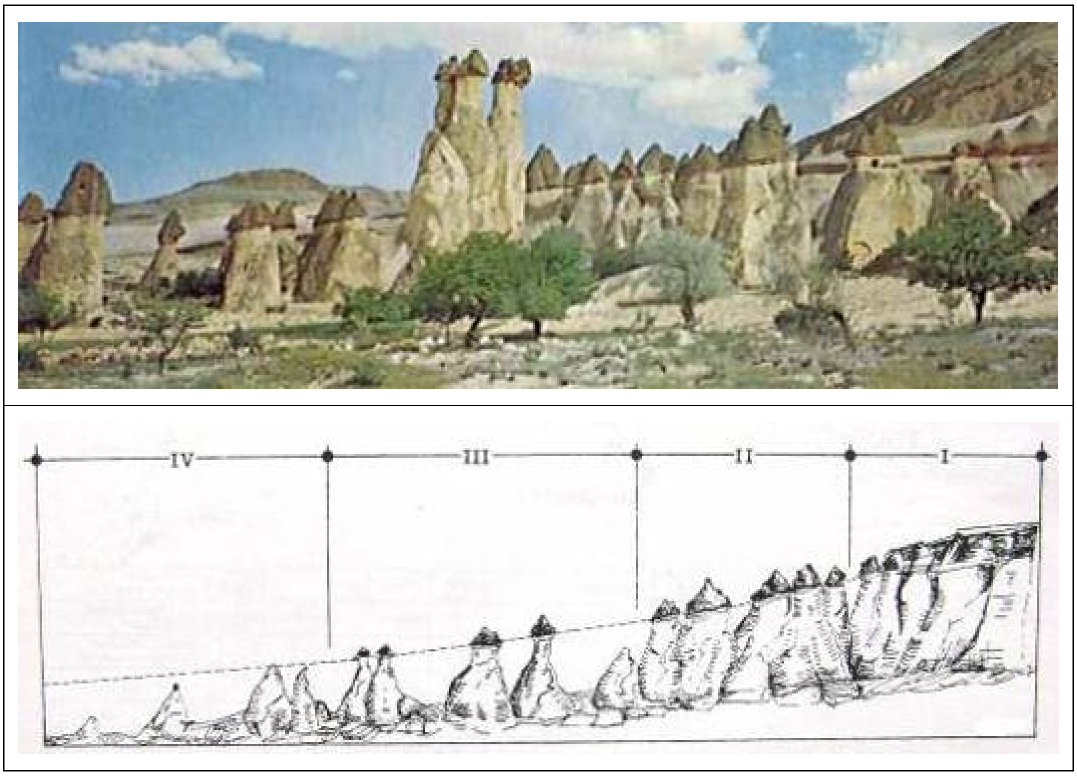
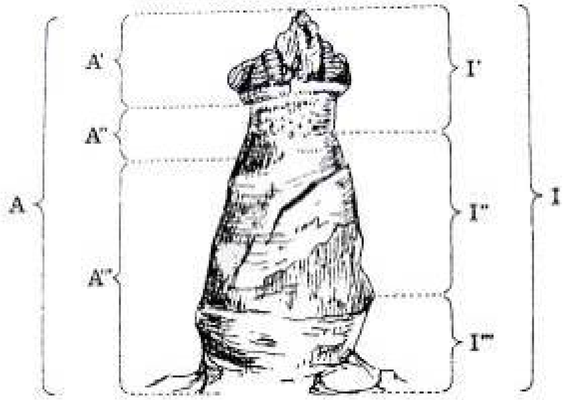


Figure 2.2. Morphological evolution of fairy chimneys suggested by Giovanni (1971). I: Vertical cracks, II: Group of cones, III: Isolated cones, IV: Levelling down.



A Rock Structure:

A’ Fine grained, homogeneous tuffs of highly compact structure
A’’ Medium-grained pumice-like tuffs of loose structure
A’’’ Medium-grained tuffs of loose structure,
with oblique cracks cutting across stratification

I Disintegration

I’ Aeolian and thermoclastic erosion
I’’ Erosion due to pre-existing cracks, precipitations and frost action
I’’’ Erosion due to rain-wash, with wearing away of base

Figure 2.3. Relationship between the rock structure and erosion (Giovanni , 1971)

Pasquaré (1968) studied the geology of the Cenozoic volcanic area of Central Anatolia. He was the investigator first named the Neogene continental sediments and ignimbritic deposits as Ürgüp formation. He divided this formation into 18 members. He indicated that fairy chimneys in the region were dominantly formed within the Kavak and Tahar Members of the Ürgüp formation.

Emre and Güner (1985 and 1988) studied the geomorphology of Ürgüp-Avanos-Üçhisar region. They indicated that the main geologic events were volcanic eruptions during Upper Miocene to Pliocene and fluvial developments during Upper Pliocene to Present. Kızılırmak river played important role for the morphologic development of the region. They indicated that both geological and geomorphological factors played roles on the formation of the fairy chimneys. The chimneys were developed on the slopes of plateau and in the valleys of the Pleistocene glacis consisting of tuff, lahar and ignimbritic units (Figure 2.4).

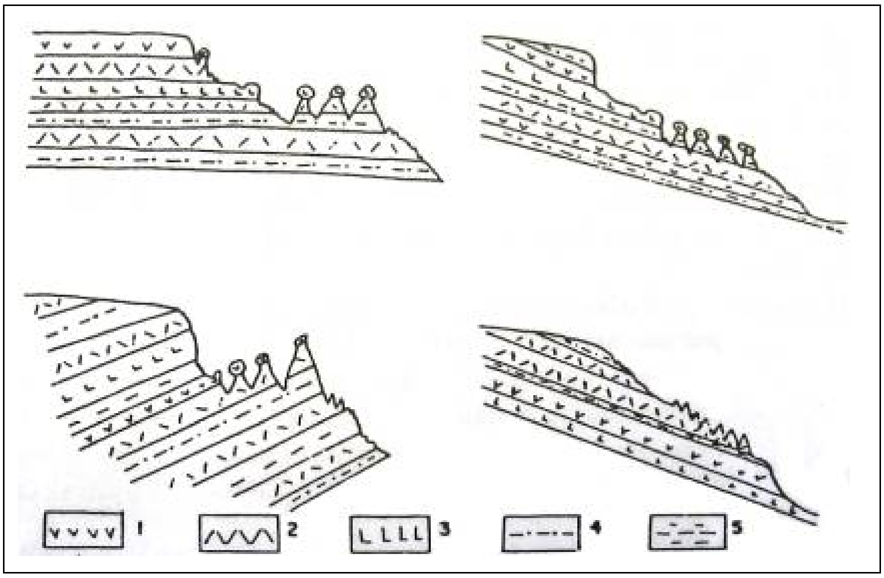


Figure 2.4. Formation of fairy chimneys according to Emre and Güner (1988) 1) Ignmibrite, 2) Tuff, 3) Lahar, 4)Volcanic ash, 5) Marl.

Topal (1995) studied the formation and deterioration of the fairy chimneys of the Kavak tuff in Ürgüp-Göreme area. He indicated that two dominant persistent joint sets which control the formation of the fairy chimneys which were developed within the Kavak tuff (Figure 2.5). The fairy chimneys were formed as a result weathering and differential erosion of the Kavak tuff. He studied the mass properties of the Kavak..

Baba et al. (2005) studied the physical and chemical properties of the fairy chimneys. The chemical analysis of the fairy chimneys showed that cementation agents such as FeO and CaO play significant role on the development of fairy chimneys according to this study. Chemical composition was a primary factor controlling the development, size and durability of the fairy chimneys. The caps of fairy chimneys were formed by welded tuffs in the Kavak Ignimbrite whereas they were formed by lahar andesite and basalt in the Tahar Ignimbrite.

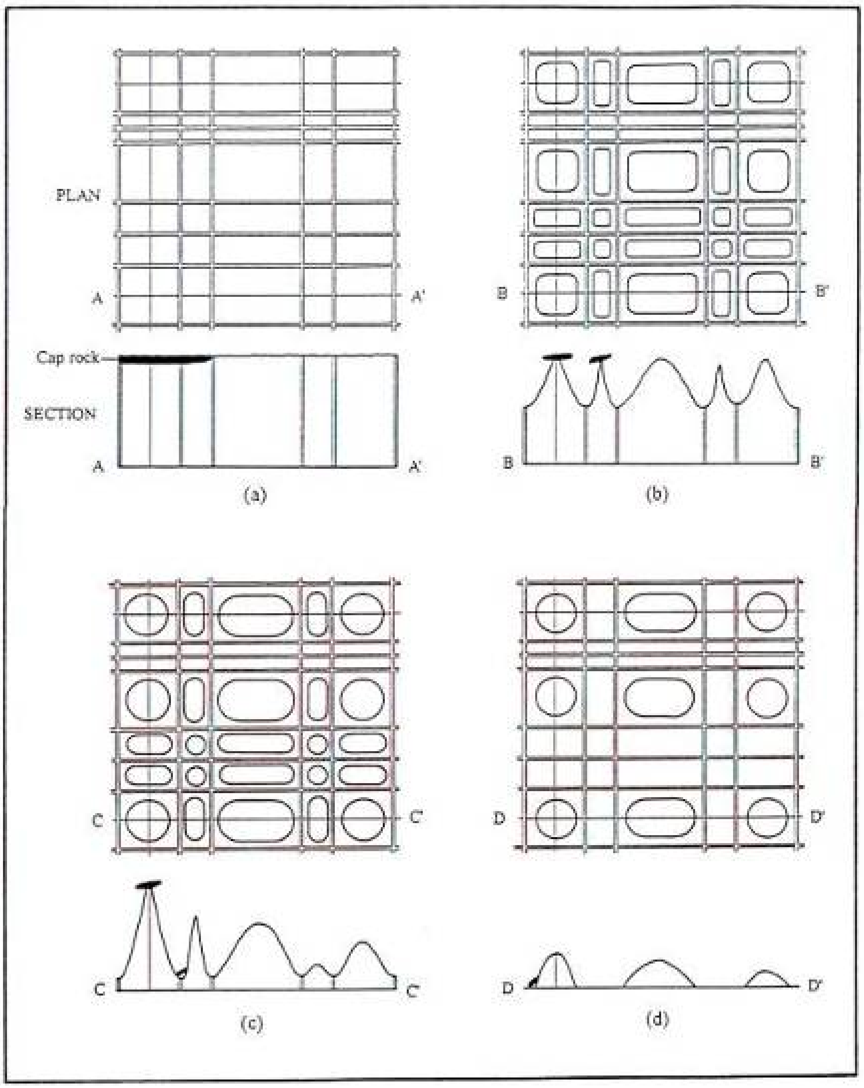


Figure 2.5. Formation of fairy chimneys according to Topal (1995). a) initial stage, b) youth stage, c) mature stage, and d) old stage (Double lines represent joints with narrow aperture, single lines represent joints with tight aperture).

2.1. Mineralogy and Geochemistry

Mineralogical and geochemical analyses of the units in the study area were taken from Temel's (1992) study who carried out petrological and geochemical analysis in all ignimbrites exposed in the study area. The main minerals observed during these analyses are feldspar, quartz, volcanic glass and clay minerals (Table 2.1). For each fairy chimney bearing ignimbrite one representative sample was selected to compare their major elements (Table 2.2) and trace elements (Table 2.3). All ignimbrites are rhyolitic-rhyodacitic in composition and plot in high-K calc-alkaline field (Temel et al, 1998).

Table 2.1. Main minerals observed in the ignimbrites exposed in the area (Temel, 1992).

	Feldspar	Quartz	Clay minerals	Biotite	Amphibole	Pyroxene	Zeolite minerals	Calcite	Opal-CT	Opaque minerals
Kızılkaya	X	X	X		X			X		X
Gördeles	X	X	X	X	X	X				X
Tahar	X	X	X	X	X	X		X		X
Cemilköy	X	X	X	X	X	X	X			X
Sarımaden Tepe	X	X	X	X	X	X				X
Zelve	X	X	X	X			X	X	X	X
Kavak	X	X	X	X			X	X	X	X

Table 2.2. Major element analyis from Temel (1992) for Kavak (sample no: U-349), Zelve (sample no: U-69), Sarımaden Tepe (sample no: U-515), Cemilköy (sample no: U-214) Tahar (sample no: U-109), Gördeles (sample no: U-238) Kızılkaya (sample no: U-196) Ignimbrites.

Ignimbrite	Geochemical Analysis (major elements)									
	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Ti_2O	P_2O_3
Kızılkaya	71.14	13.02	1.52	0.06	0.82	1.59	2.66	4.76	0.22	0.06
Gördeles	69.23	14.44	2.20	0.07	0.62	2.01	2.90	5.15	0.30	0.07
Tahar	69.88	13.80	1.58	0.06	0.41	1.80	2.35	4.47	0.24	0.06
Cemilköy	74.06	12.49	1.02	0.06	0.26	0.92	2.23	5.42	0.10	0.03
Sarımaden	69.47	14.47	1.53	0.11	1.19	1.26	2.20	4.79	0.28	0.05
Zelve	73.14	12.54	1.12	0.06	0.29	1.17	1.83	4.57	0.14	0.02
Kavak	72.34	13.52	1.33	0.06	0.25	1.91	2.07	4.26	0.15	0.05

Table 2.3. Trace element analyis from Temel (1992) for Kavak (sample no: U-349), Zelve (sample no: U-69)), Sarımaden Tepe (sample no: U-515), Cemilköy (sample no: U-214) Tahar (sample no: U-109), Gördeles (sample no: U-238) Kızılkaya (sample no: U-196) Ignimbrites.

Ignimbrite	Geochemical Analysis (trace elements)										
	Nb	Zr	Y	Sr	Rb	Co	V	Ni	Cr	Ba	Ga
Kızılkaya	14.7	123.6	4.7	124.7	204.1	0.01	9.8	7.7	18.1	618.9	14.5
Gördeles	16.3	207.8	25.1	168.4	190.8	2.2	15.2	5.1	21.7	653.5	14.5
Tahar	13.5	208.2	15.5	194.2	131.8	2.1	35.7	8.6	18.0	626.3	13.6
Cemilköy	13.3	97.3	21.8	83.4	219.5	2.0	4.4	4.8	15.9	813.5	11.0
Sarımaden	14.8	213.7	20.0	117.8	164.7	3.2	16.5	21.9	7.5	822.5	16.1
Zelve	15.3	111.1	18.4	166.1	170.5	2.2	10.7	7	23	1009	11.9
Kavak	14.7	104.4	18.7	240.6	171.6	0.6	62	5	24.9	949	12.3

2.2. Welding and Jointing

"Welding of pyroclastic deposits involves flattening of glassy pyroclasts under a compactional load at temperatures above the glass transition temperatures. Progressive welding is recorded by changes in the petrographic, textural (e.g. oblateness of pumice lapilli and micro-fabric orientation) and physical (e.g. density, porosity and uniaxial compressive strength) properties of the deposits" (Quane and Russell, 2005).

"The welding process involves sintering, compaction and flattening of hot glassy pyroclastic material. Welding is commonly accompanied by compaction resulting from gravitational loading. Although compaction is a response to load, the extent of compaction is stongly controlled by the viscosity (hence temperature) of the deposits" (Russell and Quane, 2005).

According to Streck and Grunder (2003) the welding range can be divided into five classes (nonwelded, incipiently welded, partially welded with pumice, partially welded with fiamme and densely welded) which can be quantified using density and porosity of ignimbrite. Values corresponding to these ranges are given in Table 2.4.

Table 2.4. Welding classes based on the density and porosity (Streck and Grunder, 2003).

Welding Classes	Density (gr/cm3)	Porosity (%)
Nonwelded	< 1.5	> 36
Incipiently welded	1.50 – 1.65	36 - 30
Partially welded with pumice	1.65 – 2.05	30-12
Partially welded with fiamme	2.05 – 2.30	12-2
Densely welded	2.30 – 2.34	< 2

Another classification scheme is proposed by Quane and Russell (2005). According to this classification there are six ranks of the welding. The names and description of these classes are given in Table 2.5. Six ranks (I-VI) are defined by discrete ranges in physical property values and specific macroscopic or microscopic textural characteristics (Quane and Russell, 2005). Physical properties considered in this classification are density, porosity, point load strength, uniaxial compressive strength, oblateness and fabric angle. Among these properties, only the ranges for density and porosity are included in Table 2.5.

Table 2.5. Welding classes based on physical propertiess and macroscopic or microscopic textural characteristics (Quane and Russell, 2005 and references therein).

Rank	Welding Class	Density	Porosity	Description
I	Non welded	<1.45	>0.42	Undeformed pumice lapilli in a loosely-packed, unconsolidated matrix
II	Incipiently welded	1.25 - 1.65	0.50 – 0.34	Undeformed pumice lapilli and ash. However some adhesion between clasts has occurred rendering the deposits coherent. Alternative name is “sintered”.
III	Partial welding	1.65 - 1.85	0.34 – 0.25	Inception of deformation in the ash matrix and pumice lapilli. Alternative names are “partial welding” or “partially welded with pumice”.
IV	Moderately welded	1.85 - 2.15	0.25 – 0.13	Clearly defined eutaxitic texture. However, the pumice lapilli show both moderate deformation as well as being collapsed to fiamme. Alternative name is “partially welded with fiamme”
V	Densely welded	2.15 – 2.30	0.13 – 0.07	all pumice lapilli collapsed to fiamme with strongly foliated ash matrix
VI	Densely welded	>2.30	<0.07	Welded all the way to obsidian-like vitrophyre. The eutaxitic texture is difficult to detect in hand sample and the glass shards are completely adhered to one another

CHAPTER 3

GEOLOGY OF THE AREA

In this chapter the rock units exposed within the study area will be introduced. Although the main focus of the study is on the ignimritic layers in the area, other units that exist might contribute important information on the understanding of the nature and position of ignimbrites. Therefore all the units exposed in the area will be briefly explained here. Detailed information, however, is given for the ignimbrites in which the fairy chimneys were developed. Geological map and generalized columnar section of the area prepared for this study are given in Figures 3.1 and 3.2, respectively. The units are described below from bottom to top.

3.1. Basement rocks

The basement rocks consist of Paleozoic-Mesozoic plutonic rocks (syenite and monzonite) and Mesozoic ophiolitic (dolerite, gabbro and ultramafic) rocks. The plutonic basement rock crops out in the western part of the area and the ophiolitic basement is in the north and east of Ayvalı and in the south of Kavak. The basement rocks are overlain by the Kavak Ignimbrite in all outcropping areas.

3.2. Yeşilhisar formation

The Yeşilhisar formation was named by Pasquare (1968) as "Yeşilhisar conglomerate". It is exposed as a single outcrop at north of Ürgüp, in the north-eastern part of the area (Figure 3.1). Its base is not observed in the study area. It is unconformably overlain by the Çökek Member of the Ürgüp formation. The formation is composed of thick-bedded fluvial deposits consisting of alternation of red marl, sandstone and conglomerate. The pebbles are rounded and their size range from a few mm to 20-30 cm. The formation includes granite, quartzite, marble, chert, limestone and ophiolitic rock fragments. The thickness of the formation is approximately 80 m. Age of the formation is Early Miocene (Ayrancı, 1991).

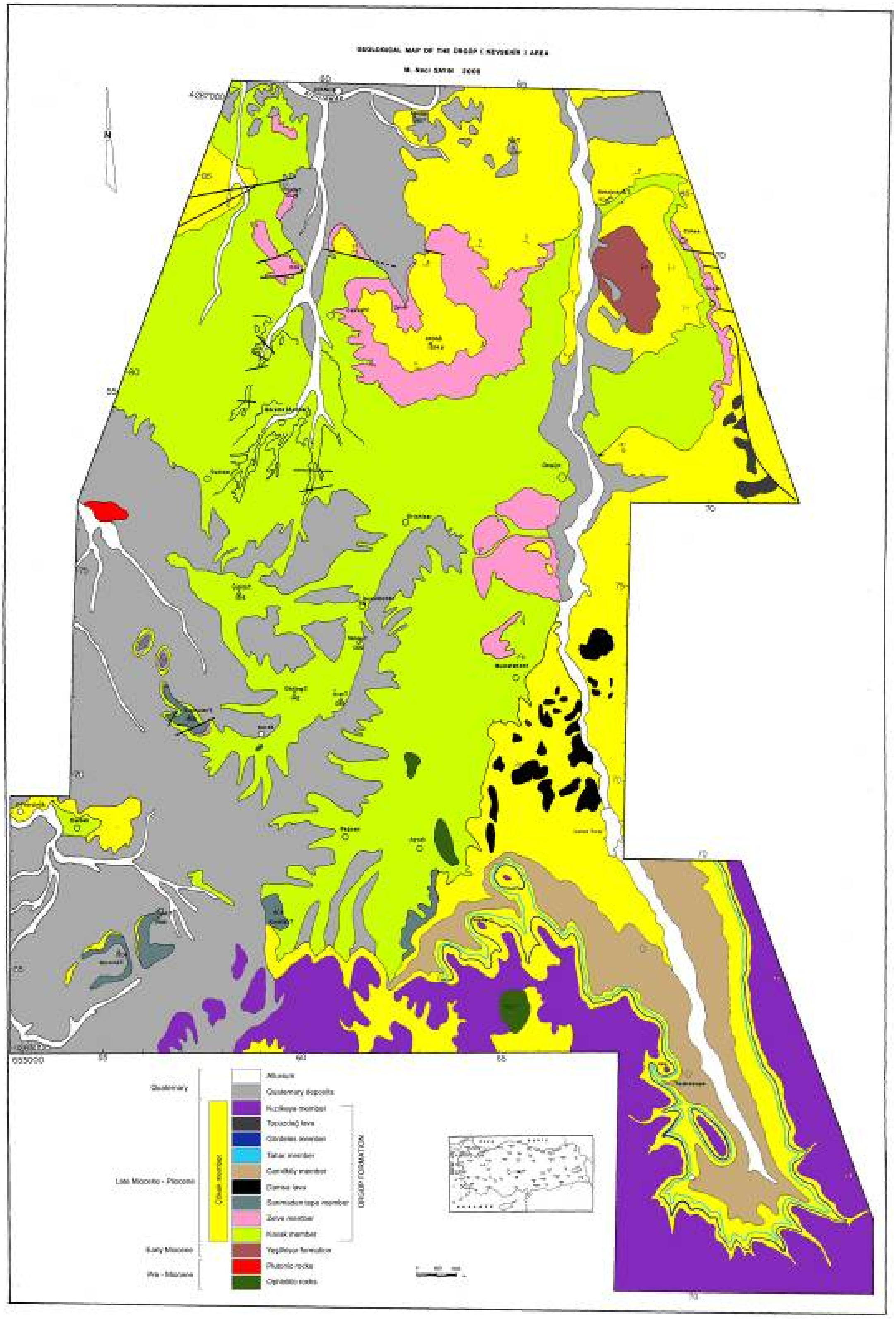


Figure 3.1. Geological map of the study area.

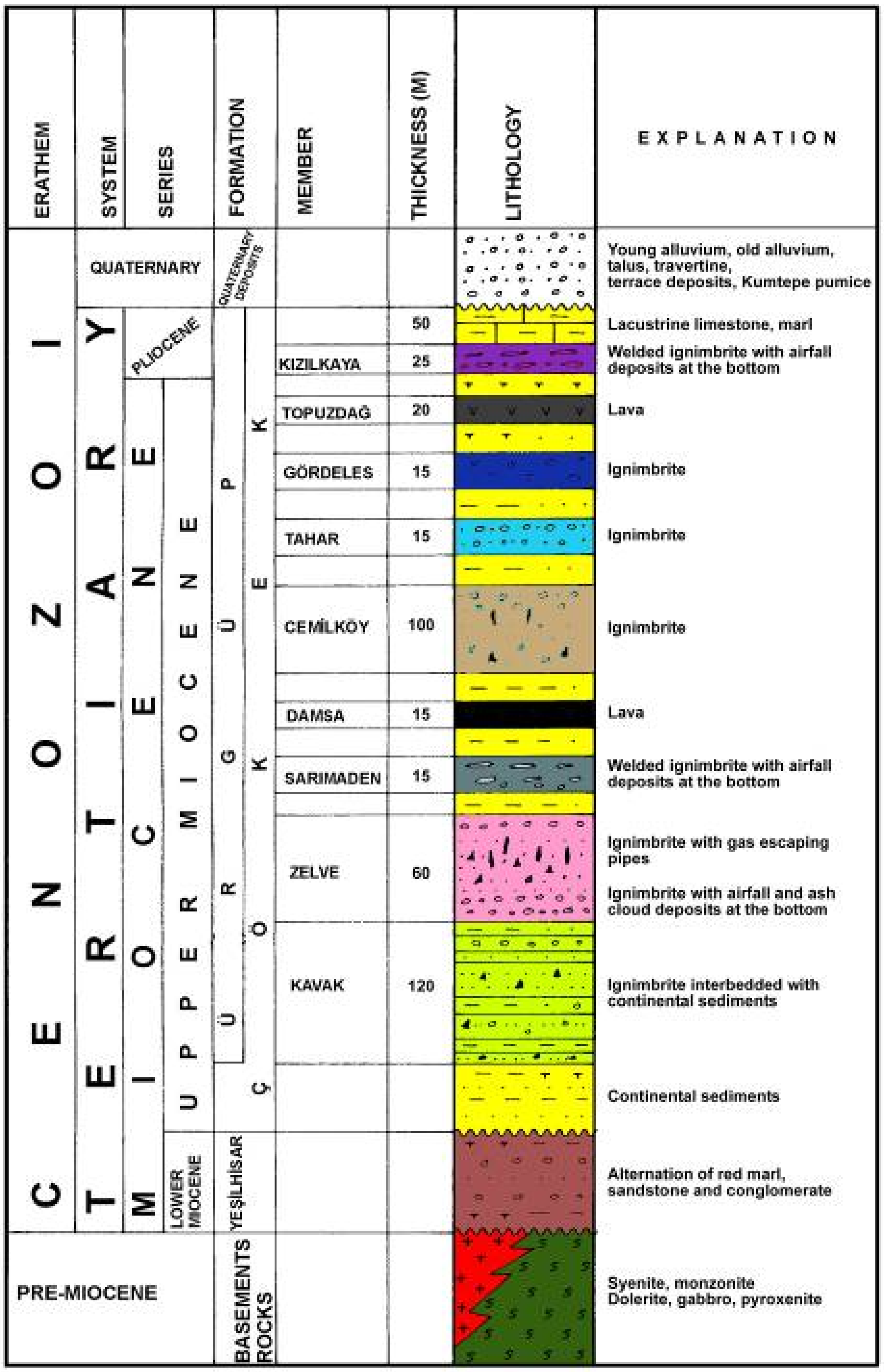


Figure 3.2. Generalized columnar section of the study area.

3.3. Ürgüp formation

The Ürgüp formation named firstly by Pasquare (1968) consists of seven ignimbritic members (Kavak, Zelve, Sarımaden Tepe, Cemilköy, Tahar, Gördeles and Kızılkaya), two lava flows (Damsa and Topuzdağ) intercalated with sedimentary rocks (Çökek Member) in the study area (Figures 3.1 and 3.2). It exceeds 340 m in thickness in the vicinity of Ürgüp. Age of the Ürgüp formation is Late Miocene-Pliocene as determined by radiometric dating of ignimbrites (Innocenti et al., 1975; Temel, 1992; Le Pennec et al, 2005) and by mammalian fossils (İzbırak and Yalçınlar 1951; Şenyürek 1953).

3.3.1 Çökek Member

The Çökek Member (Temel, 1992) consists of fluvial-lacustrine sedimentary rocks intercalated with ignimbrites of the Ürgüp Formation and lava flows (Figure 3.2). Therefore, it is not possible to observe a continuous section of the Çökek Member. In the study area, it unconformably overlies the Yeşilhisar Formation. Top of the Member is not observed in the area. The Çökek Member is observed almost in all parts of the study area. Although use of the term (Çökek Member) is not correct according to the stratigraphic nomenclature (NACSN, 1983), the name is adopted and this problem will not be questioned here because it is out of the scope of this study.

Total thickness of the Çökek Member is over 300 m around Çökek village. The unit shows strong lateral and vertical variations from fluvial cross-bedded sandstones to lacustrine limestone and mudstones (Figure 3.3). Most of the researches, studied in the area with main interest of volcanic rocks refer to the layers of the Çökek Member as “reworked material”. This term will not be used here to avoid confusion; instead “continental sediments” will be used to refer to Çökek Member.

3.3.2. Kavak Ignimbrite

The Kavak Ignimbrite covers an area of at least 2600 km^2 in the CVP (Le Pennec et al., 1994) with extensive outcrops in the study area (Figure 3.1). This unit dips 3-7º northward in most of the area. The highest elevation of this ignimbrite is 1500 m at northeast of Çardak, whereas the lowest elevation is 950 m along the Kızılırmak River.

Le Pennec et al. (1994) proposed that the source region of this ignimbrite is situated between Nevşehir and Derinkuyu (near Çardak village). It is correlated with a negative gravity anomaly reported by Ekingen and Güven, (1978) and Ekingen, (1982).

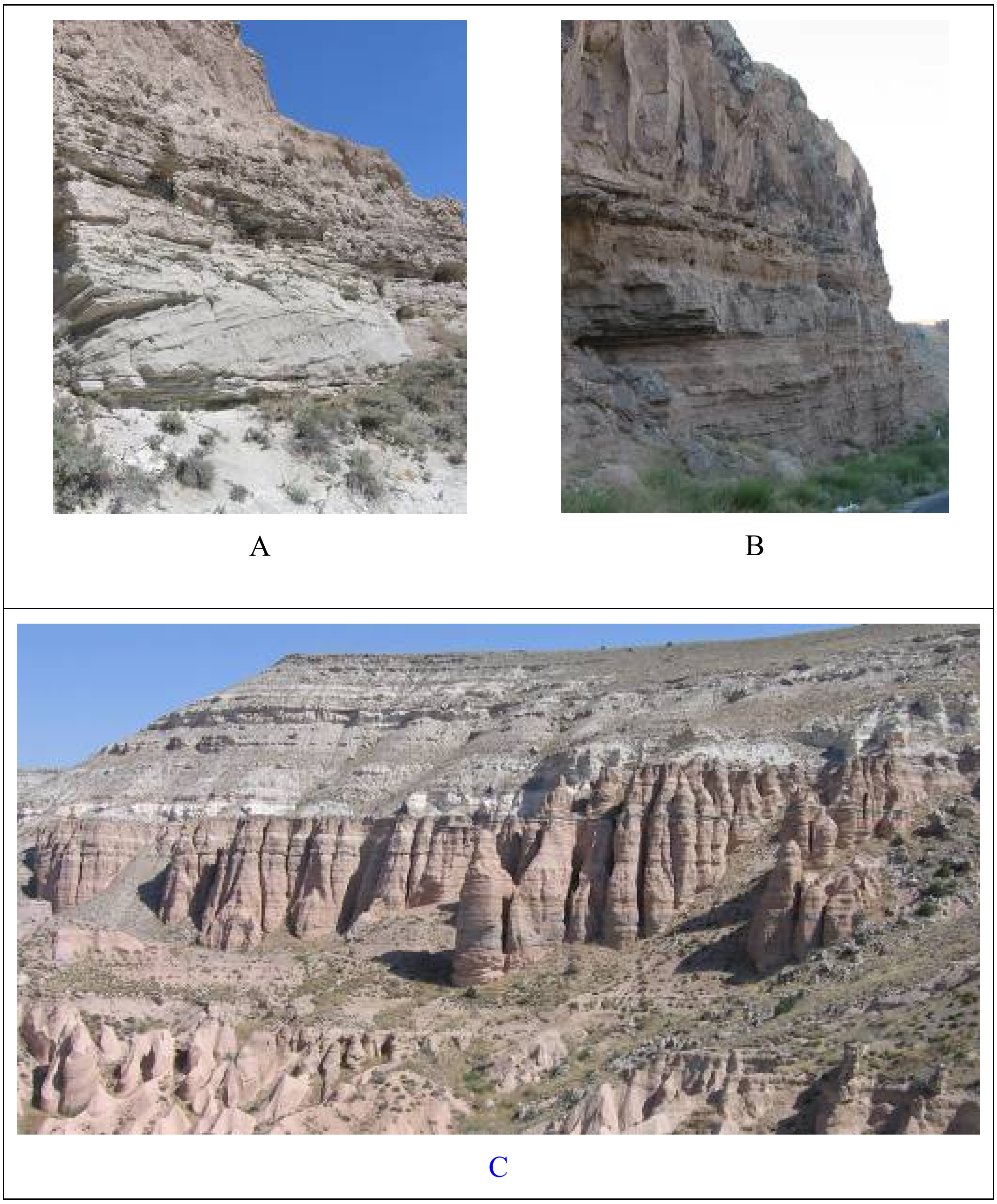


Figure 3.3. General views of the Çökek Member A) Cross-bedded sandstone below the Kızılkaya Ignimbrite (west of Şahinefendi village), B) clastic sequence below the Kızılkaya Ignimbrite (west of Cemilköy village), C) Clastic (pink) and lacustrine (white) rocks above the Zelve Ignimbrite (north of Akdağ mountain).

Based on the radiometric dating (K/Ar method), the age of the Kavak Ignimbrite was determined as 8.6±1.7 Ma (Innocenti et al., 1975), 11.2±2.5 Ma (Temel, 1992), 6.9-9.2 Ma (Mues Schumacher and Schumacher, 1996) and 9-14 Ma (Le Pennec et al, 2005). These findings suggest that the age of the Kavak Ignimbrite is Late Miocene. The unit also corresponds to the Upper and Lower Göreme Members of Schumacher et al. (1990).

This unit genarally comprises non-welded ignimbrite deposits (Figure 3.4-A). Sometimes this ignimbrite includes ash fall and ash cloud layers (Figure 3.4-B and C). A very evident feature of the Kavak Ignimbrite is its characteristic erosional forms of fairy chimneys (earth pyramids) and sweeping curves (badlands) extending through an area of over 100 km^2 with the principal centres at Ürgüp, Üçhisar, Ortahisar and Göreme.

The lithological characteristics of the Kavak Ignimbrite will be explained in two sections. The first section is observed from the bridge of Kavak towards Sarımaden Tepe where the thickest section (>120 m) of the Kavak Ignimbrite is observed (Figure 3.5-A). In this section, four white to pinkish brown ignimbrites (ash flows) were identified. These levels are seperated by brownish and light green fluvial and lacustrine sedimentary layers of the Çökek Member (totally 19 m). The Ignimbrite unconformably overlies the ophiolitic basement and is overlain by the pumice fall deposits of the Zelve Member in this secton.

The second section of the Kavak igimbrite is from northeast of Uçhisar towards Akdağ (about 100 m) (Figure 3.5-B). The base of the unit is not observed at this locality. Four ignimbritic levels are observed separated by continental-lacustrine light brown to light green continental sediments of the Çökek Member (Figure 3.4-D). Total thickness of these levels is about 25-30 m in this section. It is overlain by pumice fall deposits of the Zelve Ignimbrite in this area. Ignimbrites are mostly cream-white and sometimes pinkish colored. This coloration sometimes follows a zone, occasionally randomly distributed (Figure 3.4-E).

The fairy chimneys are systematically developed within the Kavak Ignimbrite. Therefore, this ignimbrite is one of the main units used in this study.

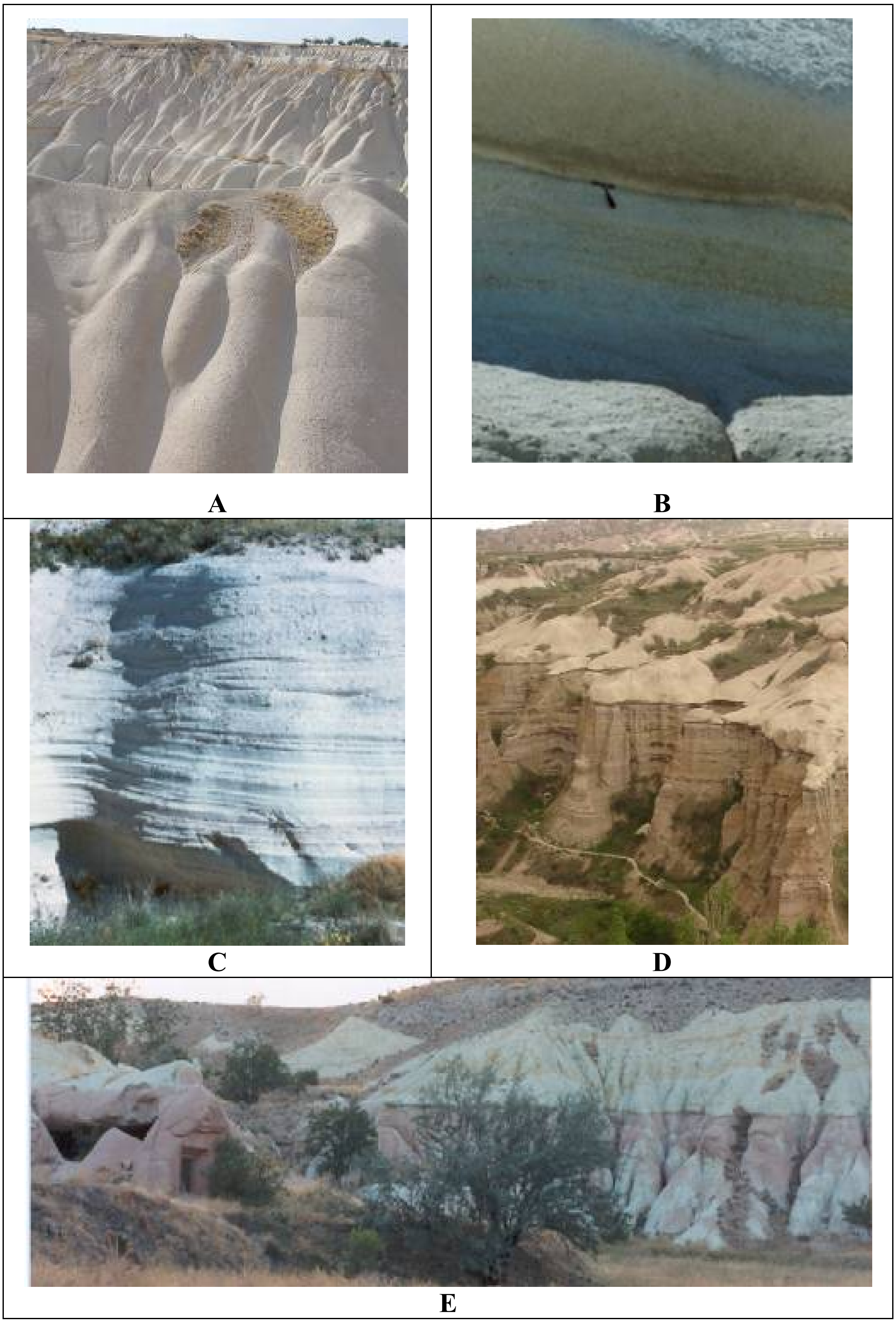


Figure 3.4. General views of the Kavak Ignimbrite: A) Ash flow deposits indicating sweeping curves in the Kavak Ignimbrite, B) Air fall deposit in the Kavak Ignimbrite, C) Ash cloud (surge) deposits in the Kavak Ignimbrite, D) continental clastics of the Çökek Member interbedded with the Kavak Ignimbrite, E) alternation of cream and pink tuffs in the Kavak Ignimbrite.

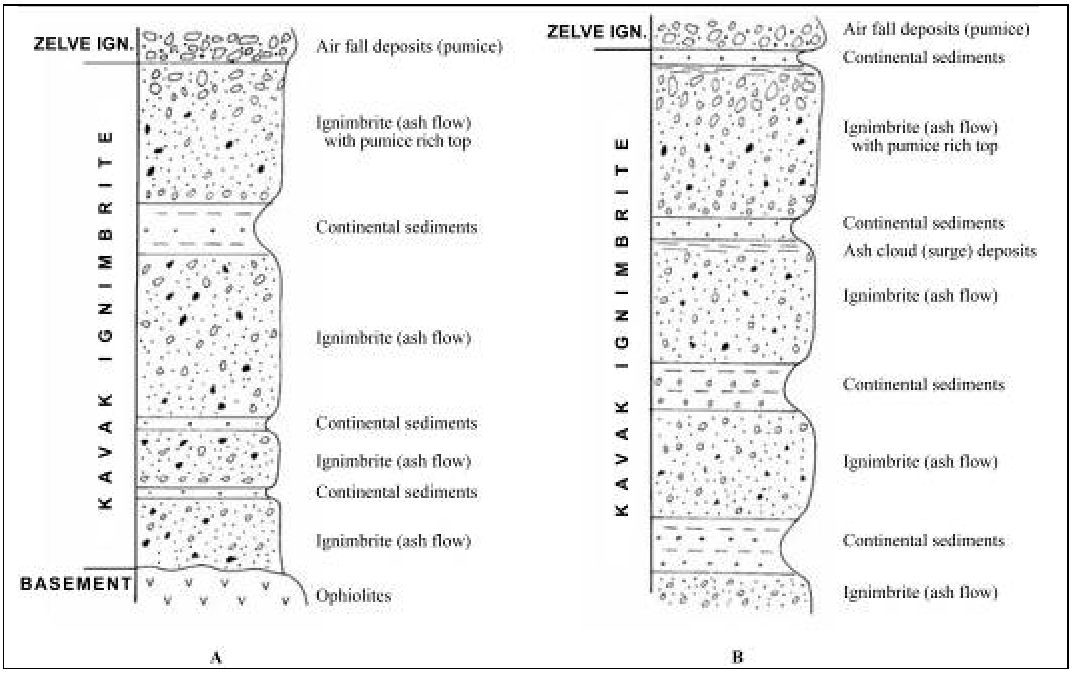


Figure 3.5. Sketch sections of the Kavak Ignimbrite at Kavak village (A) and Göreme-Akdağ area (B).

3.3.3. Zelve Ignimbrite

This unit was included into the Tahar Member by Pasquare (1968). Schumacher et al. (1990) named the Zelve and Tahar Members as the Akdağ ignimbrite. Temel (1992) and Le Pennec et al. (1994), however, indicated that both units are different in terms of their stratigraphic position and petrographic properties.

The Ignimbrite was erupted at south of Nevşehir in the Derinkuyu tectonic depression and is exposed discontinuously over an area of about 4200 km^2 in the CVP (Le Pennec et al., 1994). K/Ar age of this Ignimbrite is 7.5-7.7 Ma (Mues-Schumacher and Schumacher, 1996) and 8.5-9 Ma (Le Pennec et al., 2005). In the study area, it is exposed around Akdağ, Çökek and Ulaşlı villages, southwest of Avanos and south of Ürgüp (Figure 3.1).

The Zelve Ignimbrite consists of non-welded ignimbrite. This unit is characterized by pink color ignimbrite (Figure 3.6-A) and an extensive basal white colored air fall (pumice fall) deposits (Figure 3.6-B).

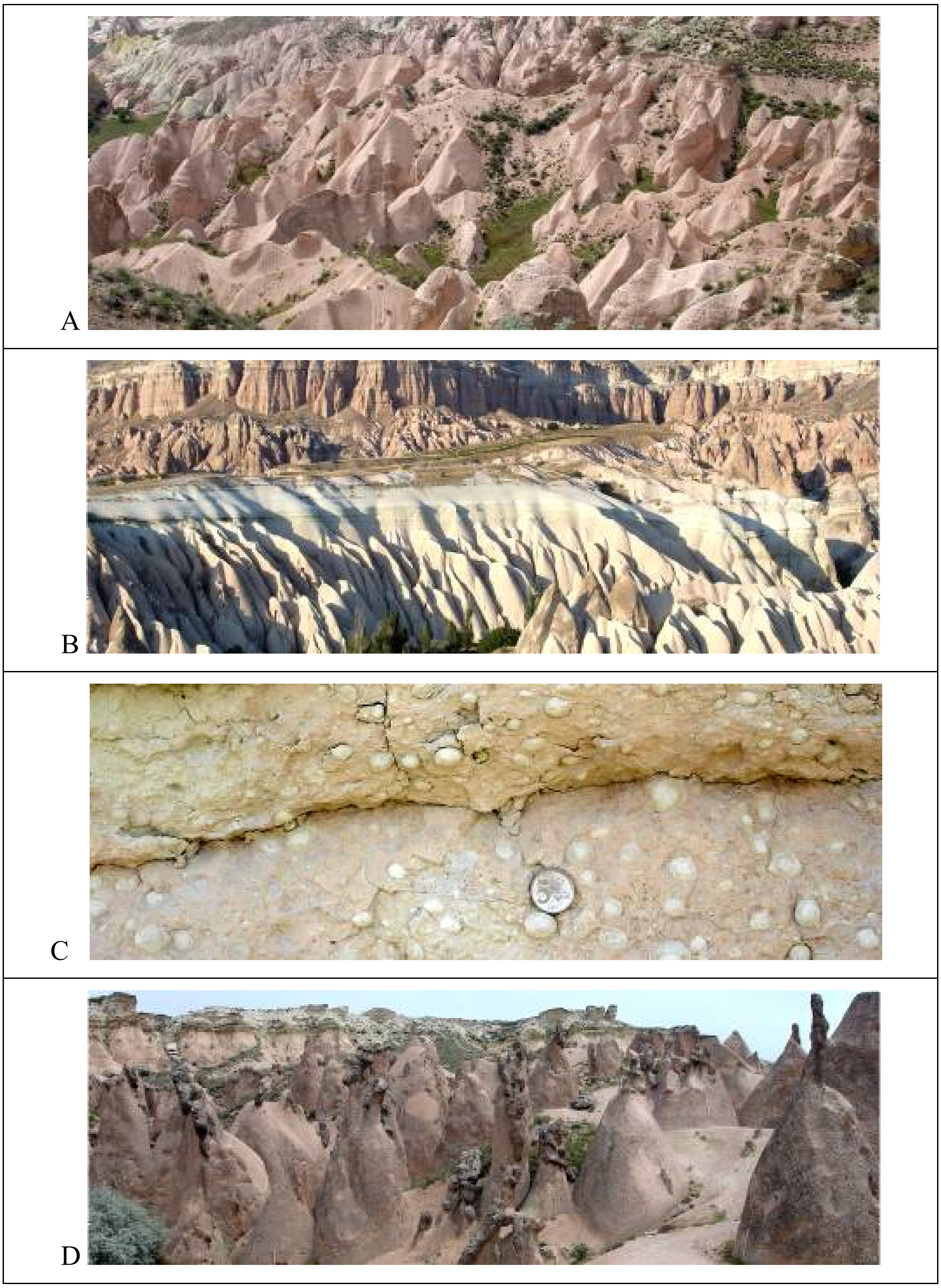


Figure 3.6. General views from the Zelve Ignimbrite. A) Pink color of the Zelve Ignimbrite, B) White pumice fall deposits between the Kavak and Zelve Ignimbrites, C) Accretionary lapilli (surge) deposits in the Zelve Ignimbrite, D) Gas pipes in the Zelve Ignimbrite.

This fallout layer, 4-15 m (mainly 5-6 m) thick, is a good stratigraphic marker horizon, which defines the boundary between the Kavak and Zelve Ignimbrites (Figure 3.7). This horizon contributes to the formation of well-known “capped” fairy chimneys around Zelve village.

It is overlain in many places by alternating units (0.5-4 m) which consist of ash cloud deposits and accretionary lapilli (Figure 3.6-C). They are defined as laminated surge deposit (Schumacher et al., 1990). These are followed by pyroclastic flow unit (Figure 3.7). Locally gas escaping structures are observed in this main flow unit (Figure 3.6-D). Similar pumice rich and accretionary lapilli levels are also observed in the upper parts of the main flow unit. The thickness of the Zelve Ignimbrite is nearly 60 m around Akdağ mountain. This unit is overlain by the continental sediments of the Çökek Member.

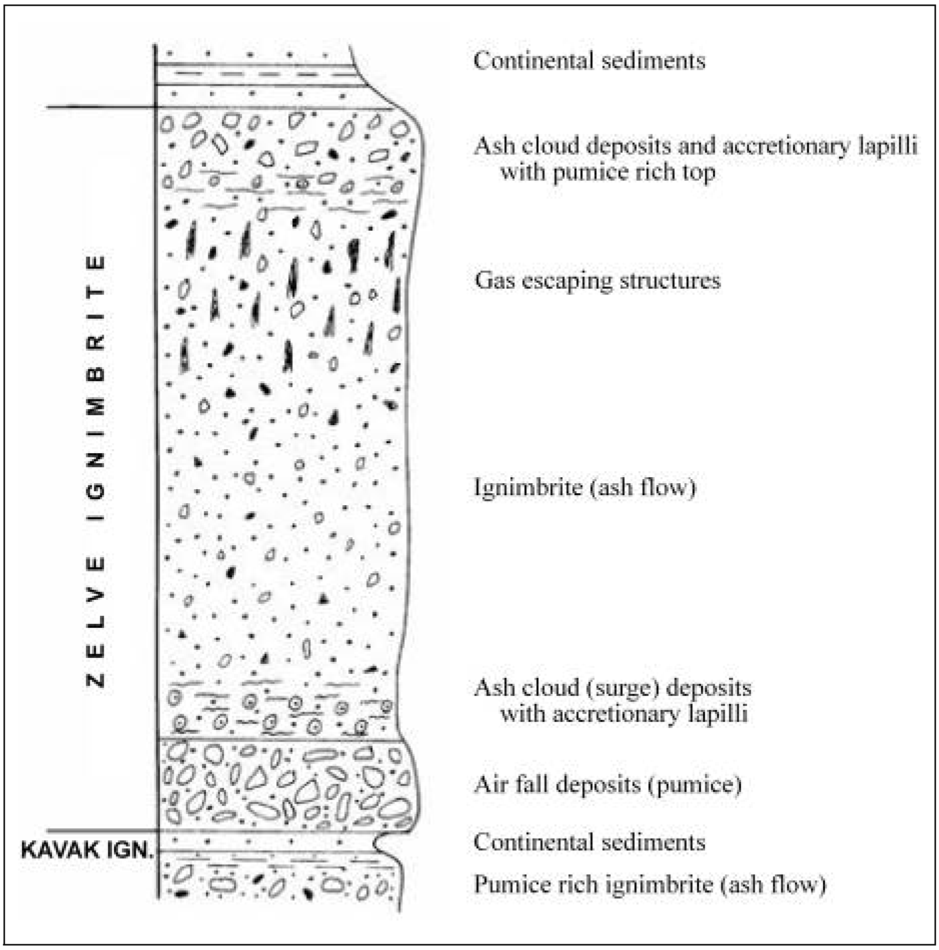


Figure 3.7. Sketch section of the Zelve Ignimbrite (Paşabağı, NW of Akdağ).

3.3.4. Sarımaden Tepe Ignimbrite

The Sarımaden Tepe Ignimbrite was first named by Pasquare (1968). Le Pennec et al. (1994) located the eruptive center in the area west of Derinkuyu and estimated the areal distribution to about 3900 km^2 in the CVP. K/Ar age of the Sarımaden Tepe Ignimbrite is 8-8.6 Ma according to Innocenti et al. (1975).

The Ignimbrite consists of one welded pyroclastic flow deposit in several localities. An air fall (pumice fall) deposit exists at the bottom of the unit (Figure 3.8). It charateristically displays a vertical variation from a white color at the basal part to a dark gray or dark brown at the middle part and to a light pinkish color at the upper part. The thickness of this member is 5-15 m in the study area. It is exposed in Sarımaden Tepe, Orta Tepe, Bucak Kepez Tepe, Üçhisar Dağ, in the northeast of Çardak village, Ören Tepe, Karanlık Tepe and Karakaya Tepe in the southeast of Çardak village, in the south of Mustafapaşa and Ayvalı villages (Figure 3.1). It overlies the pumice fall deposits of the Zelve inimbrite in Sarımaden Tepe. In other localities, it overlies the fluvial and lacustrine sedimentary and volcano-sedimentary deposits of the Çökek Member.

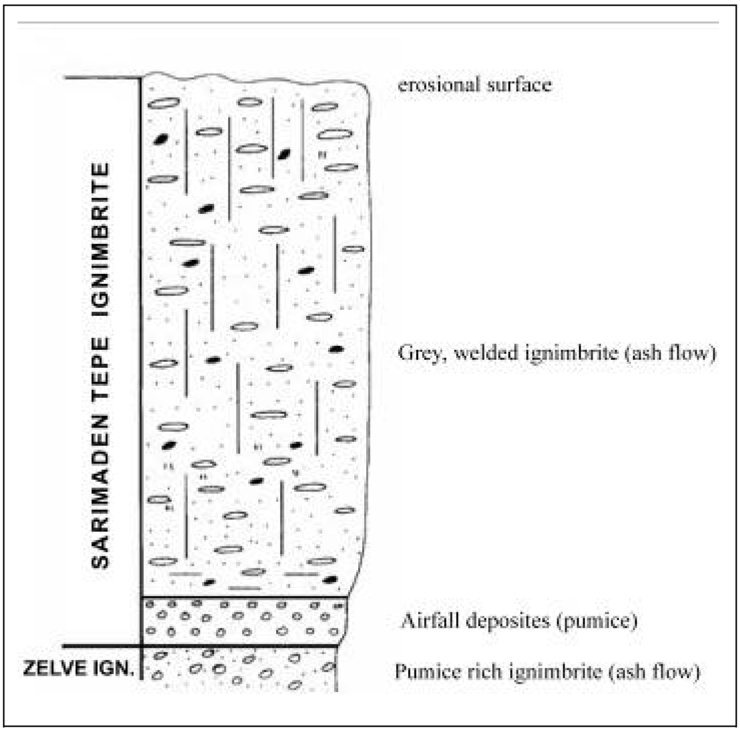


Figure 3.8. Sketch section of the Sarımaden Tepe Ignimbrite (East of Kavak).

3.3.5. Damsa Lava

The Damsa lava was named by Pasquare (1968). It is exposed in the east and south of Mustafapaşa. The thickness ranges from 10 m to 100 m (Temel, 1992). In the study area it has 5-15 m thickness. It consists of thin bedded blackish gray basaltic andesite and pinkish red volcanic breccia. K/Ar age of the lava is 8.2 Ma (Temel, 1982).

3.3.6. Cemilköy Ignimbrite

The unit was first named by Pasquare (1968). The areal extent of this non-welded ignimbrite is estimated by Le Pennec et al., (1994) to be 8600 km^2 in the CVP having spread out from the area south of Derinkuyu. K/Ar age of the Cemilköy Ignimbrite is 7.6-8.4 Ma (Le Pennec et al., 2005).

This non-welded ignimbritic unit is observed in the Damsa valley (Cemilköy, Taşkınpaşa and Şahinefendi villages) and at south of Ayvalı village (Figure 3.2). It is about 100 m thick in Cemilköy village. It comprises generally massive light cream or light gray single ash flow unit representing main body and a fine grained basal part with fine-grained pumice particles and ash cloud (surge) deposits at the bottom (Figures 3.9 and 3.10).

Concentration and size of pumice increase from bottom to top. This increase may be explained by both floating of pumice to the top of individual flow units and increase in the mass eruption rate combined with decreasing fragmentation energy. Locally, some gas escaping structures were observed in the upper parts of the ignimbrites.

The Cemilköy Ignimbrite produces systematic fairy chimneys in the western slopes of the Damsa valley. In this sense, this Ignimbrite is one of the main units of this study. Some outcrops of this units are exposed also at large distances at the east around Aksaray where fairy chimneys were developed (around Selime village). This outcrop and related ignimbrites are not covered by this study.

Figure 3.9. General views of the Cemilköy Ignimbrite. An appearence of ash flow deposits (A) and fine graned basal part at the bottom of the Cemilköy Ignimbrite (B). Length of ruler is 1 m.

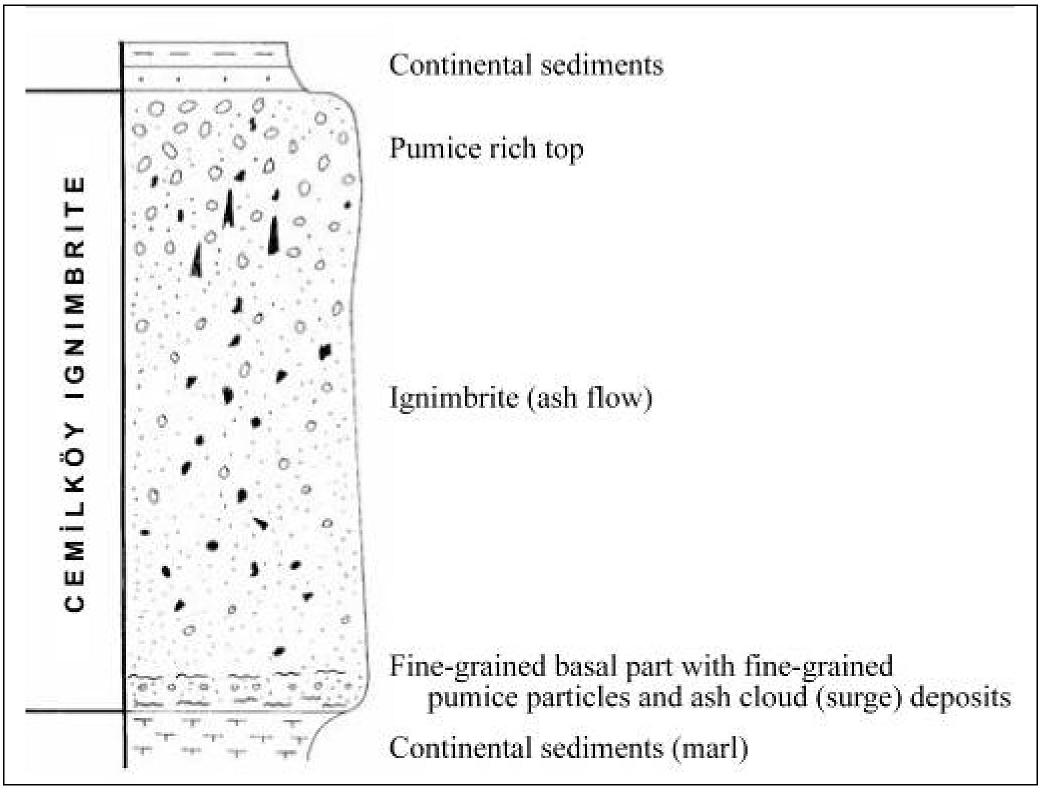


Figure 3.10. Sketch section of the Cemilköy Ignimbrite (Cemilköy village).

3.3.7. Tahar Ignimbrite

The name was first used by Pasquare (1968). The areal distribution is estimated to be about 1000 km^2 in the CVP and the eruption center was assumed in the area southeast of the village of Tahar (Le Pennec et al., 1994). K/Ar ages indicate an age of 7.2-7.8 Ma (Le Pennec et al., 2005).

The Tahar Ignimbrite consists of pinkish to cream non-welded ignimbrite and is underlain and overlain by continental sediments of the Çökek Member (Figure 3.11). It is observed on both sides of the Damsa valley in the study area (Figures 3.1 and 3.12). The thickness of the Ignimbrite is 5-15 m in the study area but locally reaches to 80 m (Temel, 1992).

The fairy chimneys were only locally developed in this Ignimbrite west of Taşkınpaşa and Şahinefendi villages. These chimneys, however, are not included in this study.

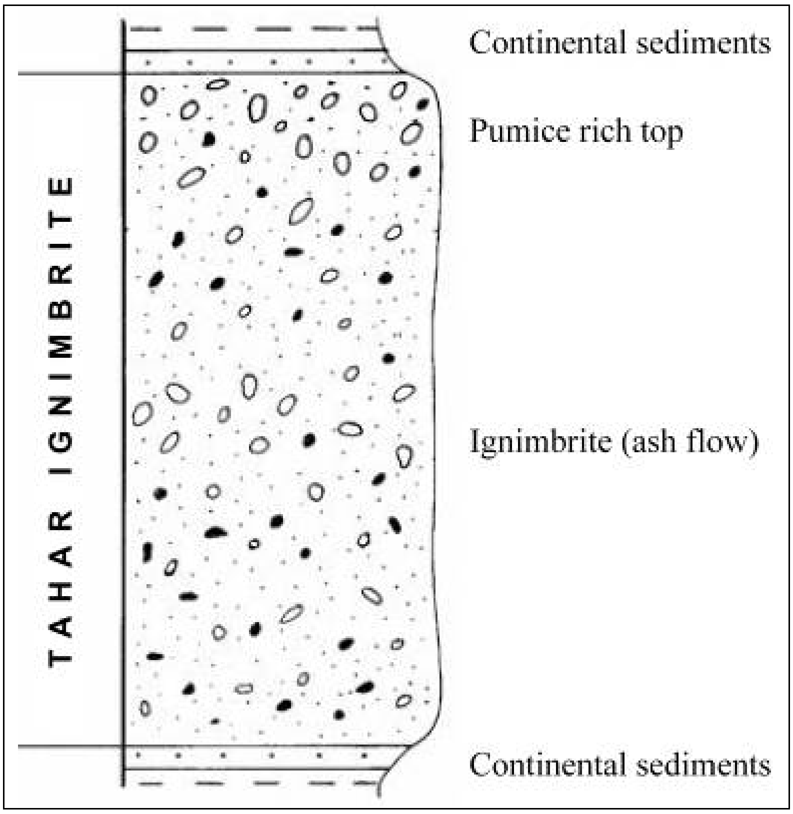


Figure 3.11. Sketch section of the Tahar Ignimbrite (Damsa valley).

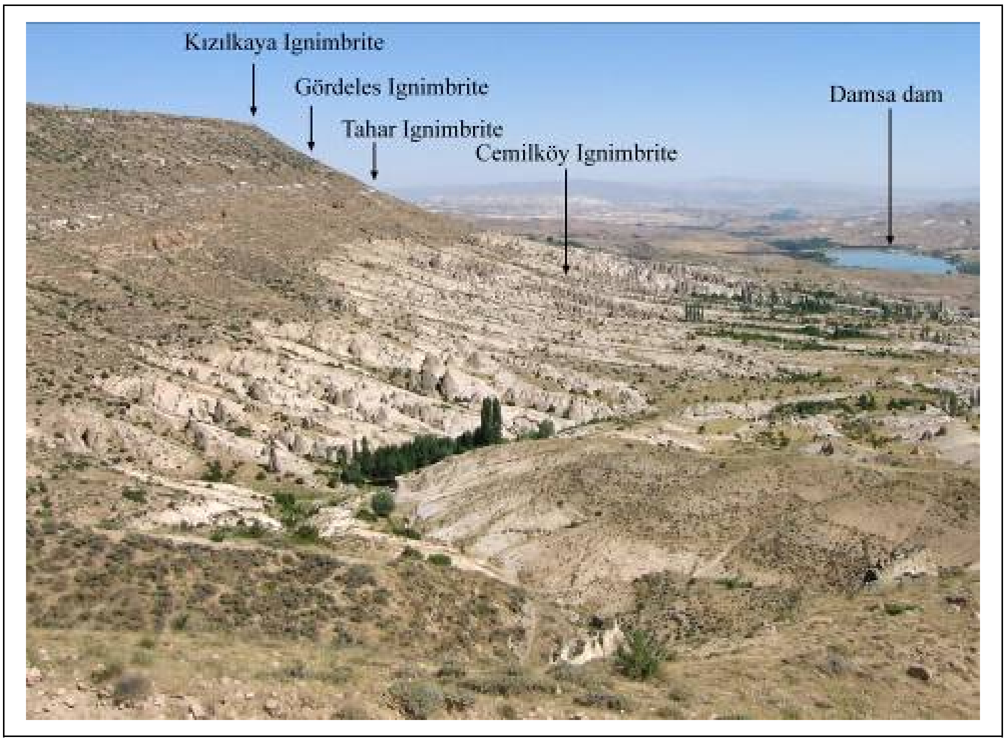


Figure 3.12. Panoramic view of west of the Damsa valley showing four ignimbrites intercalated with continental sediments.

3.3.8. Gördeles Ignimbrite

This unit was first named as “Gördeles Tongue” by Pasquaré (1968). The areal distribution is prodominantly in the southern part of the Nevşehir plateau. Available K/Ar ages range from 6.8 to 7.6 Ma (Innocenti et al., 1975; Le Pennec et al., 2005).

This unit is located stratigraphically between the Kızılkaya and Tahar Ignimbrites and is exposed on both sides of the Damsa valley and in the southern parts of Ayvalı villages (Figure 3.1). It comprises mainly light gray to pinkish ash flow unit (ignimbrite). It consists of non-welded and partly welded ignimbrite. It is overlain and underlain by continental sediments (Figures 3.12 and 3.13) of the Çökek Member. The amount and size of pumice fragments increase from bottom to top. It is about 10-15 m thick in the study area.

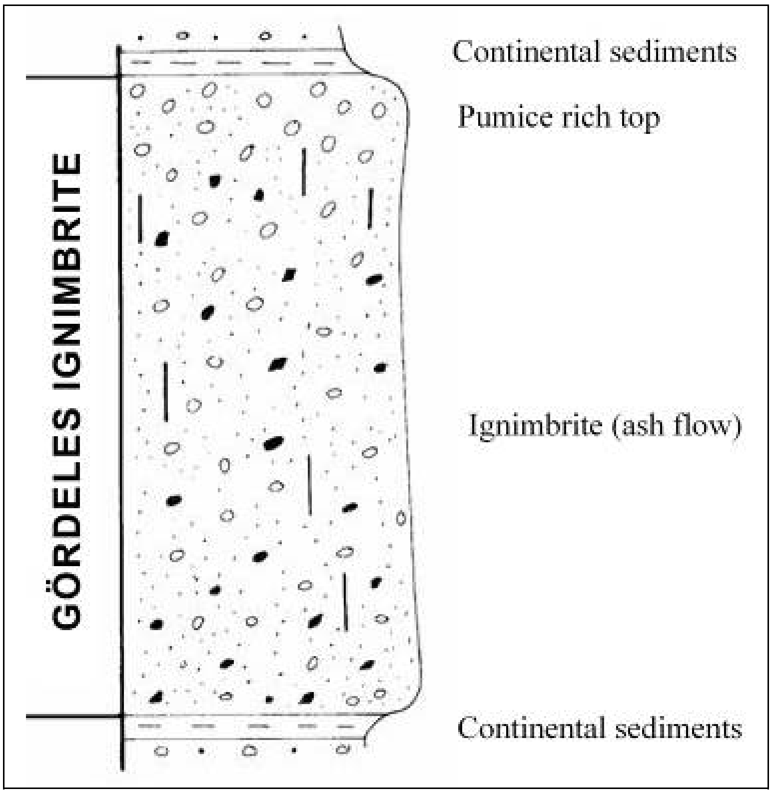


Figure 3.13. Sketch section of the Gördeles Ignimbrite (western slope of the Damsa valley).

3.3.9. Topuzdağ lava

Topuzdağ lava was named by Pasquaré (1968). It overlies the Çökek formation. The upper boundary is faulted in the study area; it is overlain by the Kışladağ formation out of the study area. K /Ar dating gives an age of 7 Ma (Temel, 1992). The unit consists of basaltic andesite. It has a thickness of 50-70 m (Pasquare, 1968). In the study area observable thickness range is 5 to 20 m.

3.3.10. Kızılkaya Ignimbrite

The name Kızılkaya was introduced by Beekman (1966). It is equivalent to the İncesu Member of Pasquaré (1968). Le Pennec et al., (1994) indicated that it covers an area exceeding 10.600 km^2, which is the most extensive unit in the CVP. According to Le Pennec et al., (1994) the source is located in the southwest of Derinkuyu. According to Innocenti et al. (1975) and Besang et al. (1977), the age is 4.4 to 5.5 Ma.

The Kızılkaya Ignimbrite consists of gray and pinkish red colored welded ignimbrite with a well developed columnar jointing and it forms the cliffs. There is a basal fallout layer with a maximum thickness of 20 cm at the base (Figure 3.15). It is exposed in the southern part of the study area (Figure 3.1). It overlies the fluvial-lacustrine deposits of the Çökek Member. Its thickness changes from 5 to 25 m in the study area but locally reaches to 70 m (Le Pennec et al., 1994).

3.4. Quaternary units

Quaternary units are composed of different Quaternary deposits (Kumtepe pumice, terrace deposits, travertine, alluvium and talus) and young alluvium actively forming in the river channels.

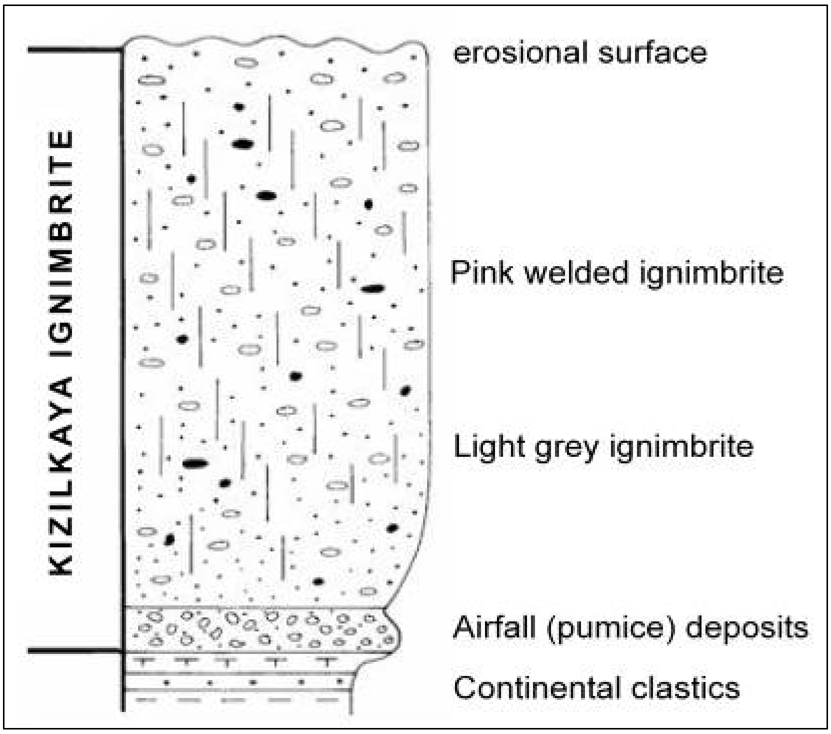


Figure 3.14. Sketch section of the the Kızılkaya Ignimbrite (west of Şahinefendi village).

Figure 3.15. Airfall and light gray ignimbrite at bottom of the Kızılkaya Ignimbrite (west of Şahinefendi village) passing to pink welded one.

CHAPTER 4

METHODOLOGY AND DATA

This chapter describes the methodology applied in this study and the data used in the analysis. The analyses carried out from these measurements are illustrated in the next chapter. A simplified flowchart of the study is given in Figure 4.1.

4.1. Preparation of Input Data (Step 1)

The first step in this study was to prepare necessary data that are needed for the related measurements from the fairy chimneys. The most important data is the geological map of the region at 1/25.000 scale showing distribution of the individual units under inspection. This map is completed and is presented in the previous chapter (Figure 3.1). The boundary of the map was drawn to include the ignimbrites that possess the fairy chimneys. This map was particularly used in the 2nd and 3rd steps of the methodology.

Other data set used in the study is the digital topographic map of the area. This map was used to extract morphological parameters (particularly slope) of the area that contain the fairy chimneys. Therefore, these maps were prepared for the selected areas where the fairy chimneys are exposed. All these maps were processed with either MapInfo of TNT-Mips softwares. The maps were converted to raster data with a pixel size of 20 m.

Another data set is the image obtained from the Google Earth web site for the determination of the fairy chimneys around Göreme for the Kavak Ignimbrite. This image was available only for that area during the preparation of the thesis. Details of this image and the measurements provided from this image is explained in Chapter 5.1.

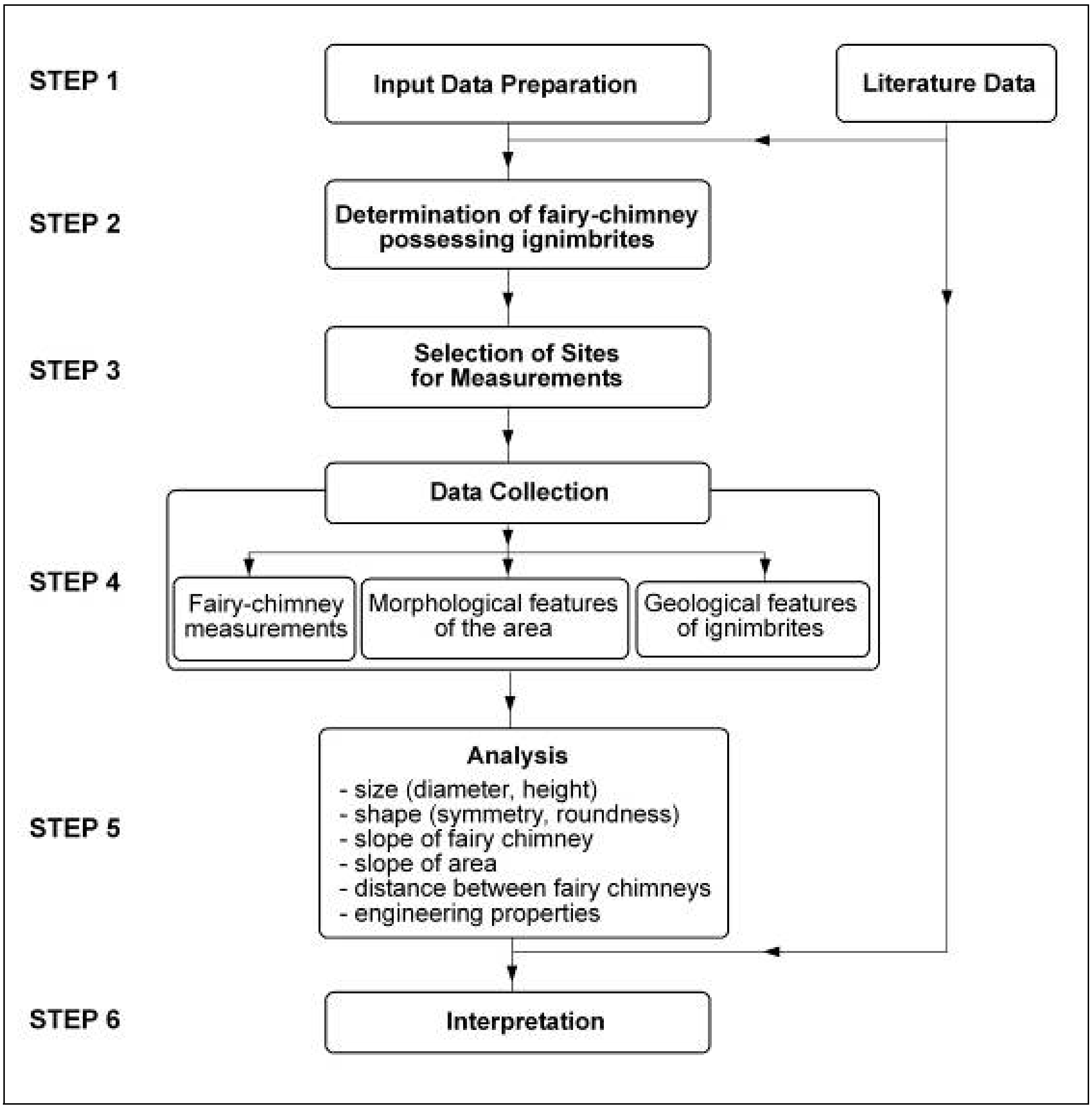


Figure 4.1. Simplified flowchart illustration of the methodology applied in this study.

The last group of the data collected in this study is related to the geological properties of the units such as thickness, dip etc.

The data published in the literature on various aspects of ignimbrites are also compiled. These data are mostly related to geochemical and engineering properties of ignimbrites. These data together with the data produced in this study are processed to investigate the main factors controlling the development of fairy chimneys.

4.2. Determination of fairy chimney developed ignimbrites (Step 2)

The next step is to determine the ignimbrites within which the fairy chimneys were formed. Since the fairy chimneys were developed within the ignimbrites, all ignimbritic units exposed in the Cappadocian volcanics are target areas for this selection. In this sense, the area theoretically extends from Aksaray in the west to Kayseri in the east. However, the field studies as well as the published data suggest that the fairy chimneys are restricted to the Ürgüp area where the lower parts of the Ürgüp formation is exposed to the surface. Nevertheless, all the ignimbrites mentioned in the literature were investigated for potential fairy-chimney development. Accordingly, four ignimbrites were determined in which the fairy chimneys were developed extensively. These are, stratigraphically, from bottom to top:

1 - Kavak Ignimbrite
2 - Kavak-Zelve Ignimbrites boundary
3 – Zelve Ignimbrite and
4 – Cemilköy Ignimbrite

Other ignimbrites in which the fairy chimneys were not developed or locally devolped (Tahar, Gördeles) are not considered in this study. A simplified columnar section is given in Figure 4.2 showing the stratigraphic location of the fairy chimneys analyzed in this study.

4.3. Selection of measurement sites (Step 3)

The next step is to select the sites for the data measurements. During this selection following factors were considered:

- The ignimbrite should be mapped at 1/25.000 scale in the area, so that its outcrop can be digitized for further analysis,
- Since the site will be a “type locality” for the fairy chimney a certain population of the chimneys should exist in the area.
- Since the area selected will be analyzed for its slope characteristics, it should be bounded by natural divides such as ridges.

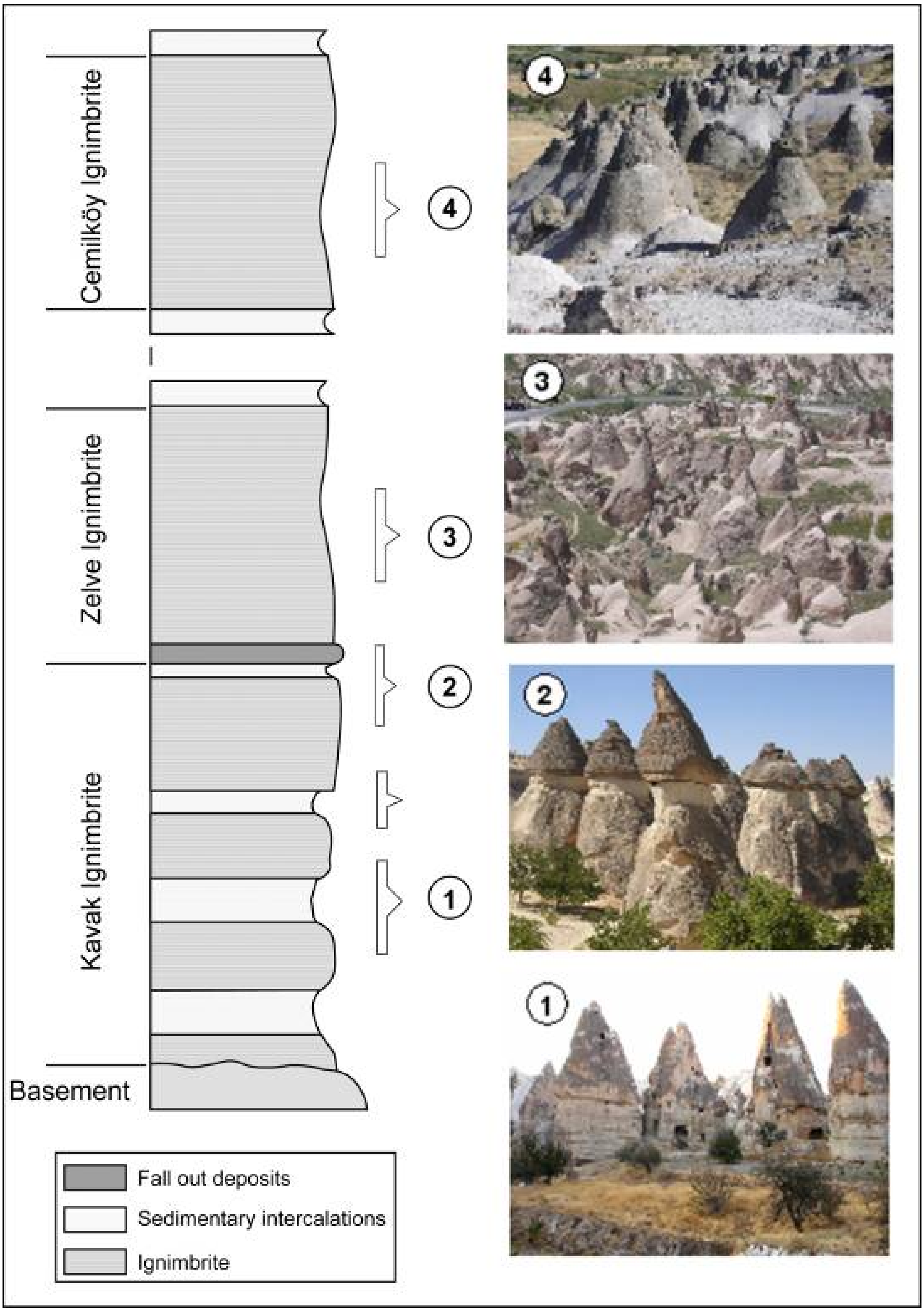


Figure 4.2. Columnar section showing stratigraphic position of the fairy chimney bearing ignimbrites analyzed in this study.

Considering these criteria a typical site was selected for each ignimbrite (Figure 4.3). Common feature of the all sites is that, they are all located within the deeply eroded part of the Ürgüp formation dissected mainly by the Damsa river and its tributaries. In the next sections, the data measured for each ignimbrite and related fairy chimney are presented.

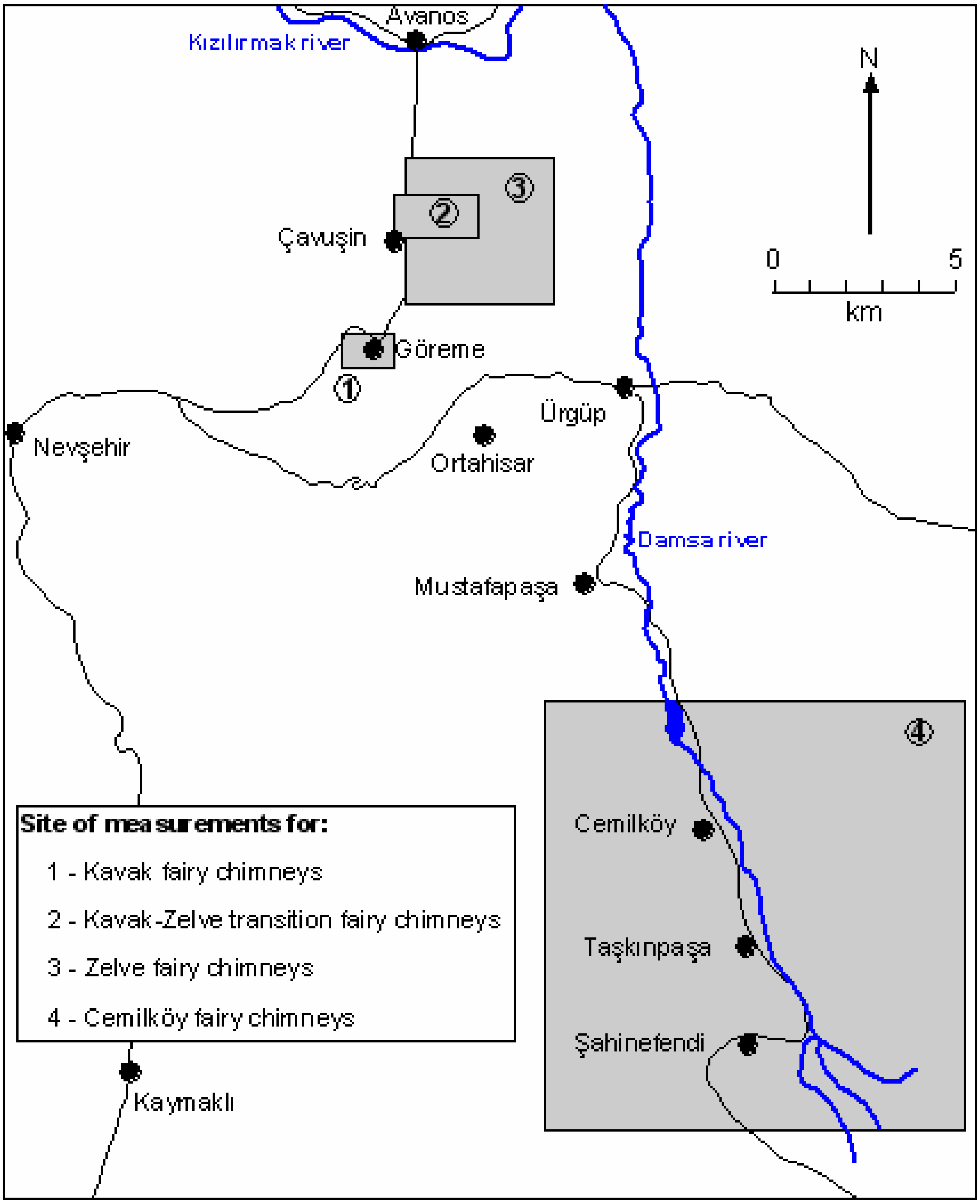


Figure 4.3. Location map of the type areas selected for measurements.

4.4. Data collection (Step 4)

The data measured in the field comprise geological features (such as thickness and dip) and fairy chimney properties in the type sections. Aim of these measurements wass to quantify the size and the shape of the chimneys. During the planning of the data to be measured, it was noted that there are three factors that should be considered: 1) the fairy chimney may have or may not have a cap, 2) the fairy chimney is mostly located on a sloping surface that results in "front" and "side" views, and 3) the fairy chimney might be asymmetric.

The parameters measured from the fairy chimneys, therefore, were setup in accordance with these aspects. For these reasons, it is decided to measure following parameters from the fairy chimneys:

- diameter of body both from front and side (B-D1 and B-D2)
- diameter of cap both from front and side (C-D1 and C-D2)
- slope of fairy chimneys from all sides (S1, S2, S3 and S4)
- height of the body (H)
- height of the cap (h)
- the distance between adjacent fairy chimneys

Front and side views were determined according to the position of the fairy chimney over the sloping surface. Accordingly, front and side views are parallel and perpendicular to surface slope, respectively.

Most of these parameters can not be measured over the fairy chimneys because of the accessibility problems. Therefore, they were measured from the photographs taken in two perpendicular directions across the fairy chimneys. Figure 4.5 shows an example of such a photo pair taken for the measurement. In each photograph a stick of 1 m was hold against the fairy chimney to be used as a scale. The camera is hold horizontal (with the help of a bubble) for accurate measurements. The data measured from these photographs include four diameters, four slopes and two height measurements. A total of 638 photographs were used for the measurement of data.

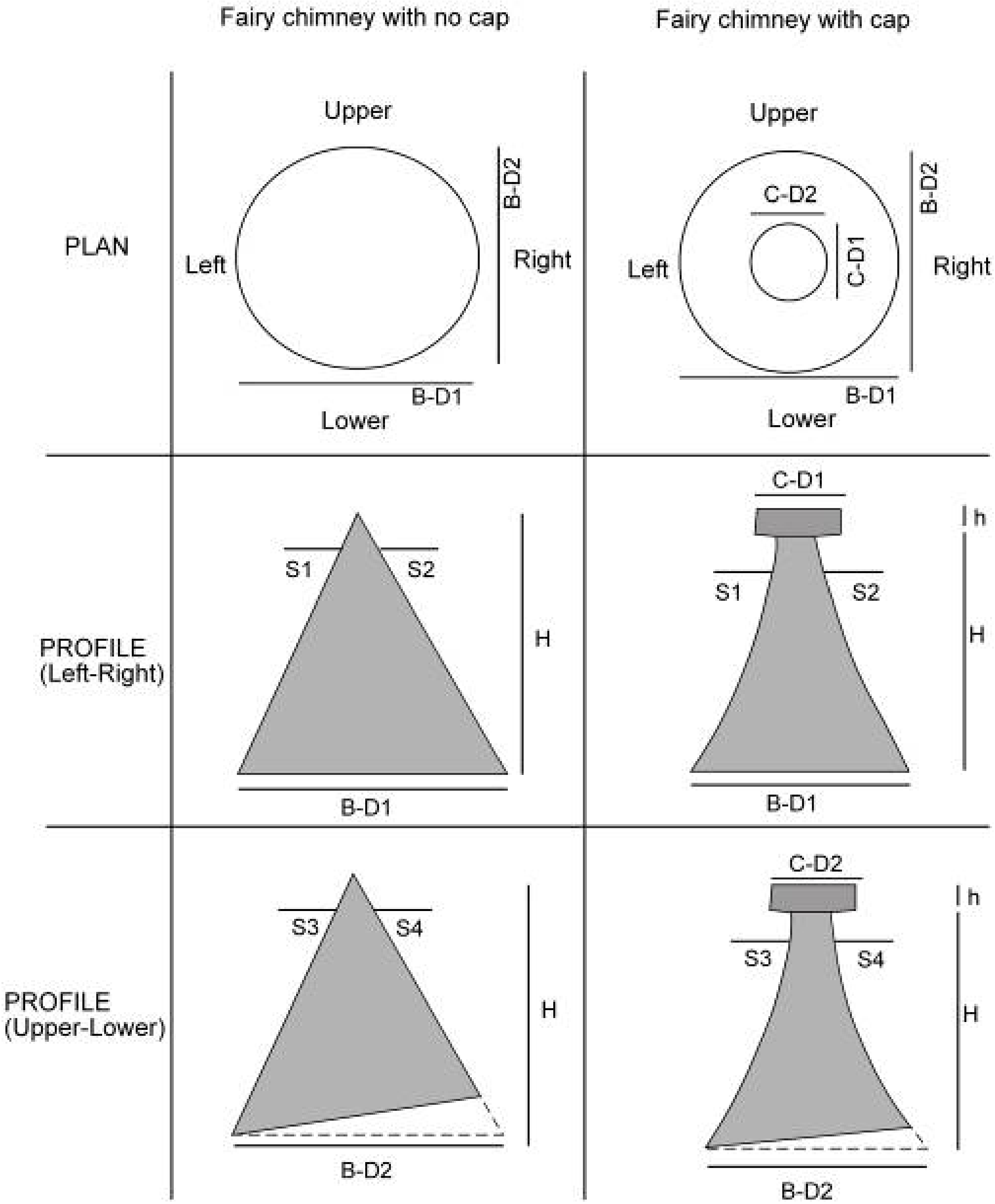


Figure 4.4. Data measured from the fairy chimneys.

The distance between the fairy chimneys, on the other hand were directly measured in the field from the reflected centers of two neighbouring fairy chimneys using a 50-m steel tape (Figure 4.6).

All these data and their analyses are introduced in the next chapter.

Figure 4.5. An example of photo-pair used for the measurement of data.

Figure 4.6. Measurement of distance between two neighbouring fairy chimneys.

CHAPTER 5

MEASUREMENTS and ANALYSIS

In this chapter, the measurements taken in the field and analyses carried out from these measurements were explained. As mentioned in the previous chapter, four ignimbritic levels were identified that possess fairy chimneys. These are from bottom to top: 1) Kavak Ignimbrite, 2) Kavak-Zelve boundary, 3) Zelve Ignimbrite, and 4) Cemilköy Ignimbrite. Other ignimbrites in which the fairy chimneys were not developed or locally devolped (Tahar, Gördeles) are not considered in this study.

5.1. Kavak Ignimbrite fairy chimneys

Measurements for the Kavak Ignimbrite fairy chimneys were taken in close vicinity of Göreme. A high resolution image of the area was taken from the Google Earth web site on which the fairy chimneys were individually identified (Figure 5.1). This image was available only for Göreme area. The image gives a chance to determine coordinates of individual fairy chimneys, therefore, to calculate the distances between the fairy chimneys and to carry out density analysis.The SE and NW corners of this image is cropped out along two small ridges and excluded from the analysis.

The fairy chimneys of the Kavak Ignimbrite were developed on alternating sequence of ignimbrites and continental sediments (volcanoclastic and reworked deposits). The main characteristic feature of these fairy chimneys is their spatial distribution. On contrast to the other fairy chimneys developed in the area, these fairy chimneys are exposed as isolated and widely spaced (Figure 5.2).

Depending on the degree of erosion and the thickness of the sedimentary material several types of fairy chimneys can form in this unit. Eight distinct types of these fairy chimneys are illustrated in Figure 5.3. These types can change from 100 % ignimbrite to fractional ratios as shown in the figure, from top to bottom, respectively. Examples of these chimneys are given in Figure 5.4.

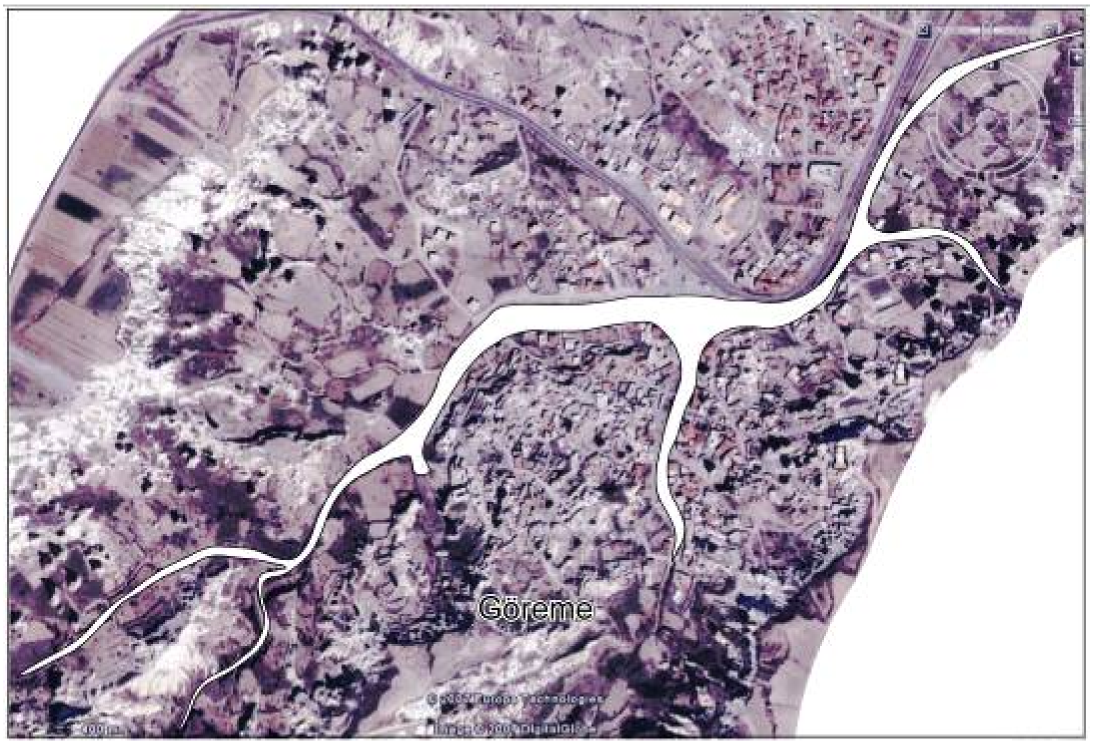


Figure 5.1. Google Earth image used for the measurements of Kavak fairy chimneys.

Figure 5.2. A general view of fairy chimney developed in Kavak Ignimbrite. The settlement in the picture is Göreme.

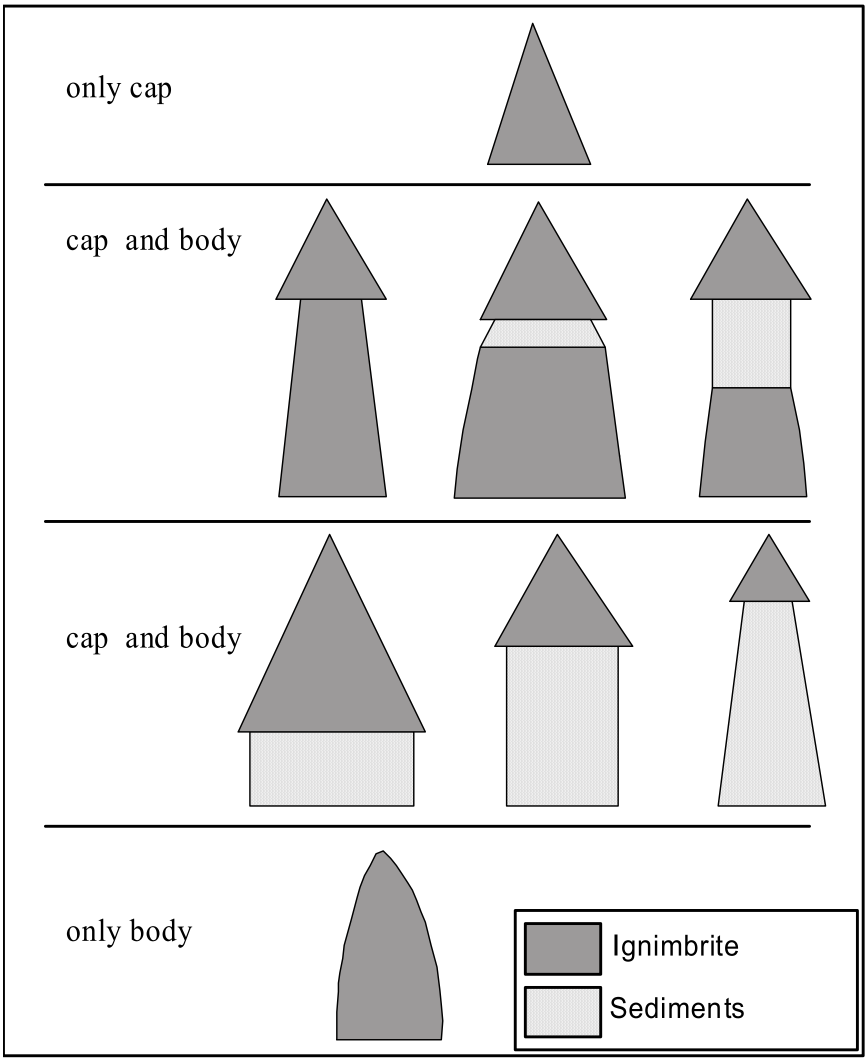


Figure 5.3. Different fairy chimney types identified within the Kavak Ignimbrite.

A total of 145 fairy chimneys were identified from the Google Earth image (Figure 5.5). All these fairy chimneys were measured in the field using the image as a base map. The measurements for these fairy chimneys consist of two sets (Appendix A). The first set is the measurements of the body and the second set is of the cap. Summary of these measurements is given in Table 5.1. Accordingly, 70 fairy chimneys are composed of a body and a cap. 39 fairy chimneys are totally exposed as only cap. On the other hand, there is only one fairy chimney which is composed of only body. 35 fairy chimneys could not be measured becaused of difficulties in the field due to accessibility problem caused by the form of the fairy chimneys. The coordinates of these chimneys, however, were measured for density analysis.

Figure 5.4. Examples of the fairy chimneys developed within the Kavak Ignimbrite varying from 100 % cap (upper part) to dominantly body (lower part). Ratio of cap and body can change from place to place. The examples in the figure show this variation in the direction of the arrow shown in the upper-left corner of the figure.

Table 5.1. Summary of the data measured for Kavak fairy chimneys.

Measurement	Frequency
All measurements	145
Only cap	39
Body + cap	70
Only body	1
No measurement	35

Distribution of the fairy chimneys measured in the Kavak Ignimbrite is shown in Figure 5.5. Each black square corresponds to one fairy chimney in the figure. The divides on both sides of the area shows the margins of the area for measurements and also for the morphological analysis that will be given below. These divides are considered as natural boundary of the area for the Kavak fairy chimneys. Therefore, the fairy chimneys that exist behind these divides were not measured.

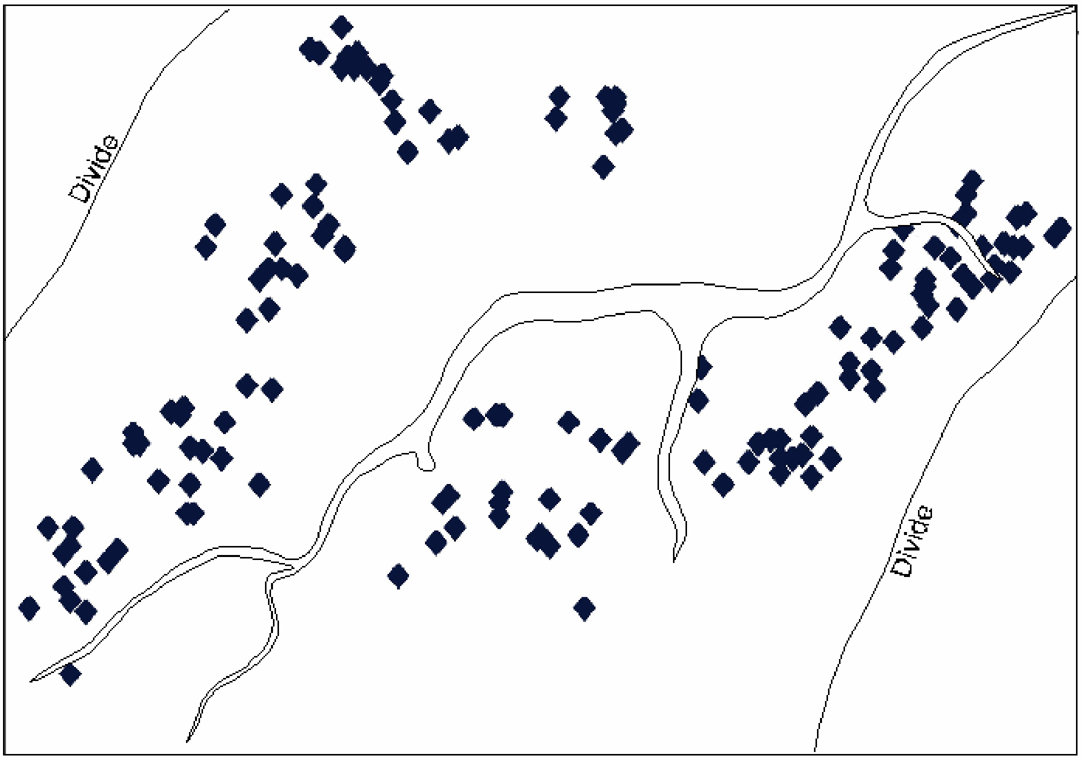


Figure 5.5. Fairy chimneys measured within the Kavak Ignimbrite.

Density analysis of all 145 fairy chimneys is performed with a grid spacing of 50 m and search radius of 100 m. The result of this analysis (Figure 5.6) indicates that:

- The fairy chimneys are concentrated in two belts parallel to each other and to the stream course in NE-SW direction.
- There is no fairy chimney in the close vicinity of the stream where the area is relatively flat. This may suggest that the former fairy chimneys developed in this area were totally eroded.
- Fairy chimneys were not developed close to the divides. Most probably, new fairy chimneys will be developed here in the future as the slopes retreat in both directions.

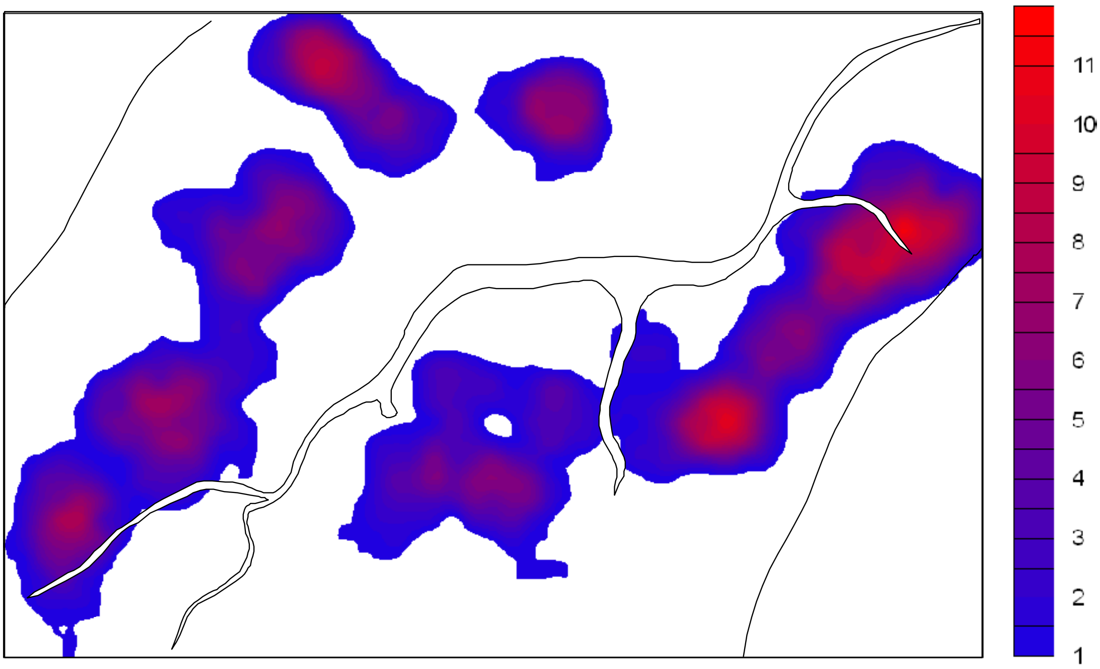


Figure 5.6. Result of the density analysis for the fairy chimneys in the Kavak Ignimbrite. (Total frequency: 145, grid spacing 50 m, search radius: 100 m).

No distinction is made between "only cap" and "cap+body" fairy chimneys in Figure 5.6. A new analysis was made in which these two types were differentiated. The result of this analysis is shown in Figure 5.7-A for "only cap" type fairy chimneys and B for "body+cap" type fairy chimneys. The fairy chimneys with no measurements are excluded in this analysis. Therefore, the number for "only cap" chimneys is 39 and for "cap+body" is 70.

The difference between two maps indicates that “only cap” fairy chimneys are exposed close to the divide whereas the “cap+body” chimneys concentrate near to the valley bottom. Since the degree of erosion is relatively greater near the stream course, it can be suggested that the “only cap” chimneys are new ones exposed near the divide and the “cap+body” chimneys are older ones and indicates a further erosion where dissection continued to expose the body.

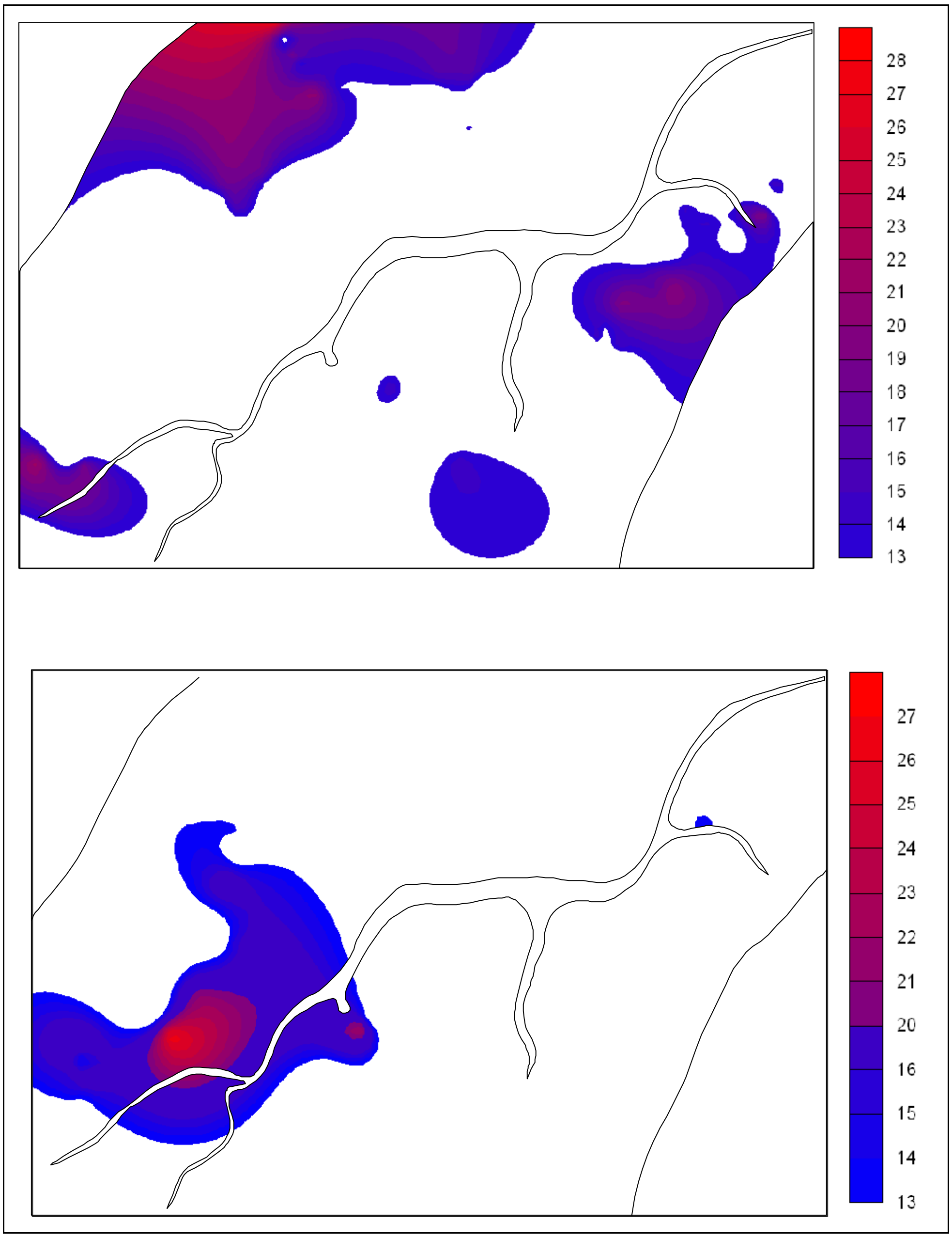


Figure 5.7. Density analysis of “only cap” (A) and “cap+body (B) type fairy chimneys in the Kavak Ignimbrite. (Frequencies for A and B are 39 and 70, respectively, grid spacing is 50 m, search radius is 100 m).

Effect of the slope of the area on the fairy chimney development was investigated using the digital elevation model of the area prepared using 10 m contour interval (Figure 5.8-A). In this figure, the three polygons indicated regions where fairy chimneys were developed. A slope map prepared from this figure is illustrated in Figure 5.8-B. The slope map was converted to a raster data with 20 m cell size. The slope map was divided into two parts as 1) fairy chimney regions (three polygons in the figure) and, 2) the rest of the area.

Histograms were prepared for both fairy chimney areas (Figure 5.9-A) and for the rest (Figure 5.9-B). The percentages of these two histograms were subtracted from each other to investigate the fairy chimney development in relation to the slope amount. The histogram in Figure 5.8-C is, therefore, the difference histograms provided by subtraction of corresponding bins of A and B.

A positive number in the resultant histogram indicates that the percentage of fairy chimney is less than the percentage of the area. Therefore, the fairy chimney does not develop or does not prefer this slope amount. On the contrary, a positive number indicate that the fairy chimneys have a greater percentage at this slope amount; therefore, they develop more than the average.

The difference histogram for the Kavak Ignimbrite indicates that the fairy chimneys prefereed to developed in the slope range of 4 to 17 degrees (Table 5.2). Other slope values are not suitable for the formation of fairy chimneys.

Table 5.2. Slope suitability for Kavak Ignimbrite fairy chimneys.

Preference	**Slope (degree)**
Preferred interval	4-17
Not preferred intervals	<4 and >17

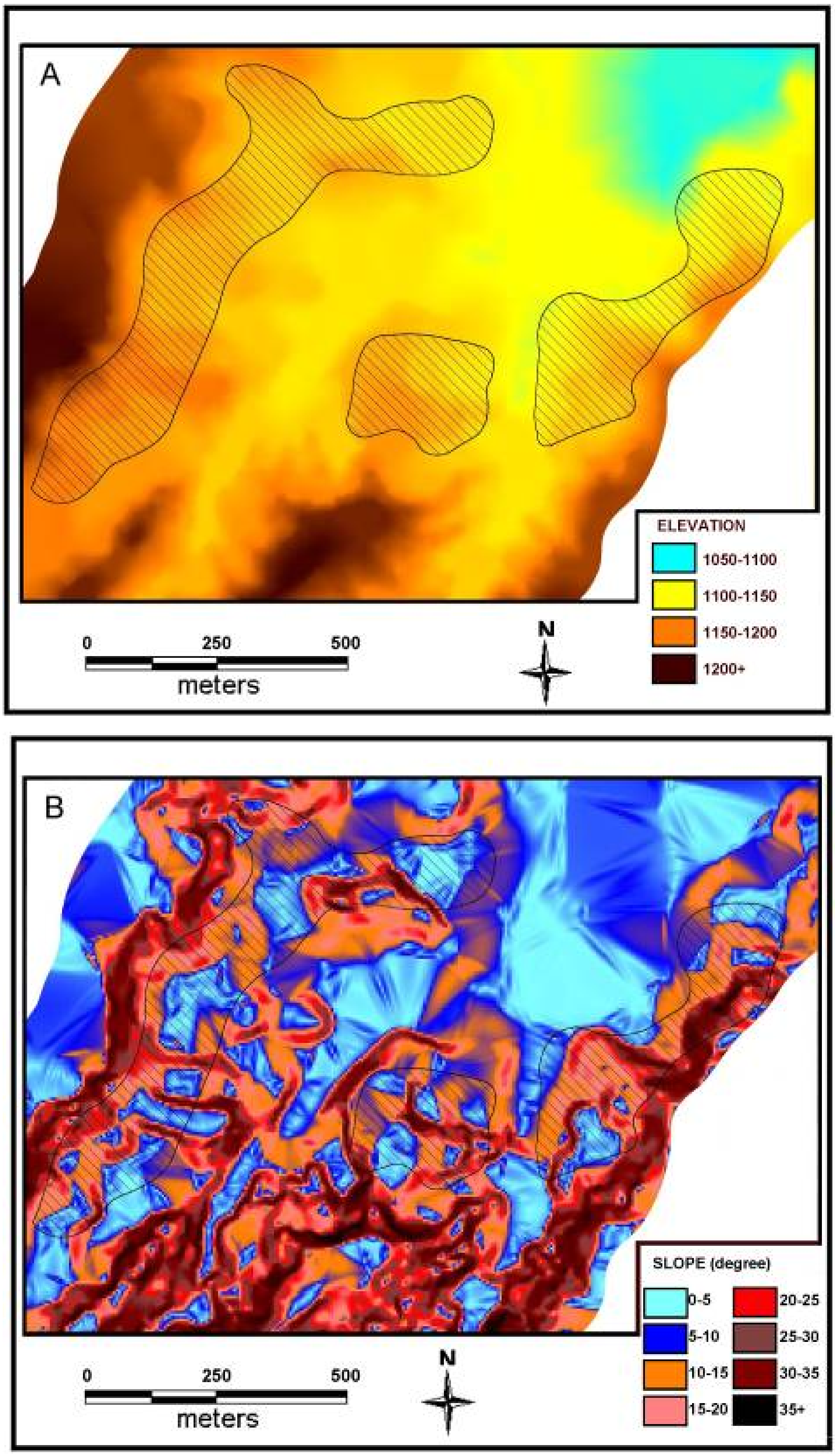


Figure 5.8. Elevation (A) and slope map (B) for the Kavak Ignimbrite. Ruled regions are regions where fairy chimneys are developed.

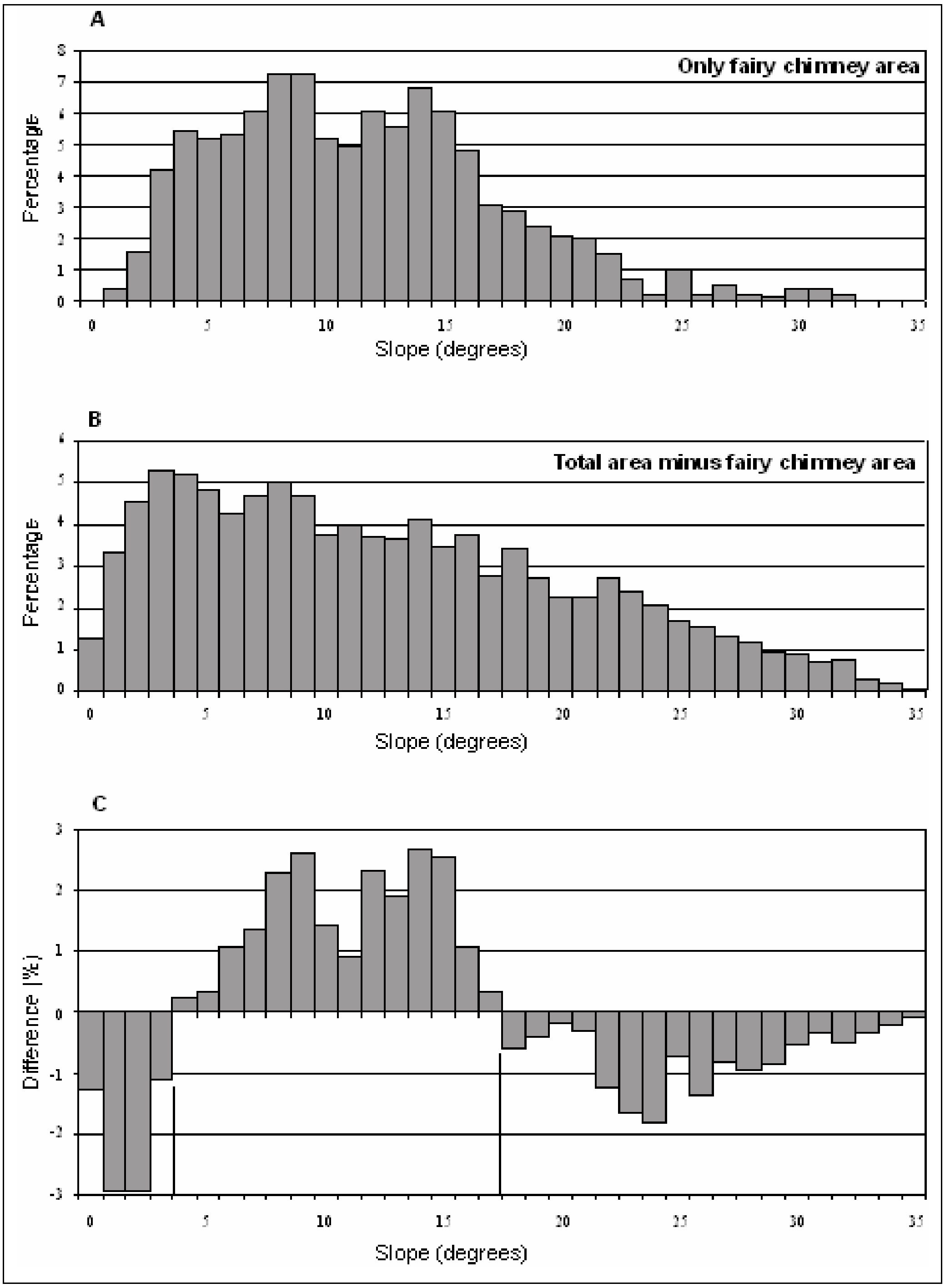


Figure 5.9. Slope histograms for the Kavak fairy chimney regions (A), for the rest of the area (B) and the difference of A and B (C).

Summary of statistics for the fairy chimneys measured in the Kavak Ignimbrite is shown in Table 5.3 and Table 5.4. The first table shows the statistics for "only cap" type fairy chimneys, and the second table for "cap+body" type.

"Only cap" type fairy chimney (n=39) are characterized by mean slope values ranging from 58.18 to 60.62 degrees with a hight of 15.82 m. Two diameters measured perpendicular and parallel to the slope of the area are, 13.08 and 16.62 m, respectively.

Table 5.3. Slope (S), diameter (D) and height (H) data measured from "only cap" type fairy chimneys of the Kavak Ignimbrite (n=39) (See Figure 4.4 for the definition of columns).

	S1	**S2**	**S3**	**S4**		**D1**	**D2**		**H**
Min Value	45	47	40	43		8.2	8.7		10.3
Max Value	72	72	76	77		20.5	31.7		28.3
Mean	**60.08**	**60.62**	**58.18**	**58.67**		**13.08**	**16.62**		**15.82**
Median	60.0	60.0	59	60		12.7	15.4		15.6
St. Dev.	7.35	6.08	6.88	8.27		13.08	5.87		4.02
St. Error	1.17	0.97	1.10	1.32		0.51	0.94		0.64
Variance	54.02	36.93	47.31	68.33		10.23	34.42		16.21

Table 5.4. Slope (S), diameter (D) and height (H) data measured from "cap+body" type fairy chimneys of the Kavak Ignimbrite (n=70) (See Figure 4.4 for the definition of columns).

	CAP							**BODY**		
	S1	**S2**	**S3**	**S4**	**D1**	**D2**	**H**	**D1**	**D2**	**H**
Min Value	45	45	44	44	1.6	1.1	0.7	3	3.5	1.3
Max Value	78	80	73	74	18.6	23	21.0	70	24.4	23.5
Mean	**62.16**	**60.84**	**59.84**	**60.24**	**8.3**	**9.75**	**8.95**	**11.70**	**13.20**	**10.10**
Median	62	60	60	60	8.35	8.95	8.4	10.8	13.0	9.3
St. Dev.	6.89	7.75	6.89	7.05	3.98	4.91	4.83	7.81	5.1	5.02
St. Error	0.82	0.93	0.82	0.84	0.47	0.59	0.58	0.93	0.61	0.60
Variance	47.44	60.05	47.58	49.69	15.85	24.12	23.32	61.07	26.01	25.25

“Cap+body” type fairy chimneys (n=70) are composed of a body at the bottom and a cap at the top. Therefore, the data measured for these chimneys differ from the previous one for which the diameter(s) and height are recorded for both upper and lower parts.

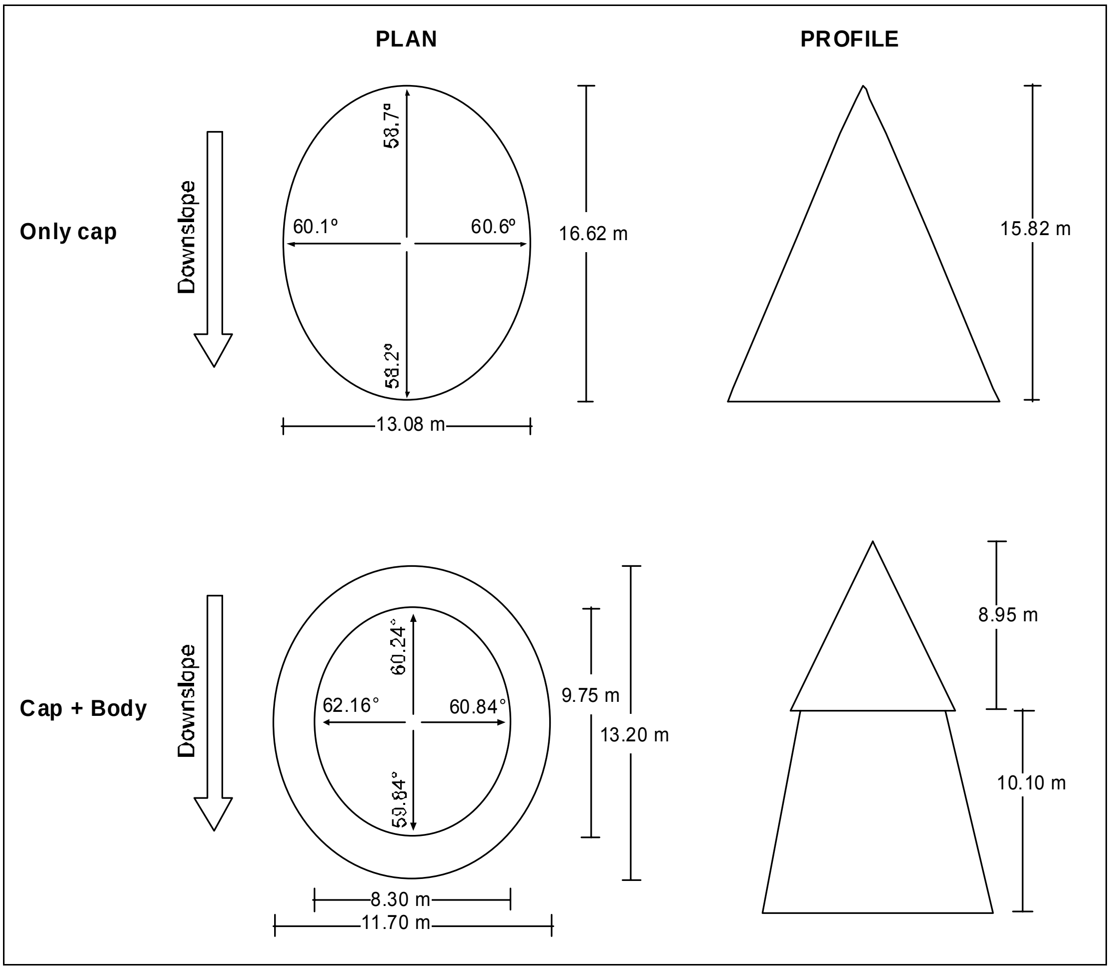


Figure 5.10. Parameters measured from the Kavak fairy chimneys in plan and profile as shown in Tables 5.3 and 5.4. Numbers are the mean values.

All the measuremets are plotted in plan and profile (Figure 5.10) from which following observations can be made:

- Height of the cap for “only cap” type chimney is greater than the cap of “cap+body” type chimney. It is, however, smaller than the total height of cap+body.

- Diameter of the “only cap” type is grater than the diameter of both body and cap of “cap+body” type fairy chimney. Diameter of cap without a body is almost one-and-a-half times greater than the diameter of the cap with a body.
- Fairy chimneys are slightly elongated parallel to the slope of the topography based on the diameters of cap and body. Two diameters are divided (D1/D2) for each type to quantify degree of elongation (roundness) of the chimneys. The results (Table 5.5) indicate that the roundness range from 0.79 to 0.89 and is consistent in downslope direction. The maximum elongation is therefore, observed in “only cap” type fairy chimney.
- Slope amounts measured in four directions are all about 60 degrees for the caps either with or without body. Therefore, the chimneys are almost symmetrical. Considering the slight variations in the slope values, it can be concluded that the slopes of the caps perpendicular to the slope of the area is greater than other direction.

All these values yield valuable information on the evolution of the fairy chimneys and will be discussed in more detail in the DISCUSSION chapter.

Table 5.5. Roundness of fairy chimneys for the Kavak Ignimbrite obtained by D1/D2.

Part of fairy chimney	Roundness (D1/D2)
Cap (only cap type)	0.79
Cap (cap+body type)	0.85
Body (cap+body type)	0.89

The last analysis for the fairy chimneys of the Kavak Ignimbrite is the calculation of distances between the chimneys by a program written in BASIC language. The coordinates of the chimneys identified from the Google Earth image (Figure 5.5) is used for this analysis. The result of this analysis is given in Table 5.6. For some chimneys the same distance value is obtained due to location of fairy chimneys in the whole population. For example two fairy chimneys close to each other and away from other will yield the same value.

Table 5.6. Distances (in meters) between fairy chimneys of the Kavak Ignimbrite.

No	Distance	No	Distance	No	Distance	No	Distance	No	Distance
1	164.6	30	72.5	59	58.3	88	19.6	117	112.0
2	37.7	31	15.9	60	52.6	89	54.1	118	60.8
3	37.7	32	72.3	61	12.4	90	76.6	119	22.9
4	56.9	33	33.3	62	19.6	91	23.6	120	20.5
5	36.0	34	24.6	63	60.0	92	23.6	121	20.5
6	27.2	35	24.8	64	28.3	93	51.6	122	19.3
7	27.2	36	17.9	65	49.4	94	47.9	123	49.4
8	50.5	37	62.3	66	26.8	95	82.8	124	17.9
9	26.1	38	42.3	67	34.8	96	12.8	125	15.9
10	26.1	39	42.3	68	35.0	97	47.7	126	39.2
11	60.8	40	56.2	69	35.0	98	12.8	127	39.2
12	19.0	41	74.0	70	80.2	99	47.9	128	56.2
13	58.1	42	63.6	71	21.3	100	17.6	129	55.0
14	117.1	43	12.8	72	149.4	101	20.5	130	33.0
15	68.3	44	32.4	73	48.5	102	20.5	131	16.6
16	34.1	45	12.8	74	97.9	103	30.0	132	26.8
17	60.8	46	29.9	75	31.8	104	33.4	133	19.0
18	19.0	47	32.8	76	108.1	105	29.8	134	19.0
19	68.3	48	40.0	77	57.4	106	22.8	135	58.3
20	82.5	49	32.4	78	37.5	107	25.1	136	30.0
21	55.7	50	39.4	79	47.1	108	65.3	137	30.0
22	44.4	51	29.9	80	22.9	109	36.0	138	34.8
23	59.9	52	44.4	81	24.4	110	57.5	139	54.1
24	62.3	53	33.8	82	28.9	111	12.7	140	76.1
25	19.3	54	32.8	83	22.2	112	57.5	141	23.9
26	83.2	55	45.3	84	22.2	113	21.3	142	23.9
27	12.7	56	12.4	85	44.8	114	90.2	143	22.0
28	72.3	57	44.4	86	41.0	115	31.8	144	25.1
29	59.9	58	45.3	87	41.0	116	69.2	145	22.8

Histogram prepared from the distances is illustared in Figure 5.11. The minimum distance is 12.4 m while the maximum is 164.6 m. The mean distance is 42.73 m with a dominant concentration between 15 and 35 m.

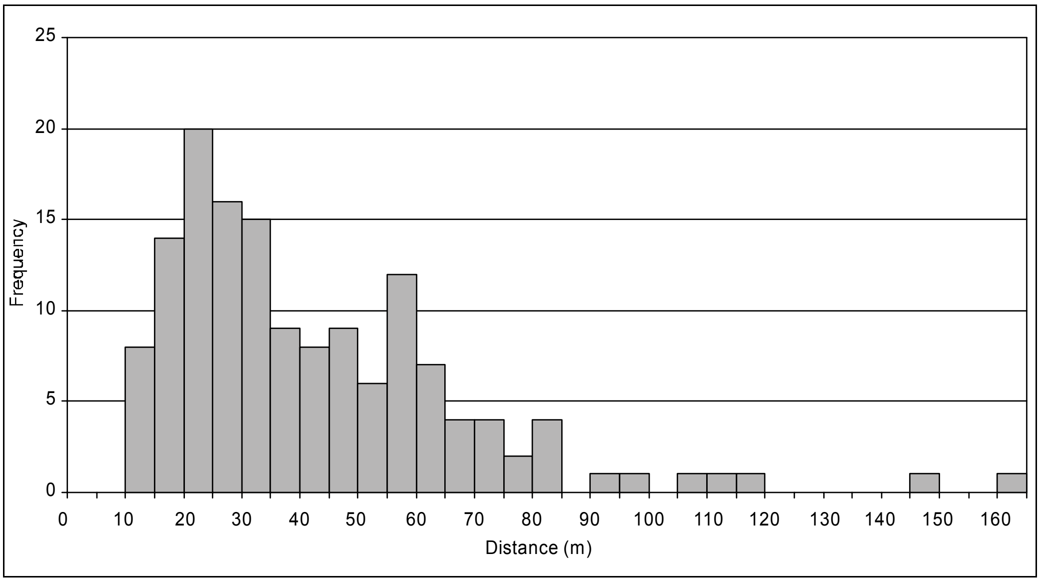


Figure 5.11. Histogram of the distances between the fairy chimneys of the Kavak Ignimbrite.

Table 5.7. Summary of distances statistics for the Kavak fairy chimneys.

Min Value	12.4
Max Value	164.6
Mean	**42.73**
Median	35.0
St. Dev.	25.78
St. Error	2.14
Variance	664.65

5.2. Kavak-Zelve transition fairy chimneys

The next fairy chimney stratigraphically above the Kavak Ignimbrites is the one developed at the boundary of the Kavak and Zelve Ignimbrites (Figure 4.2). This fairy chimney is exposed in a local area in the vicinity of Çavuşin village (Figure 4.3), particularly in a small area around Paşabağı locality which is one of the most attractive sites in the region with its panoramic view (Figure 5.12).

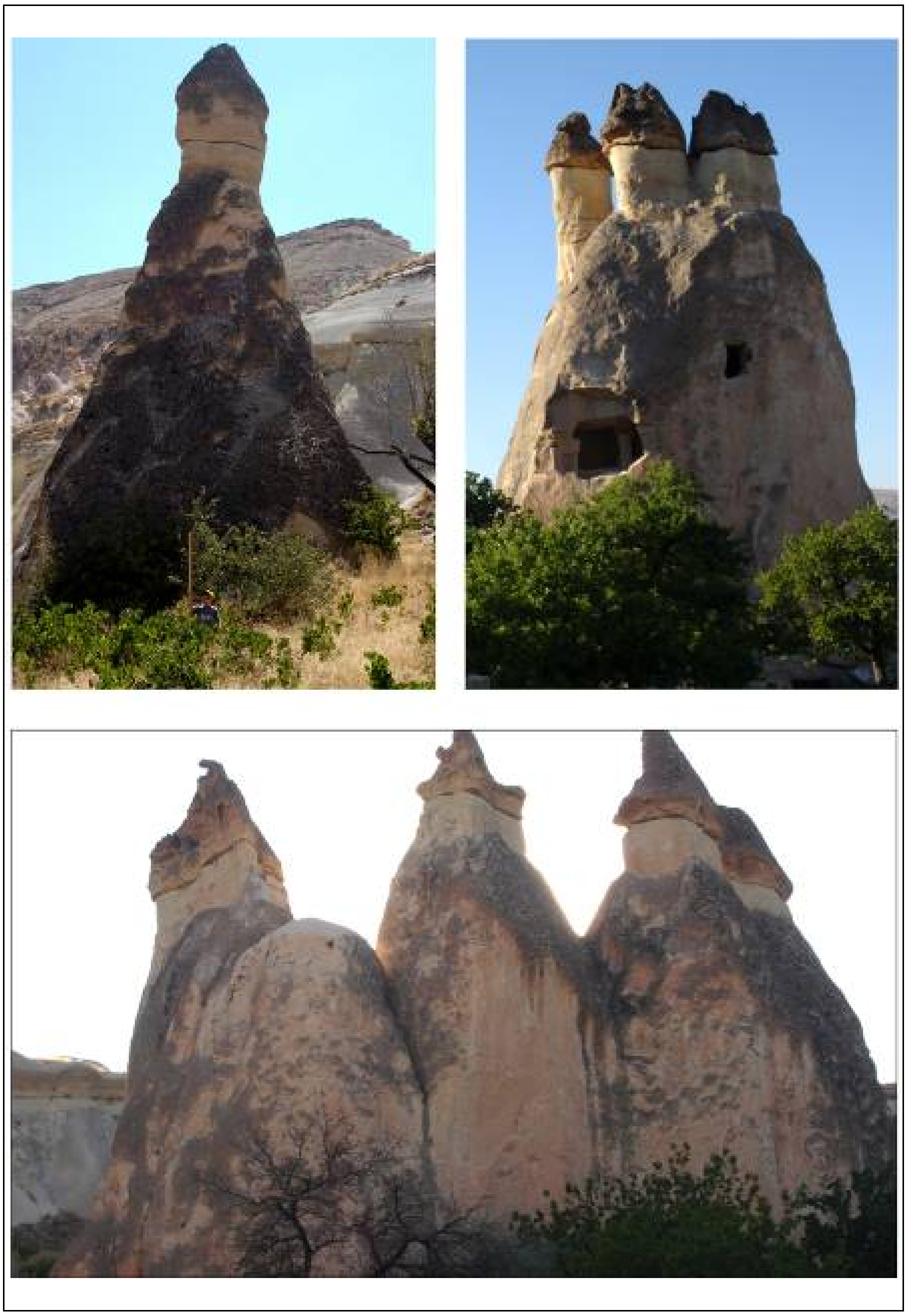


Figure 5.12. Views of fairy chimneys developed at Kavak and Zelve transition (Locality: Paşabağı).

The fairy chimneys of this transition are unique with its structure because they are composed of two different ignimbrites. The lower part (body) of the chimney belongs to Kavak, and the upper part (cap) belongs to fall deposits of the Zelve Ignimbrite. There is a thin layer of continental sediment (1-1.5 m) between the body and the cap (Figure 5.13). The cap material with a thickness of about 6 m is totally made up of pumice and is more resistant than underlying ignimbrite due to its cohesion. The whole sequence is gently dipping (3º-5º) towards N-NE.

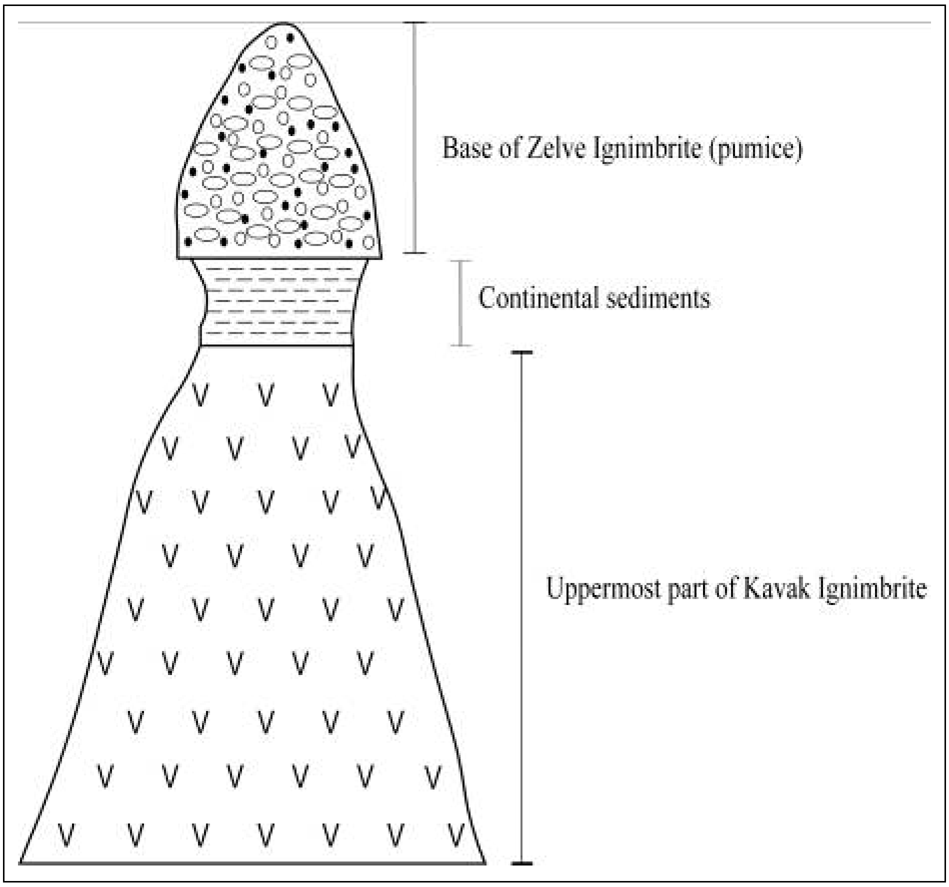


Figure 5.13. Section showing details of the lithological parts of fairy chimneys developed at Kavak-Zelve transition.

General appearance of these fairy chimneys is almost the same as far as the body and the cap are considered. The difference, however, is in the development of the the cap above the body. Although, in general, there is one cap for each body, in some cases, more than one cap can form over a single body (Figure 5.12).

Elevation and slope maps of the area where the measurements were taken are shown in Figure 5.14. Elevation gradually increases southward from 1000 to 1080 m. Maximum slope is at the southern margin which is the transitional area between Kavak and Zelve Ignimbrites where the fairy chimneys were developed.

Histograms prepared for two regions, namely for fairy chimney developed area and the rest of the area are illustrated in Figure 5.15-A and B, respectively. Both histograms indicate that maximum concentration is about 8-10 degrees. Difference of these two histograms, however, suggests that fairy chimneys prefer to develop at certain slope values. Accordingly, the fairy chimneys are formed at two intervals. These intervals are given in Table 5.8.

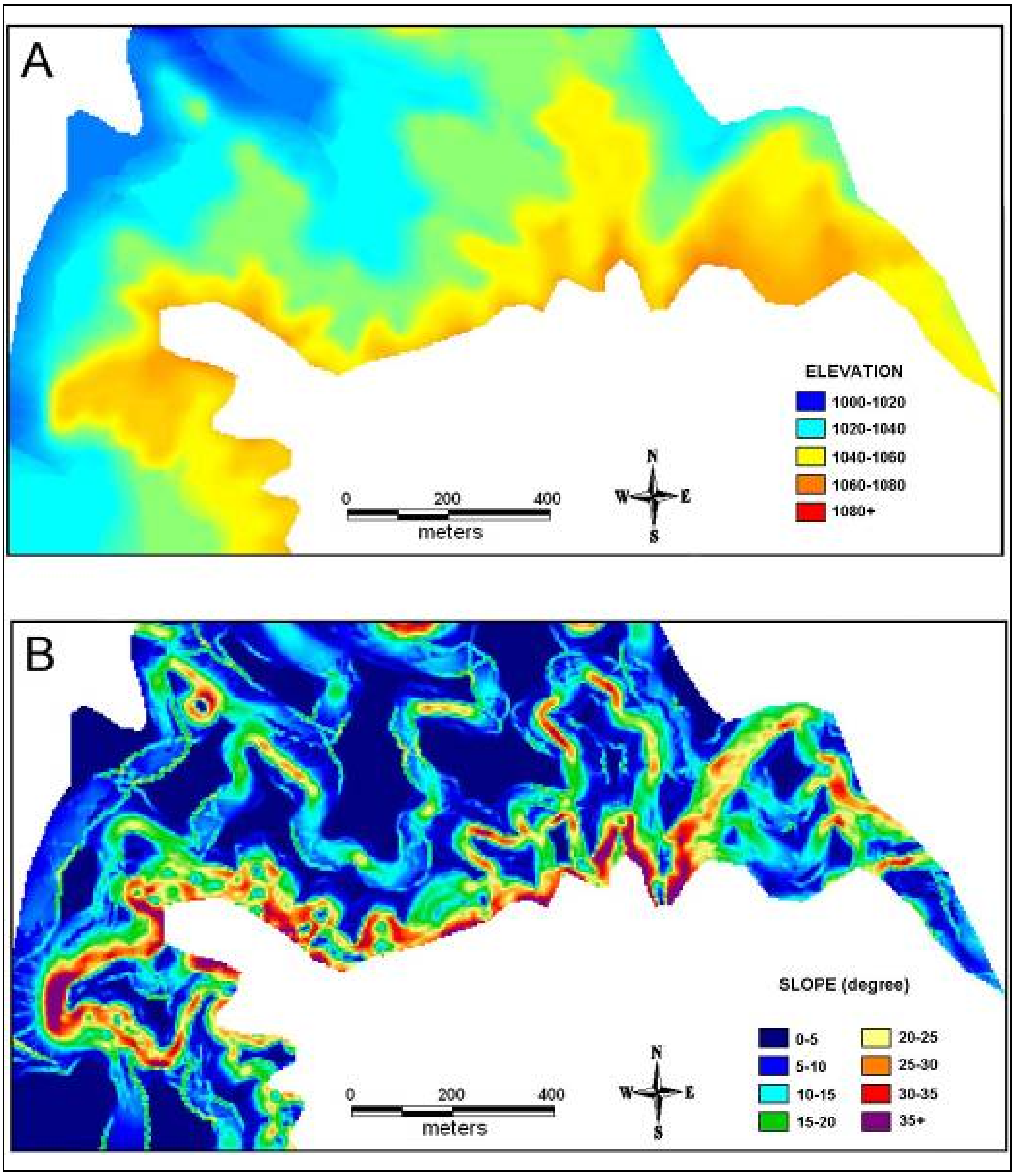


Figure 5.14. Elevation (A) and slope map (B) for Kavak-Zelve transition.

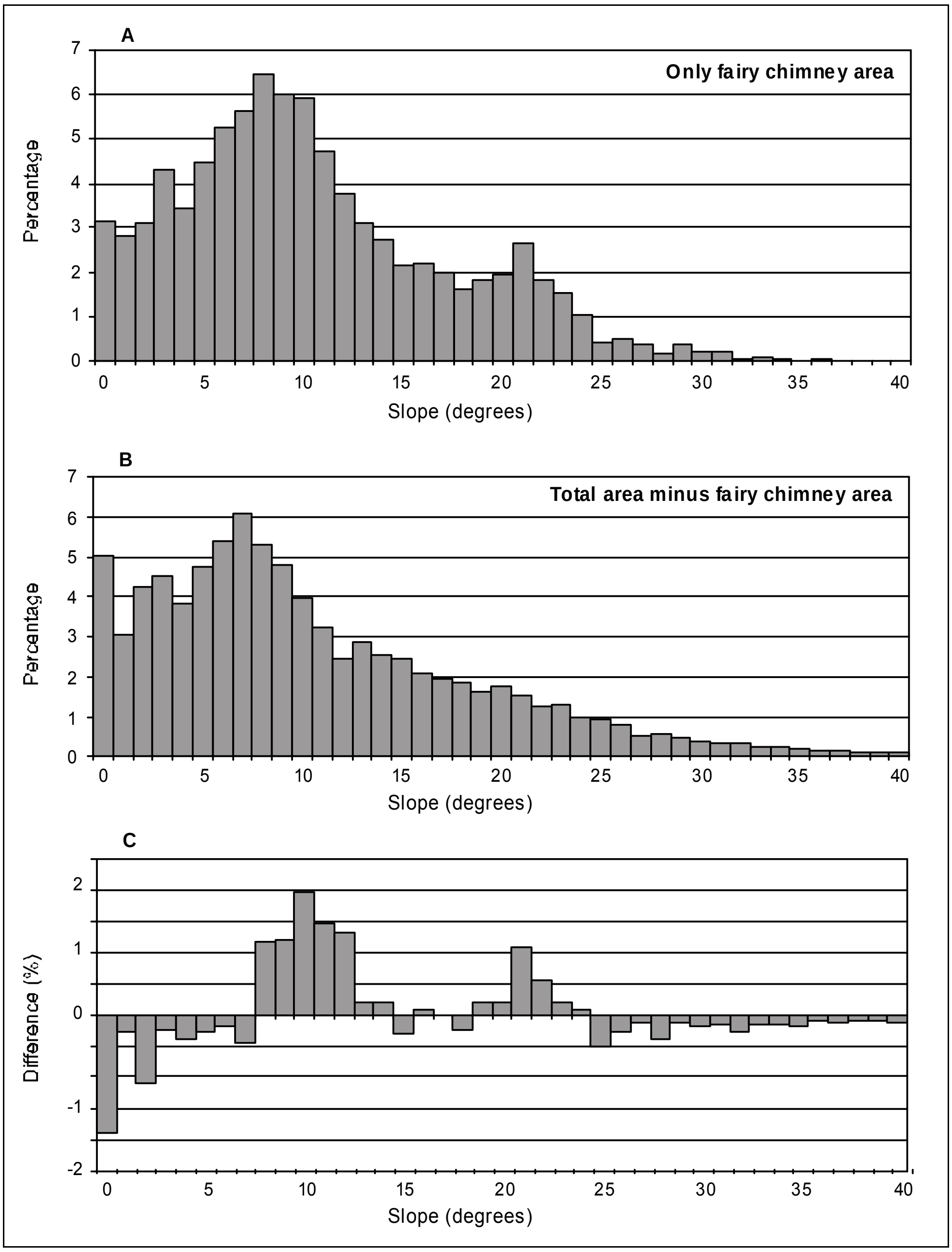


Figure 5.15. Slope histograms for the Kavak-Zelve transition fairy chimney regions (A), for the rest of the area (B) and the difference of A and B (C).

Table 5.8. Slope suitability for the Kavak –Zelve tarnsition fairy chimneys.

Preference	**Slope (degree)**
Preferred intervals	8-14 and 19-24
Not preferred intervals	<7 and 15-18 and >24

Summary of the statistics for the fairy chimneys measured at Kavak-Zelve transition (Appendix B) is shown in Table 5.9. A total of 31 chimneys were measured two of which are lacking the caps. Four slope values for the cap range from 54.43 to 60.64 degrees. The mean basal diameter and the height of cap are about 3.5 and 2.6 m, respectively. The body, on the other hand, has a basal diameter of 7-8 m and a height of 12 m.

All these measurements are plotted in plan and profile (Figure 5.16) from which following observations are made:

- Height ratio of cap to body is about 1/5. Contrary to the Kavak Ignimbrite, the cap in this one is the minor part of the chimney. Considering total thickness of cap in the area (5-6 m) it can be inferred that about 50 % of this thickness was eroded for an ideal fairy chimney.
- Diameter of cap is considerably smaller than the diameter of body (e.g. less than the half).
- Slope amounts suggest that the cap is slightly asymmetric towards downward left (SW if oriented). There is a difference of 5 degrees in both up-to-down and right-to-left directions.
- Fairy chimneys are slightly elongated parallel to the slope of the topography based on the diameters of cap and body. This elongation (roundness) is found by D1/D2 and is illustrated in Table 5.10 both for cap and the body.

Table 5.9. Data measured from the fairy chimneys of Kavak-Zelve transition (n=31) (See Figure 4.4 for the definition of columns).

	CAP							BODY		
	S1	**S2**	**S3**	**S4**	**D1**	**D2**	**H**	**D1**	**D2**	**H**
Min Value	40	50	40	49	1.1	1.2	0.7	3	5	8.5
Max Value	72	77	65	70	10.6	13	6.2	13.5	14.3	17.9
Mean	**55.11**	**60.64**	**54.43**	**59.9**	**3.48**	**3.63**	**2.62**	**7.38**	**8.11**	**12.17**
Median	55	60	55	60	3.4	3.6	2.7	7.1	7.5	11.7
St. Dev.	6.95	6.493	6.038	5.999	1.939	2.07	1.132	2.572	2.166	2.588
St. Error	1.29	1.206	1.121	1.114	0.36	0.385	0.21	0.462	0.389	0.465
Variance	48.381	42.158	36.46	35.995	3.76	4.295	1.28	6.618	4.693	6.7

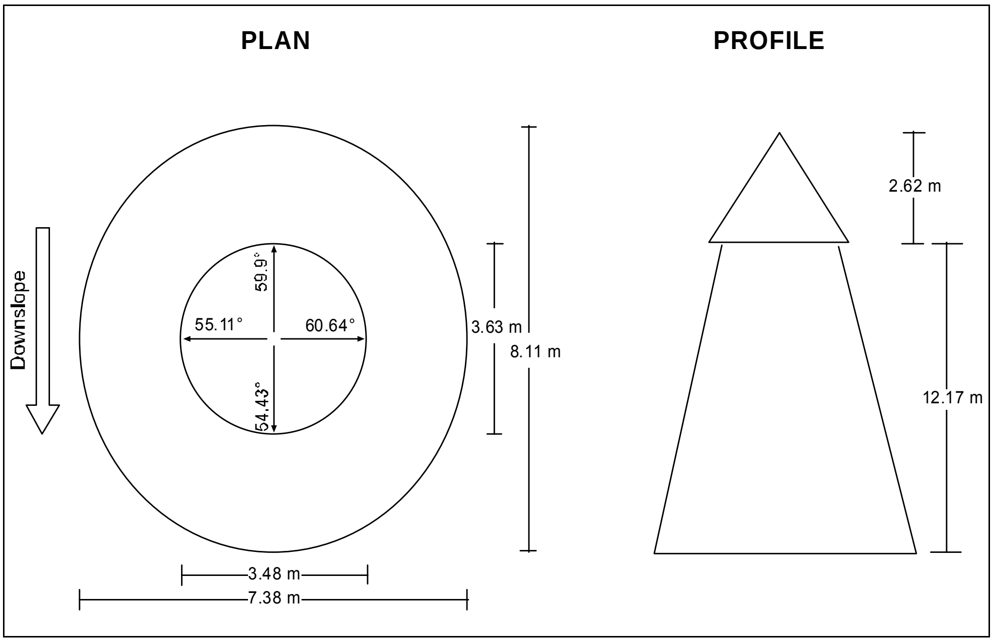


Figure 5.16. Parameters measured from the Kavak-Zelve transition fairy chimneys.

Table 5.10. Roundness of fairy chimneys for the Kavak-Zelve transition fairy chimneys (obtained by D1/D2).

Part of fairy chimney	Roundness (D1/D2)
Cap	0.96
Body	0,91

5.3. Zelve Ignimbrite fairy chimneys

The Zelve Ignimbrite stratigraphically overlies the Kavak Ignimbrite (Figure 4.2) separated by a thin sedimentary layer. The fairy chimneys developed within this ignimbrite are extensively exposed east of Çavuşin around Akdağ mountain (Figure 5.17). The chimneys were formed at the slopes of steep hills and are densely populated (Figure 5.18). Two common characteristics of these chimneys are: 1) they lack systematic cap rock and 2) gas escape structures are widely observed (Figure 5.18-A and B).

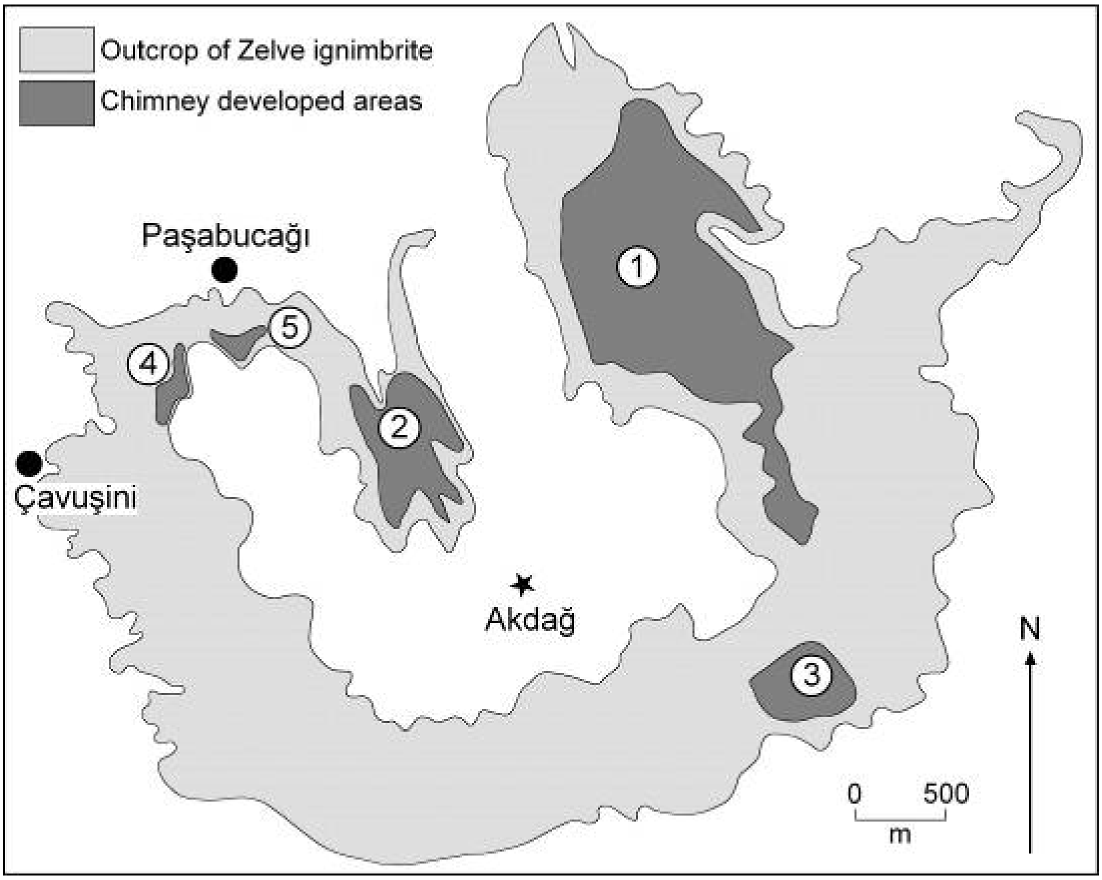


Figure 5.17. Location map for measurements of the Zelve fairy chimneys. Numbered polygon indicate the areas where fairy chimneys were developed.

Elevation and slope maps of the area analyzed and measured are shown in Figure 19. Elevation of the area gradually increases towards the south from 1000 to 1200 m. The slope, on the other hand generally increases towards the west with maximum values at the upper boundary of the Zelve Ignimbrite. The fairy chimneys are developed in certain parts of the outcrop. These regions are indicated in Figure 5.17. Histograms for the slope values for these regions are illustrated in Figure 5.19. Histogram A in the figure shows the slope values for the chimney developed areas, whereas B shows the values for the rest of the area. Difference of these histograms is illustrated in C. Positive values in this histogram are the slopes where chimneys prefer to develope. The negative numbers indicate the slope values which is not suitable for the formation of the fairy chimneys. Accordingly, the fairy chimneys were developed in the slope range of 2 to 13 degrees (Table 5.11)

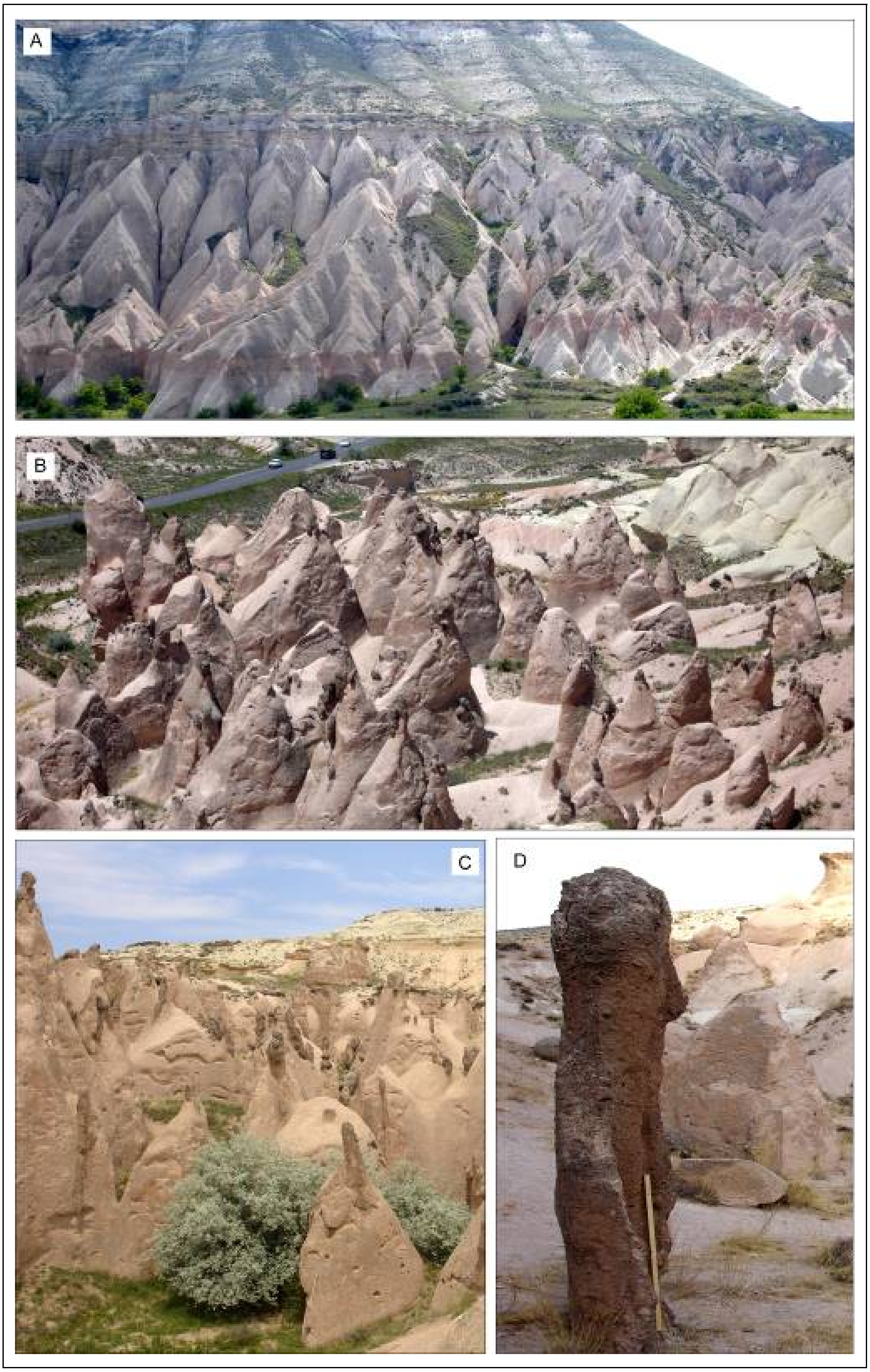


Figure 5.18. General views of the fairy chimneys of the Zelve Ignimbrite. A: General view of the Zelve Ignimbrite at the footslope of Akdağ mountain, B: fairy chimneys formed at lower slopes, C and D: Gas escape structures within the chimneys.

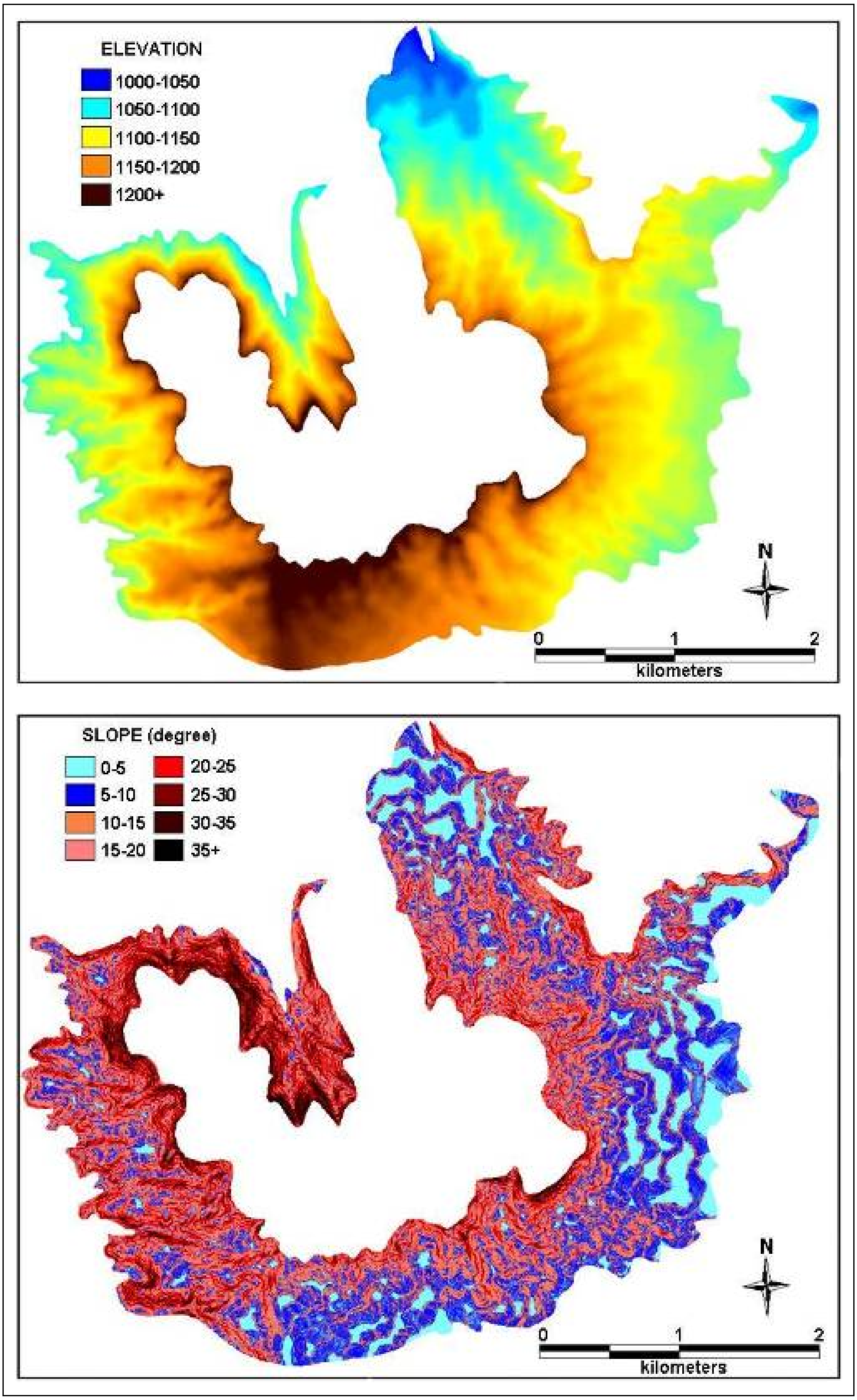


Figure 5.19. Elevation (above) and slope (below) map of the area where measurements are taken for the fairy chimneys developed in the Zelve Ignimbrite.

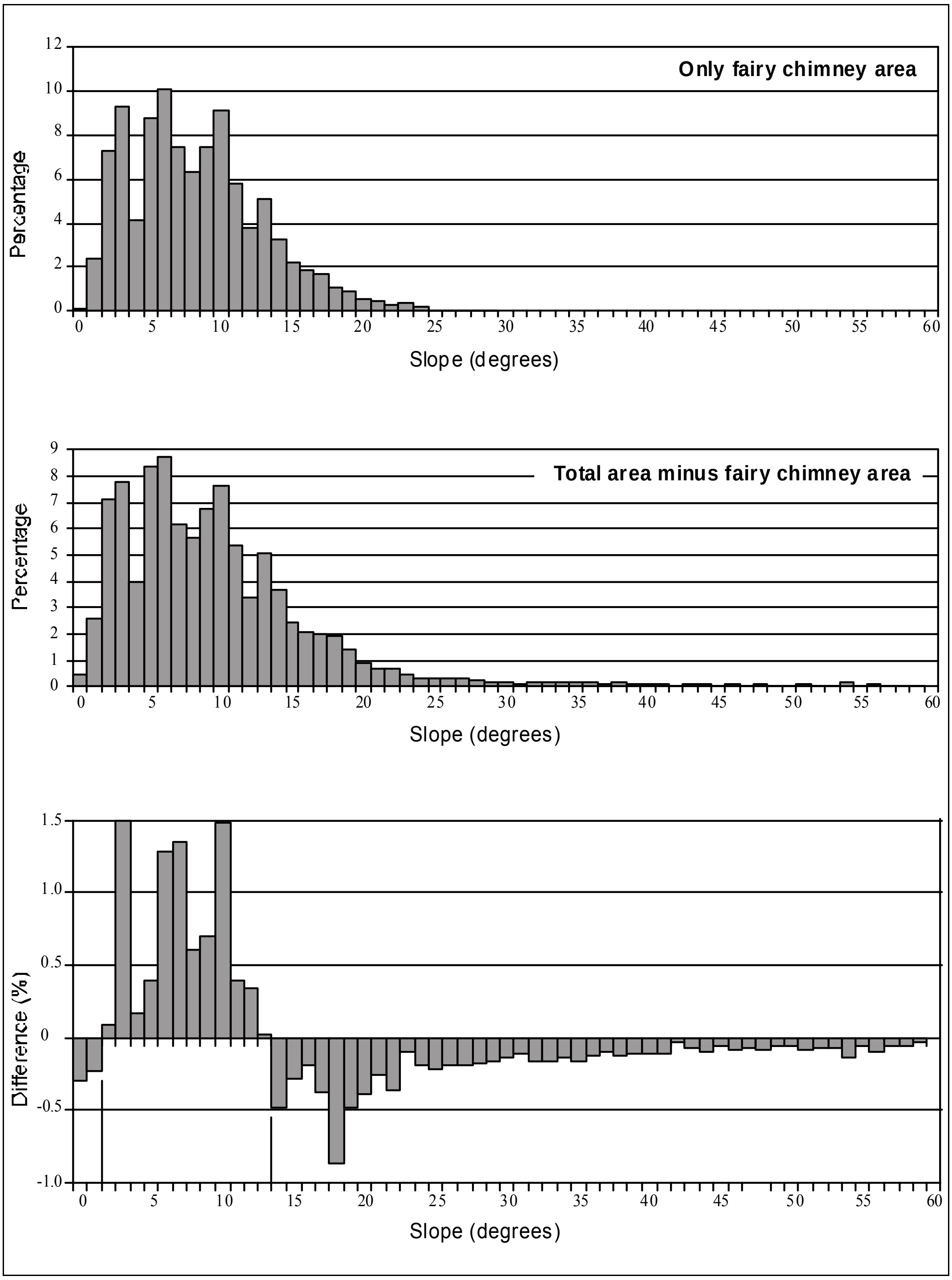


Figure 5.20. Slope histograms forthe Zelve fairy chimney regions (A), for the rest of the area (B) and the difference of A and B (C).

Table 5.11. Slope suitability for the Zelve fairy chimneys.

Preference	**Slope (degree)**
Preferred intervals	2-13
Not preferred intervals	<2 and >13

Summary of the statistics for the fairy chimneys measured at the Zelve Ignimbrite (Appendix C and D) is shown in Table 5.12. A total of 90 chimneys were measured in the area. These data were collected from two sites; one from the northern slope of Akdağ mountain (45 measurements) and the other from the eastern slope (45 measurements). Four mean slope values range from 69.51 to 70.06 degrees. The basal diameters are 5.62 m (parallel to slope of topography) and 4.70 m (perpendicular to slope). Mean elevation of the chimneys is 7.47 m.

Table 5.12. Data measured from the fairy chimneys of the Zelve Ignimbrite (n=90) (See Figure 4.4 for the definition of columns).

	S1	**S2**	**S3**	**S4**		**D1**	**D2**		**H**
Min Value	52.0	50.0	47.0	51.0		0.8	0.9		2.7
Max Value	88.0	88.0	84.0	89.0		15.0	14.4		20.5
Mean	**70.06**	**69.51**	**65.34**	**69.34**		**4.70**	**5.62**		**7.47**
Median	70.0	70.0	65.0	70.0		4.0	4.95		5.85
St. Dev.	8.43	9.10	8.42	8.85		2.90	3.27		4.22
St. Error	0.89	0.96	0.89	0.93		0.30	0.34		0.44
Variance	71.11	82.81	70.81	78.41		8.40	10.70		17.85

Plan and profile views of these measurements are shown in Figure 5.21. Following observation can be made from these plots:

- Slope values are almost the same in three directions (left, right and upslope) with values of about 70 degrees. The amount in downslope direction, on the other hand, is 65 degrees indications an asymmetric body inclined towards the downslope.

- Fairy chimneys are slightly elongated parallel to the slope of the topography based on two diameters. This elongation (roundness) is 0.84 found by dividing D1 into D2.

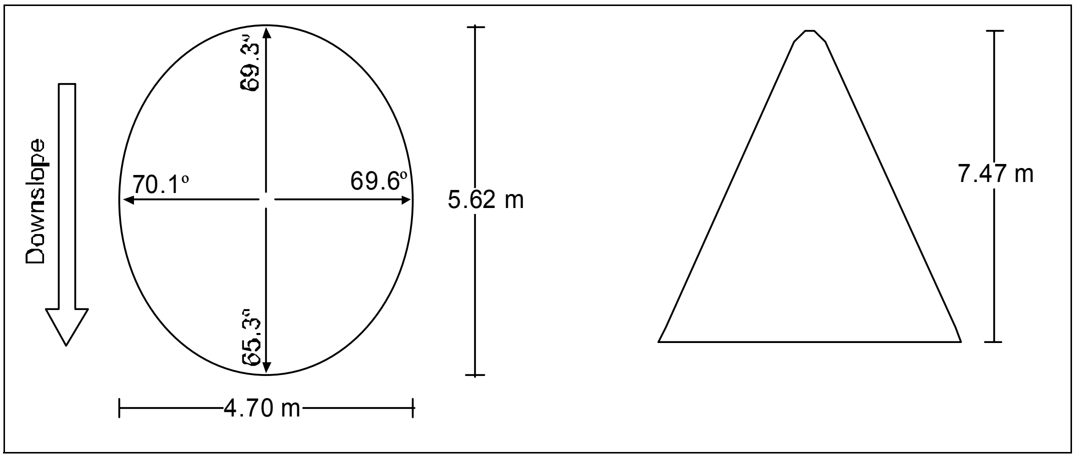


Figure 5.21. Parameters measured from the Zelve fairy chimneys in plan and profile as shown in Table 5.12. Numbers are the mean values.

The last analysis made for the Zelve fairy chimneys is the measurement of the distances between neighbouring chimneys. There is no base map with a suitable scale on which individual fairy chimneys can be plotted. Present GPS technology is also not sensitive enough for this measurement as the error is about 5 m. Therefore, the distances between fairy chimneys were measuered in two sites where other data were measured by using a steel tape of 50 m as shown in Figure 4.6. The distance was measured from the center of one chimney to the center of other chimney. A total of 100 distances were measured from two sites (Table 5.13)

Histogram of the distance measurements and basic statistics are given in Figure 5.22 and Table 5.14, respectively. The minimum and maximum distances, and the mean distance are 3.1, 8.5 and 5.45 m, respectively.

Table 5.13. Distances (in meters) between fairy chimneys of the Zelve Ignimbrite.

No	Distance	No	Distance	No	Distance	No	Distance	No	Distance
1	4,0	21	7,5	41	5,5	61	6,5	81	4,2
2	5,4	22	3,3	42	7,1	62	5,2	82	7,2
3	3,3	23	4,9	43	4,0	63	6,3	83	5,4
4	6,5	24	4,2	44	5,8	64	7,0	84	3,8
5	6,2	25	8,6	45	4,2	65	7,2	85	4,7
6	5,4	26	5,8	46	6,7	66	6,4	86	6,2
7	3,9	27	6,9	47	5,2	67	5,1	87	4,6
8	3,7	28	6,1	48	4,4	68	6,6	88	5,9
9	4,1	29	3,5	49	7,1	69	4,4	89	5,1
10	3,9	30	4,7	50	6,8	70	4,9	90	4,3
11	5,9	31	3,8	51	6,6	71	6,2	91	3,7
12	3,1	32	8,1	52	5,9	72	5,3	92	7,1
13	4,4	33	4,6	53	6,2	73	5,7	93	6,1
14	3,6	34	5,7	54	7,1	74	7,6	94	4,6
15	3,2	35	6,2	55	4,8	75	5,2	95	5,3
16	5,3	36	7,7	56	5,4	76	4,9	96	6,6
17	5,2	37	5,1	57	7,3	77	6,6	97	5,4
18	3,1	38	8,3	58	4,2	78	4,1	98	5,9
19	3,7	39	5,4	59	6,9	79	5,5	99	4,7
20	5,5	40	6,4	60	5,1	80	4,8	100	6,3

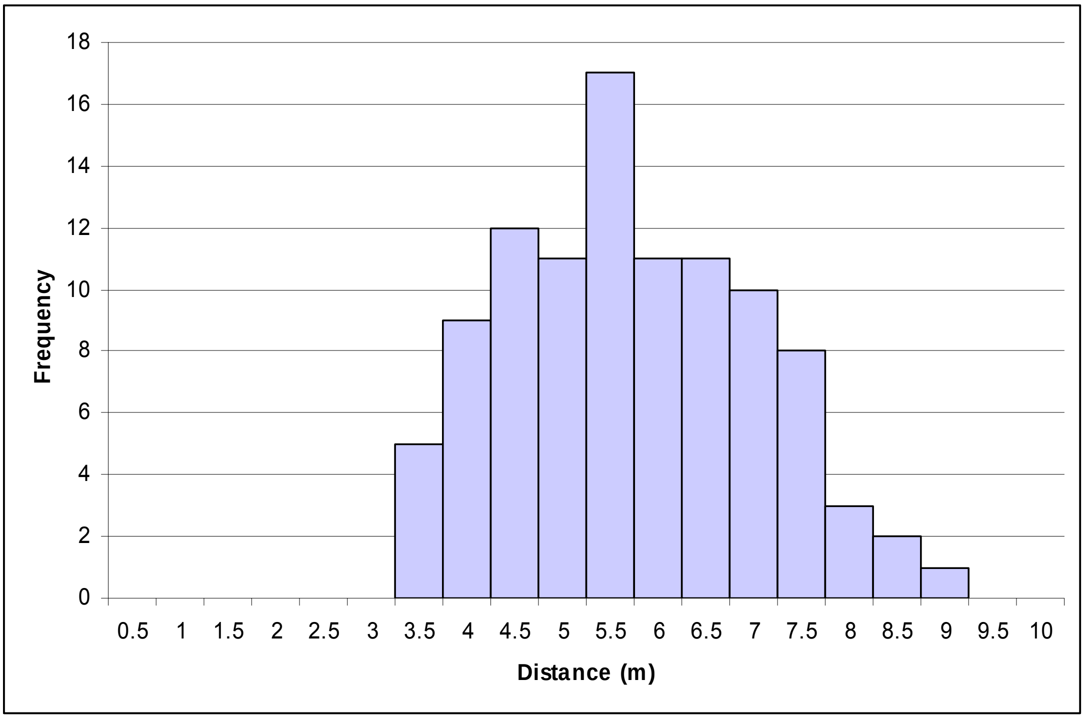


Figure 5.22. Histogram of the distances between fairy chimneys of the Zelve Ignimbrite.

Table 5.14. Summary of distance statistics for the Zelve fairy chimneys.

Min Value	3.1
Max Value	8.5
Mean	**5.45**
Median	5.4
St. Dev.	1.28
St. Error	0.13
Variance	1.64

5.4. Cemilköy Ignimbrite fairy chimneys

The Cemilköy Ignimbrite is exposed in the southeastern part of the area (Figure 3.1) around Cemilköy, Taşkınpaşa and Şahinefendi villages on both sides of Damsa valley (Figure 5.23). The fairy chimneys of this Ignimbrite were formed as populated groups at the slopes of the hills (Figure 5.24). Field studies indicate that most of the chimneys were formed on the western side of the valley (grey area in Figure 5.23).

The fairy chimneys have an ideal shape of cones and look like tents in the field. Although cap is not an essential part, in some chimneys a cap exists at the top. These caps unlike to Kavak and Kavak-Zelve transition fairy chimneys do not belong to a stratigraphic layer above the Ignimbrite, but rather belong to the Kızılkaya Ignimbrite which is startigraphically located at the upper level of the Ürgüp formation.

Elevation and slope maps of the area analyzed and measured are shown in Figure 5.25. Elevation of the area gradually decreases towards the south from 1400 to 1200 m. The fairy chimneys were developed almost at the interval 1300-1350 m. The slope of the area, on the other hand, reaches to values of 35 degrees although most of the fairy chimneys are located in the 5-15 degrees interval.

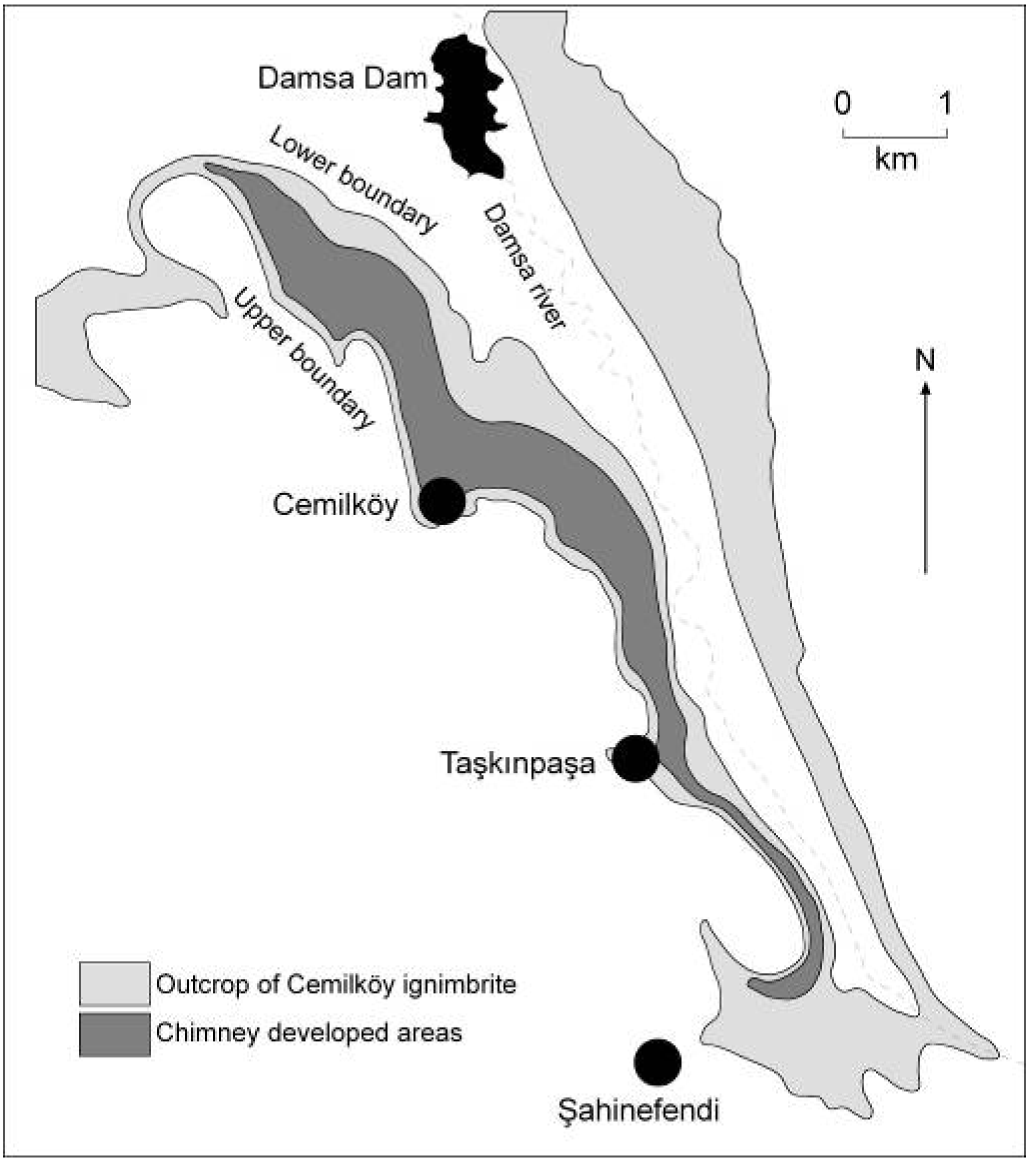


Figure 5.23. Location map for measurements of the Cemliköy fairy chimneys.

Histograms for the slope values for these regions are illustrated in Figure 5.26. Histogram A in the figure shows the slope values for chimney developed areas, whereas B shows the values for the rest of the area. Difference of these histograms is illustrated in C. Positive values in this histogram are the slopes where chimneys prefer to develope. The negative numbers indicate the slope values which is not suitable for the formation of the fairy chimneys. Accordingly, the fairy chimneys were developed in the slope range of 8 to 23 degrees (Table 5.15)

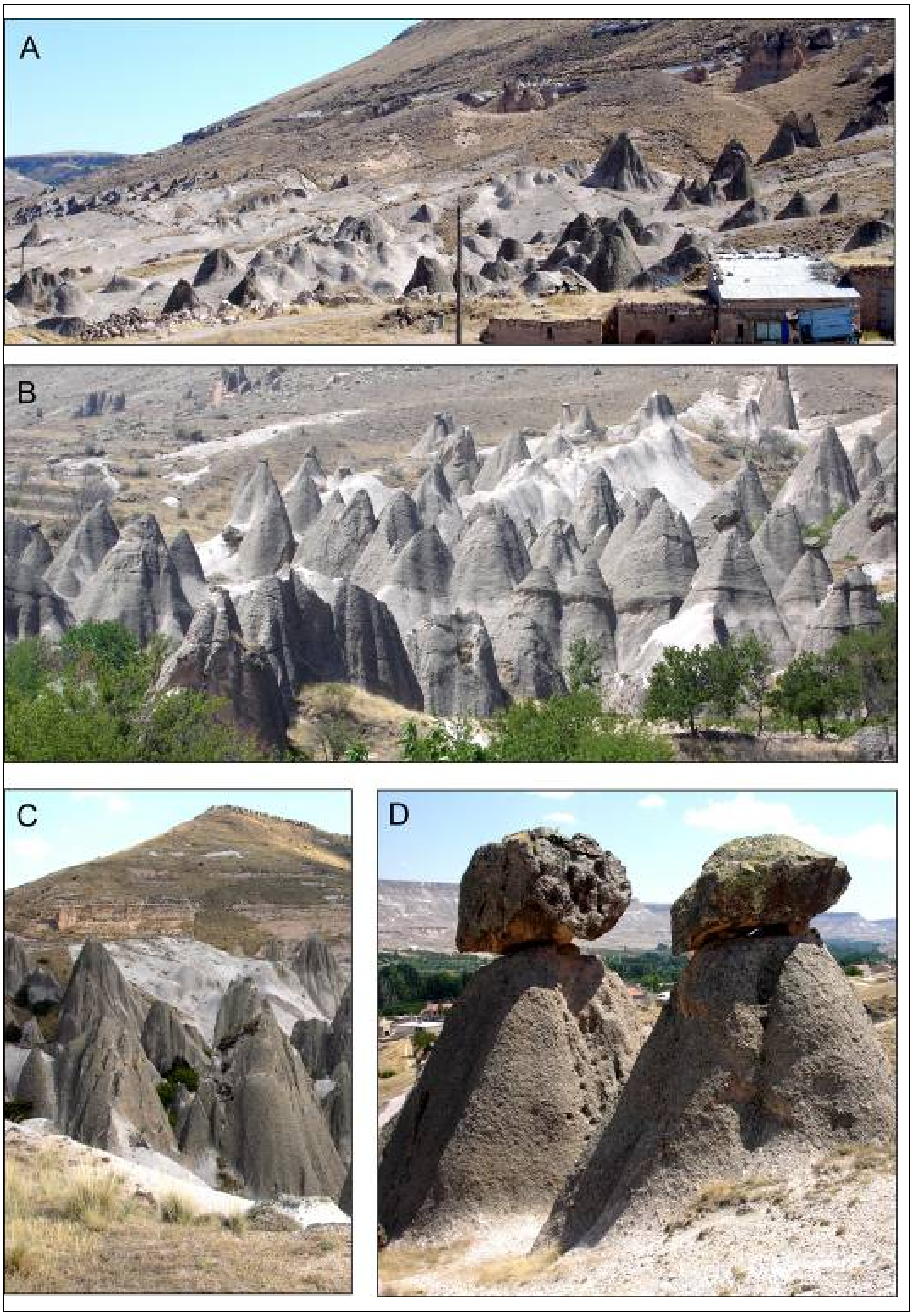


Figure 5.24. General views of the Cemilköy fairy chimneys between Cemilköy and Taşkınpaşa villages.

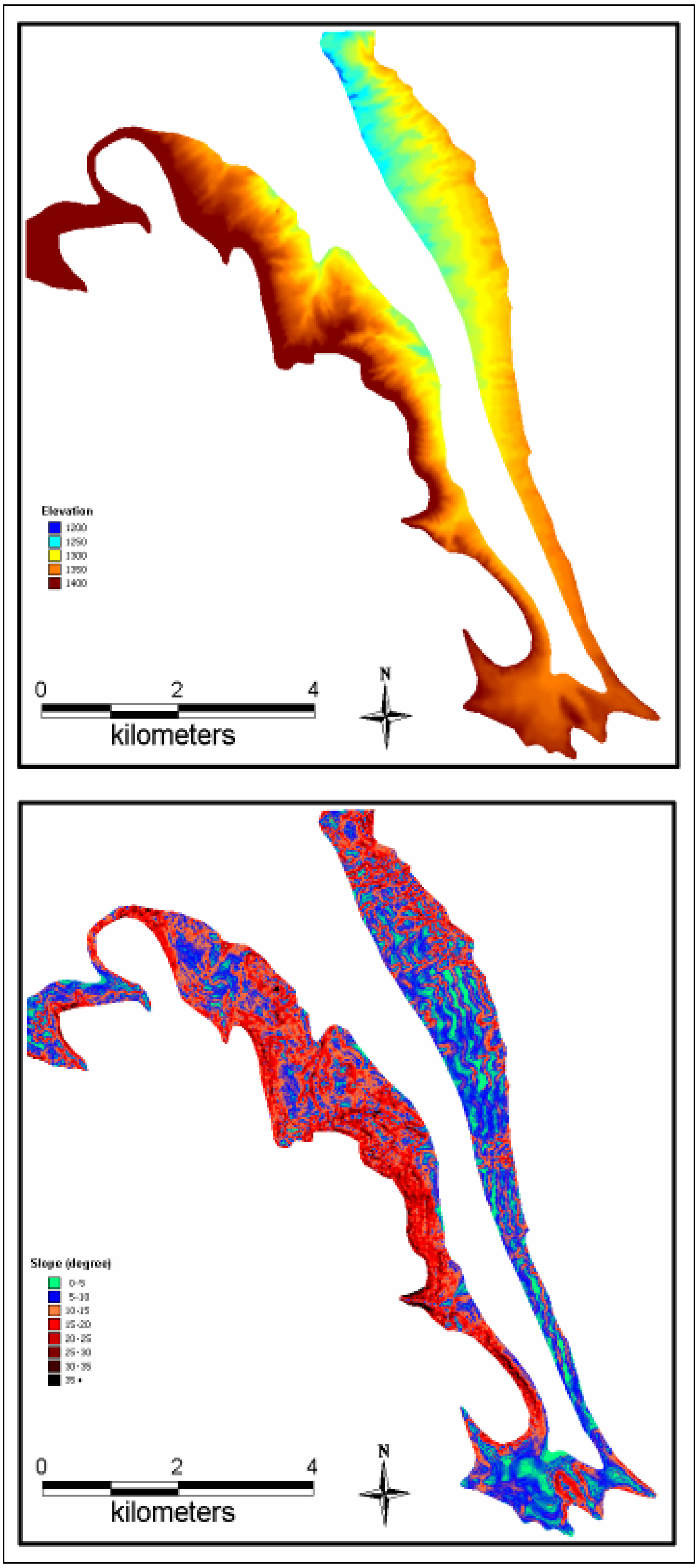


Figure 5.25. Elevation (above) and slope (below) map of the area where measurements were taken from the fairy chimneys developed in the Cemilköy Ignimbrite.

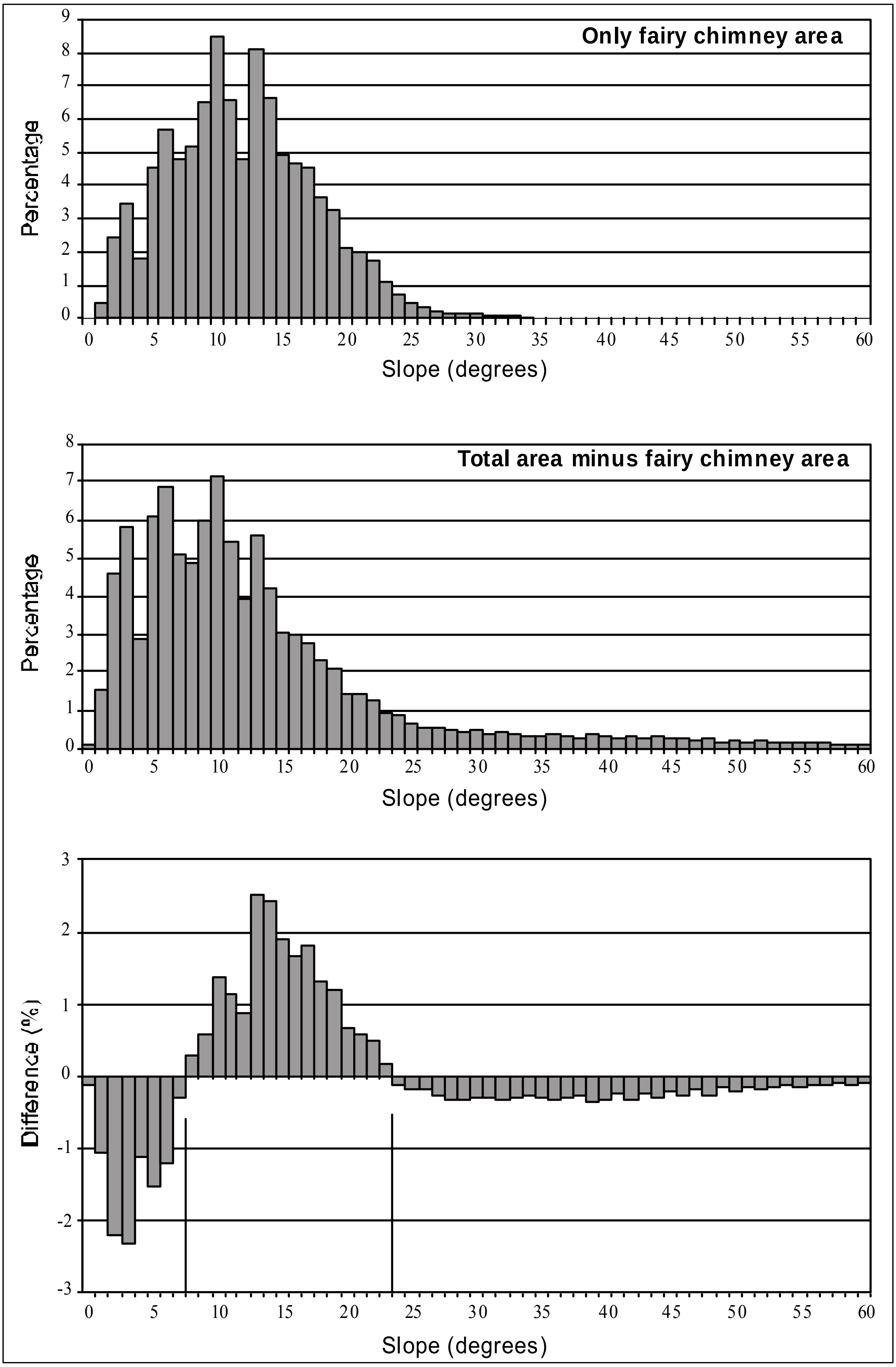


Figure 5.26. Slope histograms for the Cemilköy fairy chimneys regions (A), for the rest of the area (B) and the difference of A and B (C).

Table 5.15. Slope suitability for the Cemilköy fairy chimneys.

Preference	**Slope (degree)**
Preferred intervals	8-23
Not preferred intervals	<8 and >23

Summary of the statistics for the fairy chimneys measured at the Cemilköy Ignimbrite (Appendix E and F) is shown in Table 5.16. A total of 90 chimneys are measured in the area. These data are collected from two sites; one in the vicinity of Cemilköy village (45 measurements) and the other around Taşkınpaşa village (45 measurements). Four mean slope values range from 56.83 to 60.12 degrees. The basal diameters are 8.68 m (parallel to slope of topography) and 9.70 m (perpendicular to slope). Mean elevation of the chimneys is 8.41 m.

Table 5.16. Data measured from the fairy chimneys of the Cemilköy Ignimbrite (n=90) (See Figure 4.4 for the definition of columns).

	S1	**S2**	**S3**	**S4**		**D1**	**D2**		**H**
Min Value	30.0	32.0	35.0	30.0		2.8	3.4		2.9
Max Value	75.0	80.0	80.0	80.0		16.4	18.0		14.2
Mean	**60.0**	**60.12**	**56.83**	**59.56**		**8.68**	**9.70**		**8.41**
Median	60.0	60.0	58.0	61.0		8.15	8.95		8.5
St. Dev.	7.11	7.40	7.84	8.60		3.23	3.38		2.68
St. Error	0.75	0.78	0.83	0.91		0.34	0.36		0.28
Variance	50.56	54.74	61.47	73.96		10.46	11.45		7.19

Plan and profile views of these measurements are shown in Figure 5.27. Following observation can be made from these plots:

- Slope values are almost the same in three directions (left, right and upslope) with values of about 60 degrees. The amount in downslope direction is 57 degrees indications a slight asymmetric body inclined towards the downslope.
- The fairy chimneys are slightly elongated parallel to the slope of the topography based on two diameters. This elongation (roundness) is 0.89 found by dividing D1 into D2.

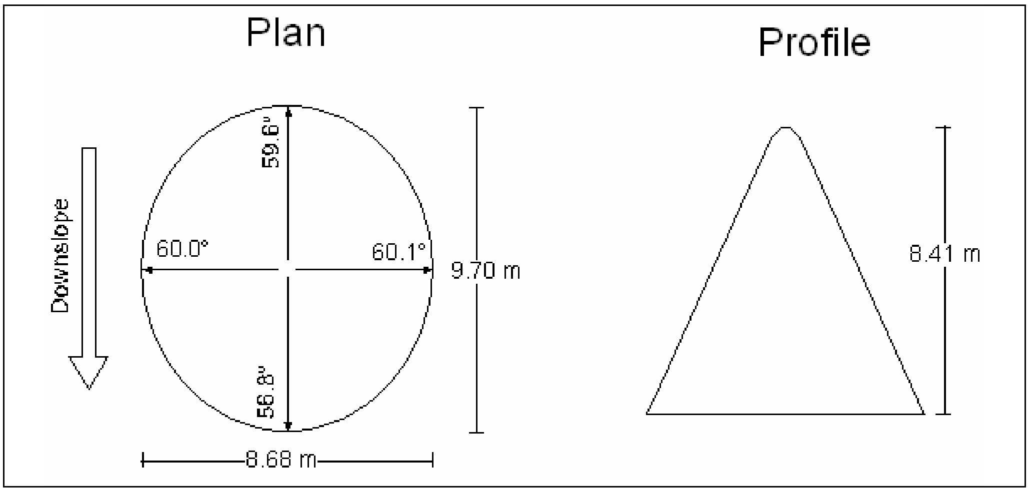


Figure 5.27. Parameters measured from the Cemilköy fairy chimneys in plan and profile as shown in Table 5.16. Numbers are the mean values.

The last analysis made for the Cemilköy fairy chimneys is the measurement of the distances between chimneys (Appendix G). Similar to the Zelve fairy chimneys, there is no base map on which individual fairy chimneys can be plotted. Therefore, the distances between fairy chimneys were measured using a steel tape of 50 m as shown in Figure 4.6. A total of 100 distances were measured from two sites (Table 5.17).

Table 5. 17. Distances (in meters) between the fairy chimneys of the Cemilköy Ignimbrite.

No	Distance	No	Distance	No	Distance	No	Distance	No	Distance
1	9,1	21	10,4	41	13,2	61	7,6	81	8,6
2	11,2	22	8,6	42	15,9	62	9,4	82	8,8
3	14,2	23	8,8	43	14,2	63	10,9	83	13,6
4	14,1	24	9,1	44	16,3	64	8,9	84	8,3
5	13,5	25	13,6	45	15,8	65	6,4	85	9,3
6	10,5	26	10,6	46	14,5	66	7,6	86	8,1
7	7,1	27	12,1	47	10,8	67	10,3	87	8,6
8	4,5	28	10,9	48	11,7	68	12,8	88	10,5
9	10,4	29	10,7	49	14,9	69	10,7	89	5,7
10	14,2	30	12,1	50	13,8	70	13,4	90	10,8
11	14,3	31	7,8	51	11,2	71	9,6	91	7,9
12	11,5	32	10,4	52	16,8	72	10,4	92	14,0
13	10,9	33	18,5	53	14,2	73	12,2	93	9,5
14	9,8	34	12,1	54	11,6	74	11,7	94	8,6
15	10,5	35	9,1	55	12,1	75	13,4	95	12,7
16	14,7	36	10,2	56	5,4	76	14,8	96	12,4
17	20,4	37	9,9	57	4,7	77	12,8	97	11,3
18	18,8	38	13,7	58	20,6	78	13,1	98	11,5
19	17,9	39	16,8	59	16,8	79	12,4	99	17,1
20	14,1	40	7,2	60	6,9	80	12,3	100	10,4

Histogram of the distance measurements and basic statistics are given in Figure 5.28 and Table 5.18, respectively. The minimum and maximum distances, and the mean distance are 3.1, 8.5 and 5.45 m, respectively.

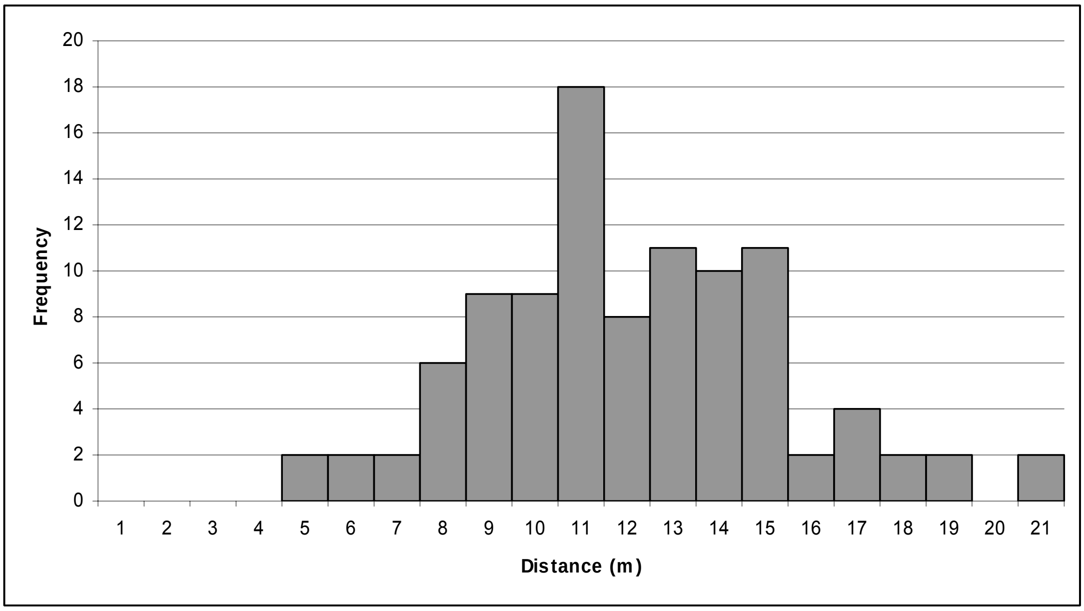


Figure 5.28. Histogram of the distances between the Cemilköy fairy chimneys.

Table 5.18. Summary of distance statistics for the Cemilköy fairy chimneys.

Min Value	4.5
Max Value	20.6
Mean	**11.64**
Median	11.4
St. Dev.	3.28
St. Error	0.33
Variance	10.75

CHAPTER 6

DISCUSSION

In this chapter, the outcomes of this study are discussed under four headings: 1) quality of the data used, 2) comparison of the fairy chimneys of different ignimbrites, 3) evaluation of the factors that control formation of the fairy chimneys, and the model proposed in this study for the formation of the fairy chimneys.

6.1. Quality of data used

Results obtained on the shape and form of the ignimbrites and the slope of the area are all dependent on the measurements made in the field. Therefore, the quality and the accuracy of the results are highly affected from the data used in the study. In this section several aspects of the data measured were discussed.

Scale of the base maps: Available topographic and geological maps have a scale of 1/25.000. This scale is not suitable and has negative affect on quantifying the data. These affects can be listed as follows:

- The fairy chimneys have diameters and sizes ranging from a few m to a few tens of m. Therefore, none of the chimneys are observable on these maps.
- Since the fairy chimneys can not be individually plotted on the maps, the spatial relationship between the fairy chimneys (the pattern of the chimneys) can not be constructed. Availibility of Google Earth image enabled to plot the fairy chimneys in the Kavak Ignimbrite. However since other ignimbrites are lacking such input data, a comparison of pattern was not possible for all ignimbrites.
- Avaliable topographic contour interval is 10 m. Therefore, the slope maps prepared from these data can miss minor topographic features such as a small creek, and cause a misinterpretation of the results. For this reason in this study only the slope amounts are used to compare the fairy chimneys.

Measurements from photographs: The measurements that quantify fairy chimneys, namely slopes, diameters and height were obtained from the photographs taken in two directions (downslope and normal to the slope). These measurements are listed in the Appendices for four fairy chimney types.

Although a maximum attention was given to hold the camera in horizontal position (with the help of spirit level), this actually can only prevent an error in the symmetry of the chimney. A certain deformation can not be avoided in the image because there is only one point of observation which results in difffernt scales in different parts of the area depending on the distance between the object and the observation point (Figure 6.1).

This error is believed to be negligible and doesnot affect the overall quality of the data because of following reasons:

- Amount of error should not be more than a few cm to a few tens of cm depending on the distance to and the size of the fairy chimney,
- The error will be consistently present in all measurements because the same technique is applied for all. Therefore, comparison of the chimneys will be reliable.

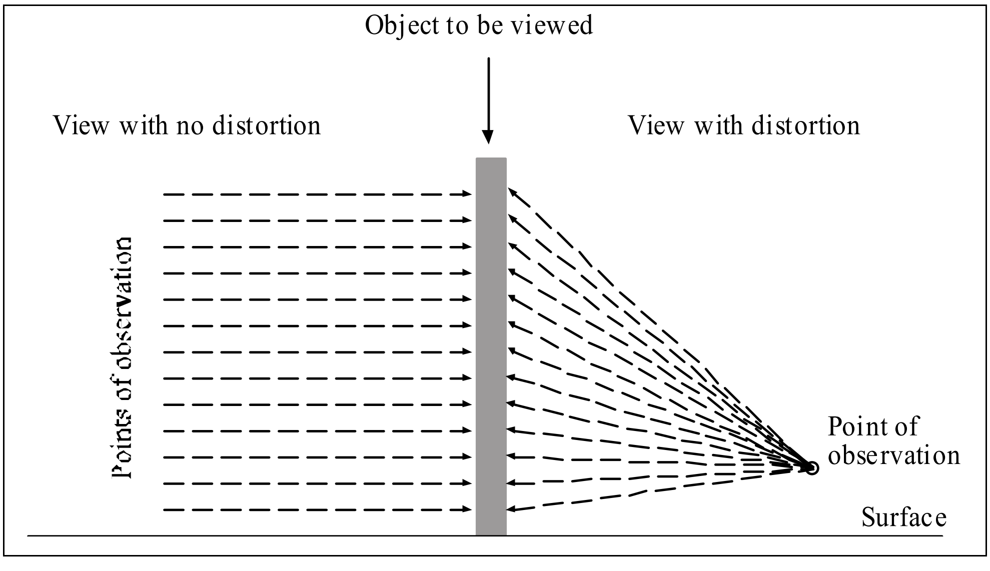


Figure 6.1. Example of distortion formed during measurements. Data used in this study were measured on the photographs taken one point of observation which causes certain distortion because of the differential scale of the object on different parts of the image.

Determination of fairy chimney developed areas: The fairy chimneys were not developed throughout the outcrop of the corresponding ignimbrite. In this study, an attempt was made to draw the boundary of the area where the chimneys were formed. This area was later used to find the slopes of chimney-formed and non-chimney areas. The density of the chimneys, however, can change from dense to loose in different parts of the area. Although, this is a problem related to the scale of the map, the chimney formed areas can be categorized into classes for better results depending on their densities.

6.2. Comparison of fairy chimneys

The fairy chimneys were developed at four stratigraphic levels, namely within the Kavak Ignimbrite, at the Kavak-Zelve transition, and within the Zelve and Cemilköy Ignimbrites in the study area. Other ignimbrites in which the fairy chimneys were not developed or locally devolped (Tahar, Gördeles) are not considered in this study. To compare these fairy chimneys a major problem is to distinguish the body and the cap of the chimney. In the Zelve and Cemilköy fairy chimneys there is no cap and the main bodies of chimneys are composed of ignimbrites. In the Kavak fairy chimneys, if cap exist, this part is composed of the ignimbrite and body can be formed of both ignimbrite and sedimentary rocks. In the Kavak-Zelve transition type fairy chimneys, on the other hand, the cap is composed of pumice (bottom of Zelve) and body is made up mainly by the uppermost part of the Kavak Ignimbrite with a thin sedimentary layer in between.

To avoid the confusion in the comparison of the fairy chimneys, it was decided that only the chimneys totally developed in the ignimbrites should be used. Therefore the fairy chimneys formed at Zelve-Kavak transition were not considered in this comparison. For the Kavak fairy chimneys, on the other hand, only those defined as “cap” in this study which are 100 % composed of ignimbrites were used. As a result, the comparion is made for “only cap” type of the Kavak, Zelve and Cemilköy fairy chimneys.

Size of fairy chimneys: Size of a fairy chimney refers to its basal diameter and height. Mean diameter and height values for Kavak, Zelve and Cemilköy are given in Tables 5.3, 5.12 and 5.16, respectively. (All these values are shown in Table 6.1).

Table 6.1. Summary of the results on the morphological characteristics of fairy chimneys made of ignimbrite only.

Fairy chimney	Mean value						
	Slope 1 (°)	Slope 2 (°)	Slope 3 (°)	Slope 4 (°)	Diameter 1 (m)	Diameter 2 (m)	Height (m)
Cemilköy	60	60.12	56.83	59.56	8.68	9.7	8.41
Zelve	70.06	69.51	65.34	69.34	4.7	5.62	7.47
Kavak	61.41	60.76	59.28	59.68	10.86	13.23	15.82

Plan and profile of these three types are drawn at the same scale both separately (Figure 6.2) and combined (Figure 6.3) for visiual comparison. Following conclusions can be derived from these two figures:

- The Kavak fairy chimneys are the biggeset and the Zelve chimneys are the smallest based on both basal diameter and height,
- Although the increment from Kavak to Zelve and from Zelve to Cemilköy is almost equal in basal diameters, it is quite different for height. The height of Kavak is much bigger than the heights of other two.
- To quantify the difference in size, the ratio of diameter over height (((D1+D2)/2) / H) was calculated for each chimney type (Table 6.2). The values indicate that the Cemilköy fairy chimneys have relatively largest base and the Zelve chimneys have the smallest and therefore is the most elongated chimney.

Table 6.2. Diameter-height ratios of fairy chimneys (calculated as ((D1+D2)/2) / H)

Fairy chimney	Ratio
Cemilköy	1.09
Zelve	0.69
Kavak	0.94

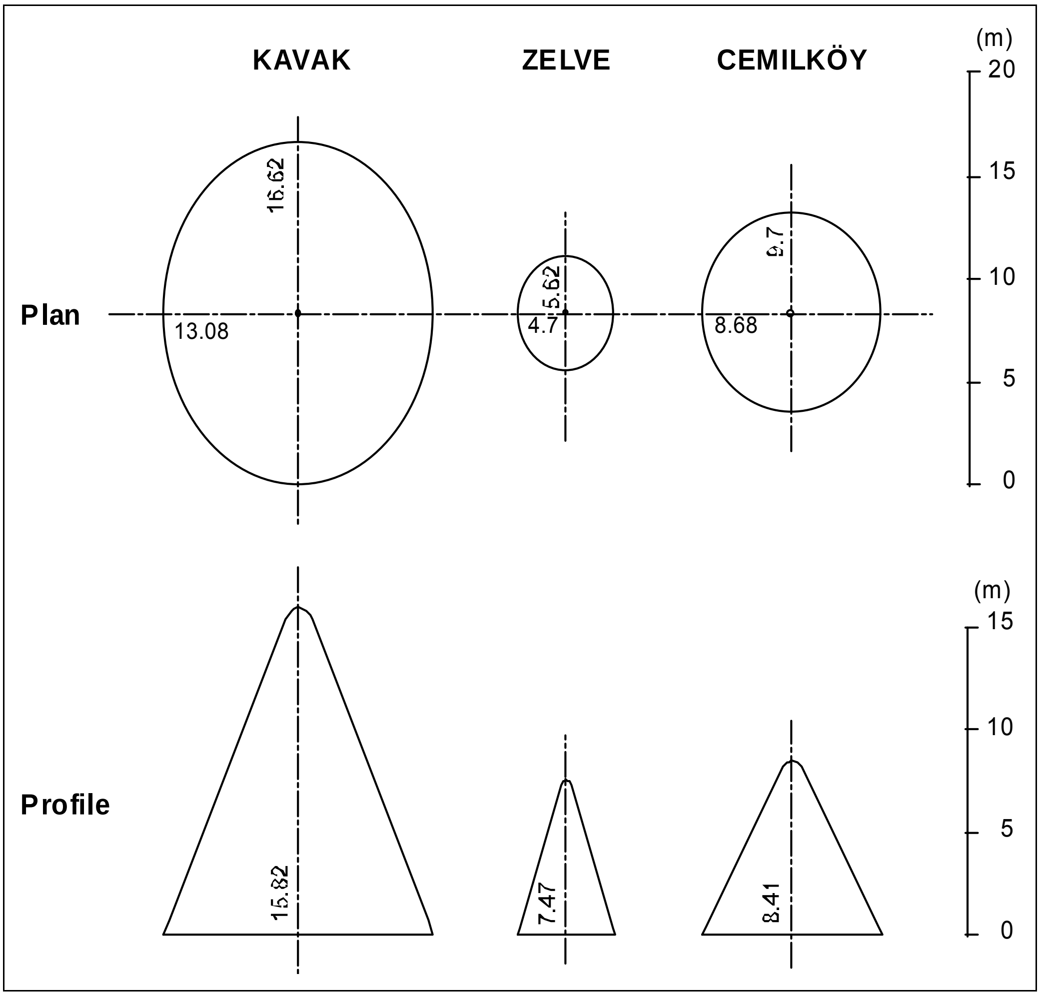


Figure 6.2. Size comparison of fairy chimneys made of ignimbrite only.

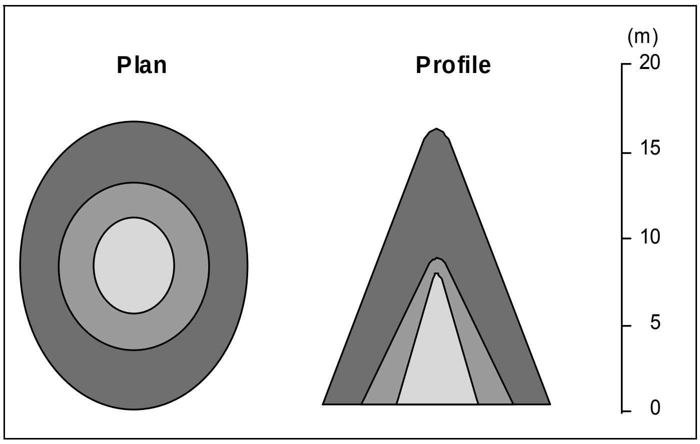


Figure 6.3. Comparison of fairy chimneys made of ignimbrites only on combined figures. (order is: Zelve, Cemilköy, Kavak from center to the periphery).

Roundness of fairy chimneys: Two diameters were measured for each fairy chimney. These are normal and parallel to the slope of area where chimney is developed. The ratio of two diameters (Table 6.3) can be used as a parameter to quantify roundness of the chimneys. The results suggest that:

- They are all elliptical ranging from 79 % to 89 %,
- The long axes of chimneys are consistently in downslope direction,
- The most elliptical fairy chimneys were developed in the Kavak Ignimbrite.

Possible explanation of the roundness being parallel to the slope is due to the degree of erosion along minor streams (Figure 6.4). Because of the scale of the base maps, none of minor streams can be identified in the field. However, since the roundness consistently observed in downslope direction, this might be related to the lateral erosion occurred along the minor streams.

Table 6.3. Roundness of three fairy chimney types (D1 / D2).

Fairy chimney	Roundness	Direction
Cemilköy	0.89	Downslope
Zelve	0.84	Downslope
Kavak	0.79	Downslope

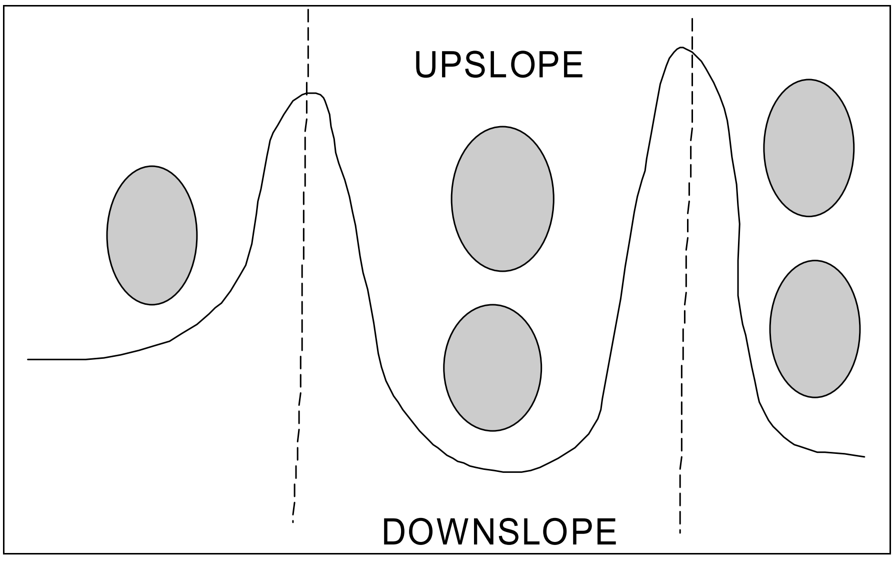


Figure 6.4. Relationship between roundness and minor stream course. Since the roundness of all fairy chimneys types was developed normal to the slope of topography, erosion along the minor streams might be the main reason for this.

Symmetry of fairy chimneys: For each fairy chimney four slope values were measured along two perpendicular lines normal and parallel to the slope of topography. Mean slope values for the Kavak, Zelve and Cemilköy fairy chimneys are given in Tables 5.3, 5.12 and 5.16, respectively. Plan view plots of these values (Figure 6.5) suggest that:

- Kavak and Cemilköy fairy chimneys have slopes about 60° whereas Zelve has about 70°. Accordingly, the Zelve fairy chimneys are steeper than the others as also determined by diameter-height ratio mentioned above.
- In each fairy chimney type, left and right slopes are almost identical suggesting symmetry in their frontal views (Figure 6.6). The slope values in side views, however, are consistently smaller than the others. In all fairy chimney types, minimum slopes are observed in “downslope direction” with a maximum difference of about 5° in the Kavak fairy chimneys.

Therefore, it can be concluded that all three fairy chimney types have common properties as far as symmetry is considered. They are symmetrical in front, and asymmetrical in side views. Steeper slope in the upslope direction which is consistently observed in all types is not a primary feature but rather is related to the erosion of the chimneys after they developed.

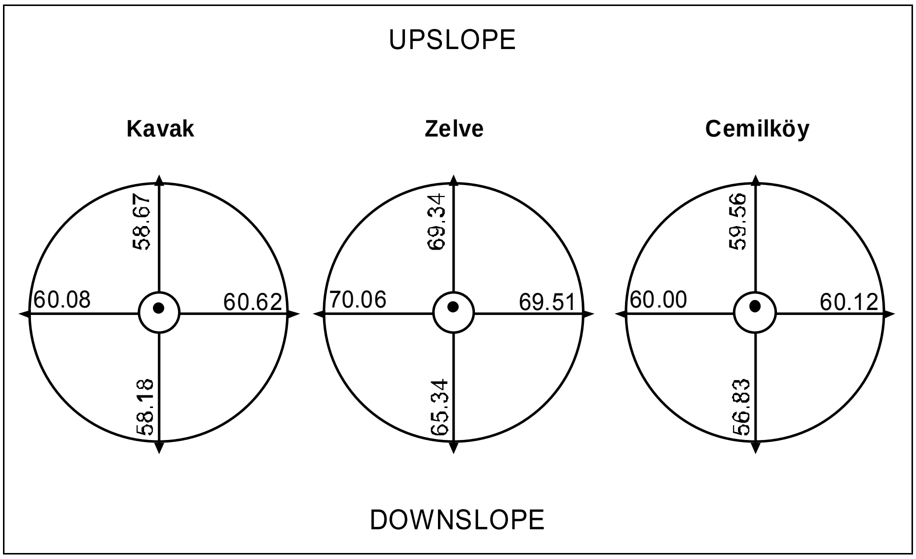


Figure 6.5. Plan views showing slope amounts for the fairy chimneys. Small black circles at the center of figures shows the position of the chimney top as an indicator of symmetry.

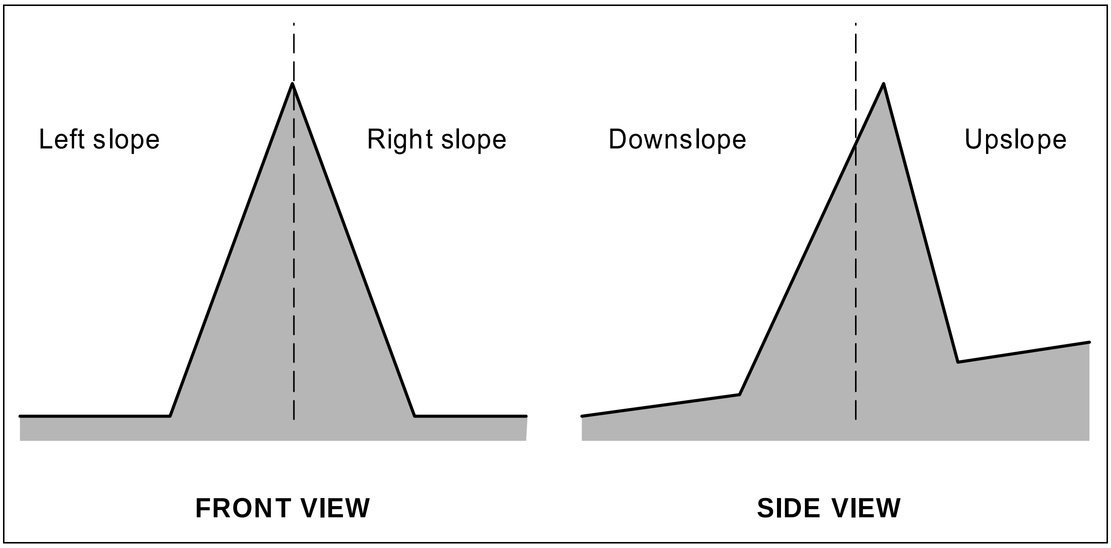


Figure 6.6. Profiles across fairy chimneys showing asymmetry in side view

Shape of the fairy chimneys: Shape of the fairy chimneys is suggested by Emre and Güner (1985) to be either conical or cylindrical. They claimed that the shape is conical if the fairy chimney was developed in one single lithology; it is cylindrical if it is developed in a unit of various lithologies.

This observation is partly correct and needs to be clarified. As mentioned previously, the lithological characteristics of the fairy chimneys can change from one type to another. The relationship between the lithological characteristics and the shape of the fairy chimneys can be summarized as follows:

1. The Cemilköy chimneys are totally formed within a single ignimbritic layer (Cemilköy Ignimbrite). There is no sedimentary intercalations nor repetition of ignimbritic layers in this unit. The fairy chimneys developed in Cemilköy Ignimbrite are all conical in shape.
2. The Zelve chimneys have almost similar characteristics as far as the tiltology and the shape are considered. That means the unit is composed of a single lithology and the shape is conical.
3. The Kavak-Zelve transition fairy chimneys were developed within three lithologies. These are the Kavak Ignimbrite at the bottom, a layer of sedimentary rock at the middle, and base of the Zelve Ignimbrite at the top. The average thicknesses of these layers for the cap, the sedimentary layer and

the body are about 2.5, 1 and 12 m, respectively. This fairy chimney is defined to be composed of a “body” and a “cap” that correspond to Kavak+sedimentary and Zelve, respectively. Both the body and the cap are conical in shape as illustrated in Figure 5.16. It should be noted that the thickness of the sedimentary layer is very small compared to the rest of the chimney. Therefore, the conical shape exist for this fairy chimney both for the cap and the body.

4. The Kavak Ignimbrite produces the most complicated fairy chimneys as far as their shape and their lithologies are considered. This complication is reflected to the analysis in this study and all measurements are plotted under two headings as “cap” and “body”. The cap part of the chimney is composed of one of the ignimbritic layers of the Kavak Ignimbrite The body, on the other hand, in most cases is totally composed of sedimentary layers. These sedimentary layers are mostly vertical and therefore have a shape cylinder in 3 dimensions. For this reason, slope amounts were not measured for the body part of the chimney in this study.

Distinct cylindrical fairy chimneys were formed in lower parts of the Kavak Ignimbrite. and are locally observed in the region. One typical area characterized by such fairy chimneys is observed to the NW of Göreme (Figure 6.7-A). These fairy chimneys are not included in this study. The major difference of these chimneys relative to other ones is that the thickness of the sedimentary section is very high with a small ignimbritic cap at the top. Therefore, the cylindrical shape of the chimney is almost totally controlled by the sedimentary section.

The shape of the fairy chimney, therefore, is dependent on the lithology. If the chimney was developed within ignimbrite it is conical; if is developed dominantly within sedimentary rocks it is cylindrical. Both conical (cap) and cylindrical (base) shapes can co-exist in the same fairy chimney as in the case of the Kavak fairy chimneys (Figure 6.7-B).

Figure 6.7. Examples of cylindrical shapes in the Kavak fairy chimneys formed within the sedimentary section of the chimney. A) NW of Göreme, B) Göreme center.

Distances between fairy chimneys: Distances of the fairy chimneys were measured from Google Earth image for the Kavak chimneys and in the field for the Zelve and Cemilköy chimneys. All the values for distances and corresponding basal diameters are illustrated in Table 6.4.

Plan view of the fairy chimneys based on their diameters and distances for three types are plotted (Figure 6.8) assuming a spatial distribution on a regular grid system. Since there is no real data on the coordinates of fairy chimneys (except Kavak fairy chimneys), the exact distribution of chimneys can not be identified in this study.

Table 6.4. Diameters and distances of the fairy chimneys.

Fairy chimney	Diameter D1 (m)	Diameter D2 (m)	Distance (m)
Cemilköy	8.68	9.70	11.64
Zelve	4.70	5.62	5.45
Kavak	13.08	16.62	42.72

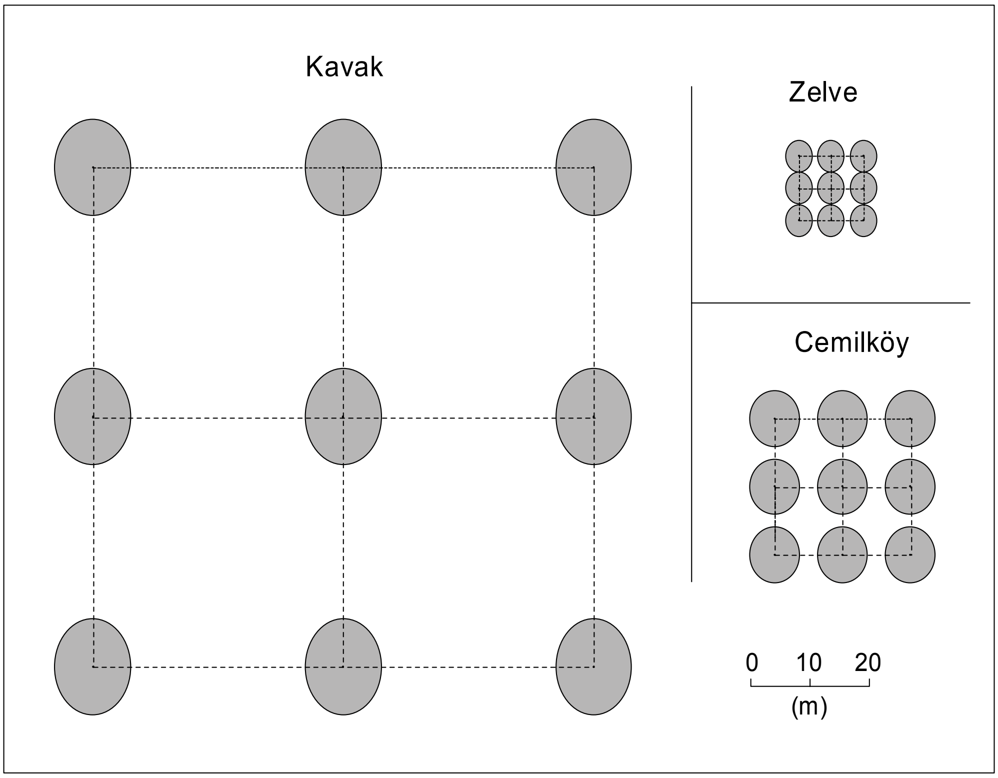


Figure 6.8. Plan view plots of the fairy chimneys on a regular grid system based on their distances.

These plots suggest that the Kavak fairy chimneys are widely spaced resulting in the formation of individual structures. Other two types, on the other hand, are relatively closely spaced resulting in the development of groups of fairy chimneys. One interesting result is that the mean distance of Zelve fairy chimneys (5.45 m) is 17 cm smaller than the the mean diameter (5.62 m) which is parallel to the slope. That means an overlap of base at that direction.

Topographic slope: Topographic slope of the area where the fairy chimneys developed was identified using 1/25.000 scale maps. Comparison of these slopes with non-developing areas yields a range of slope suitable for fairy chimney formation using the slope histograms of the regions (Figures 5.9, 5.20 and 5.26 for Kavak, Zelve and Cemilköy, respectively). Resultant suitable slope ranges are illustrated in Table 6.5.

The first thing to emphasize in the evaluation of these values is the scale of the map used to find the slopes. Although the size of the pixel is 20 m in the resultant slope maps, these maps may miss minor topographic features due to its original scale.

Comparison of maximum slope values (Figure 6.9) indicates that the Cemilköy fairy chimneys can survive on relatively steeper slopes upto 23°. The Zelve fairy chimneys have the lowest maximum value with 13°. Accordingly the fairy chimneys of the Zelve Ignimbrite should be the most sensitive one to the topographic slope.

The minimum slope value of the Cemilköy fairy chimneys is also greater than the minimum values of the Kavak and Zelve chimneys. That means, the Cemilköy chimneys are eroded at gentle slopes while others still continue to exist.

Table 6.5. Suitable slope ranges for three fairy chimney types

Fairy chimney	Suitable slope range (degree)
Cemilköy	8-23
Zelve	2-13
Kavak	4-17

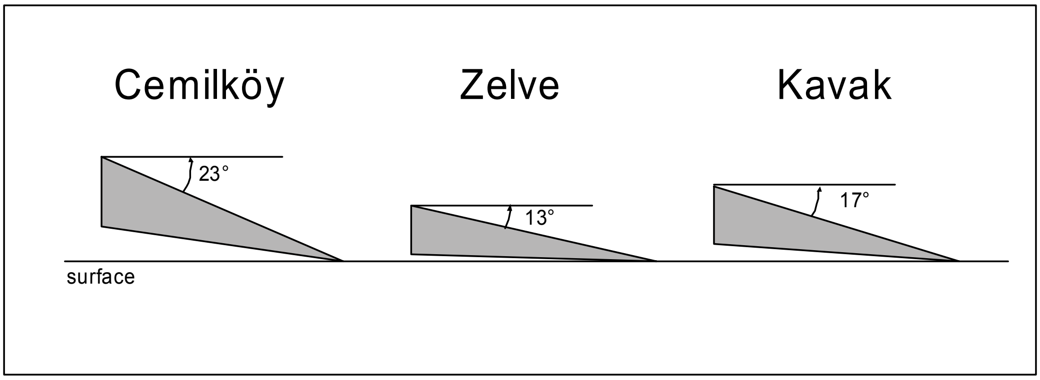


Figure 6.9. Profiles showing maximum slope values for fairy chimneys

6.3. Evaluation of factors controlling formation of fairy chimneys

In this section parameters that contribute to the formation of the fairy chimneys will be discussed individually. These parameters are: erosion, lithology, welding and jointing, topographic slope and thickness. Other properties of the rock units such as engineering properties, chemical composition and presence of gas escape pipes will referred to as the parameters are discussed.

Erosion: Erosion plays a role both at regional and scale at local scale in the development of the fairy chimneys. At regional scale, all fairy chimney producing ignimbrites are exposed around Ürgüp dissected by the tributaries of Kızılırmak river where the lower parts of the Ürgüp formation is exposed. This is the main reason why the fairy chimneys are exposed in a limited area. Because the ignimbrites in the upper part of the Ürgüp formation (Tahar, Gördeles and Kızılkaya) that extends large areas do not produce fairy chimneys.

At local scale, the role of erosion is observed to be different in different ignimbrites depending on the conditions existing in the area. These conditions are explained below seperately for each fairy chimney.

Kavak fairy chimneys are developed within Kavak Ignimbrite and underlying sedimentary layers. Those chimneys totally developed within the ignimbrite are referred to as “only cap” and 39 chimneys of this type are measured in this study (Table 5.3). The chimneys, on the other hand, developed both in ignimbrites and sedimentary layers are called as “cap+body”. A total of 70 chimneys are of this type is measured in this study (Table 5.4). Shape of the chimney is different in this level depending on the stage of the erosion shape of the chimney. Three main stages are identified in the erosion of these chimneys and are summarized in Figure 6.10.

In the initial stage (Figure 6.10) only the cap of the chimney is observed as the sedimentary rocks are not exposed to the surface yet. The chimney is conical in shape in this stage. An example of this stage is illustrated in Figure 6.11-A.

In the intermediate stage the sedimentary rocks are exposed to the surface. The sedimentary rocks are characterized by closely spaced vertical cracks which are confined to the sedimentary layer and do not extend to the overlying ignimbrite. Examples of these cracks are shown in Figure 6.12. As the sedimentary layer is exposed to the surface, the erosion along these cracks become dominant. The most important erosional form along these cracks is the formation of gorges that penetrates inward (Figure 6.12-B) and separate the sedimentary units as cylindrical bodies from each other. A close up vies of the initial penetration is shown in Figure 6.12-C. At the same time the cap over the sedimentary sequence starts to erode so that the traces of the future several small caps are shaped (Figure 6.10-B, Figure 6.11-B). The shape of the chimney in this stage is almost conical for the cap and cylindrical for the body.

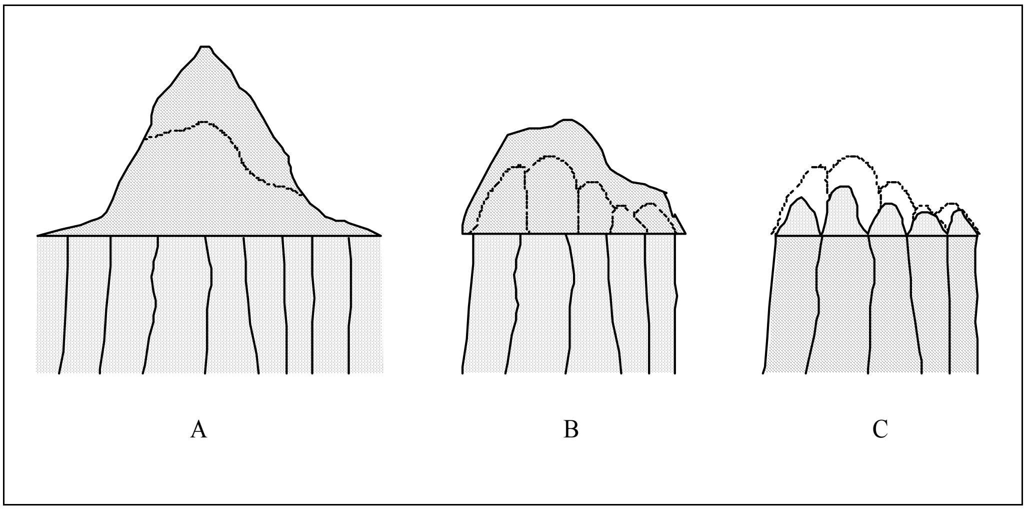


Figure 6.10. Develpoment of fairy chimneys in Kavak Ignimbrite . A) Initial stage: Only “cap” is formed, B) Intermediate stage: Underlying sedimentary rocks are exposed to the surface, C) Late stage: The chimney is disintegrated due to cracks in sedimentary layers.

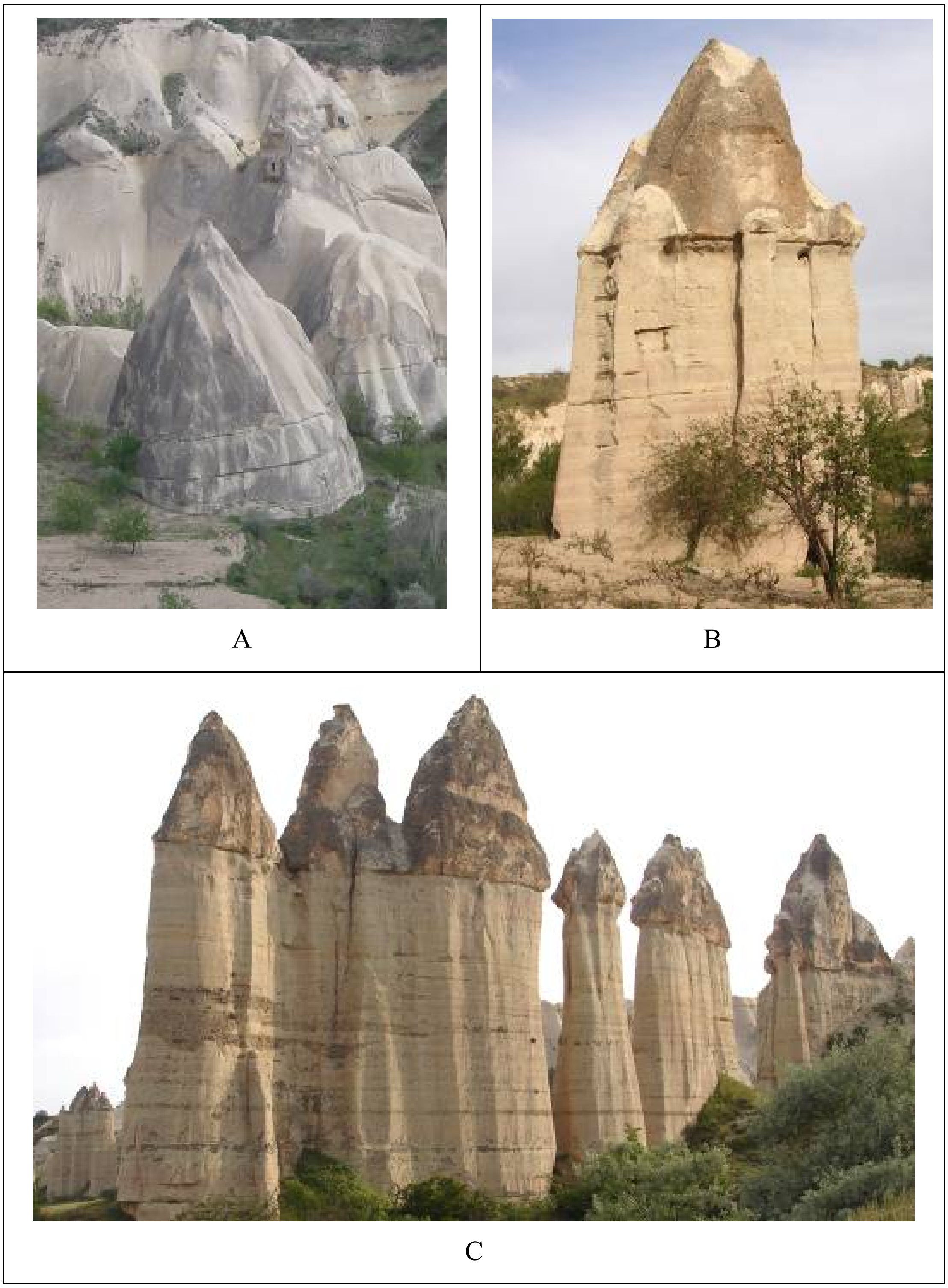


Figure 6.11. Examples of three stages of erosion in Kavak fairy chimneys. A) Initial stage (Only cap stage), B) Intermediate stage (Cap+body stage), C) Late stage (fairy chimney disintegrated into smaller ones dominated by sedimentary body).

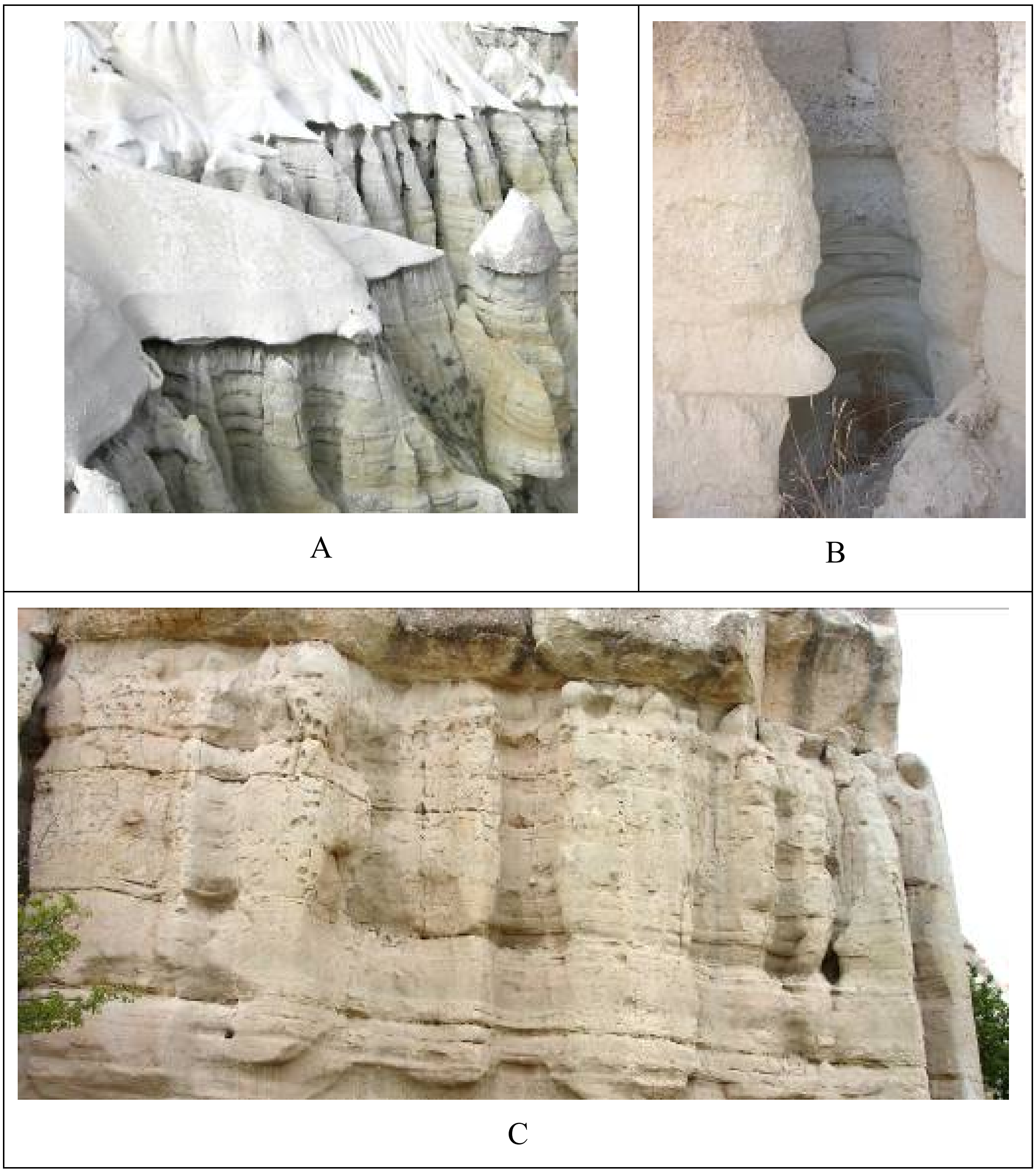


Figure 6.12. Examples of erosion lead by vertical cracks in sedimentary rocks. A) General view, B) A close up vies of gorge formed by erosion along the cracks, C) Details of erosion within the sedimentary rocks below the cap.

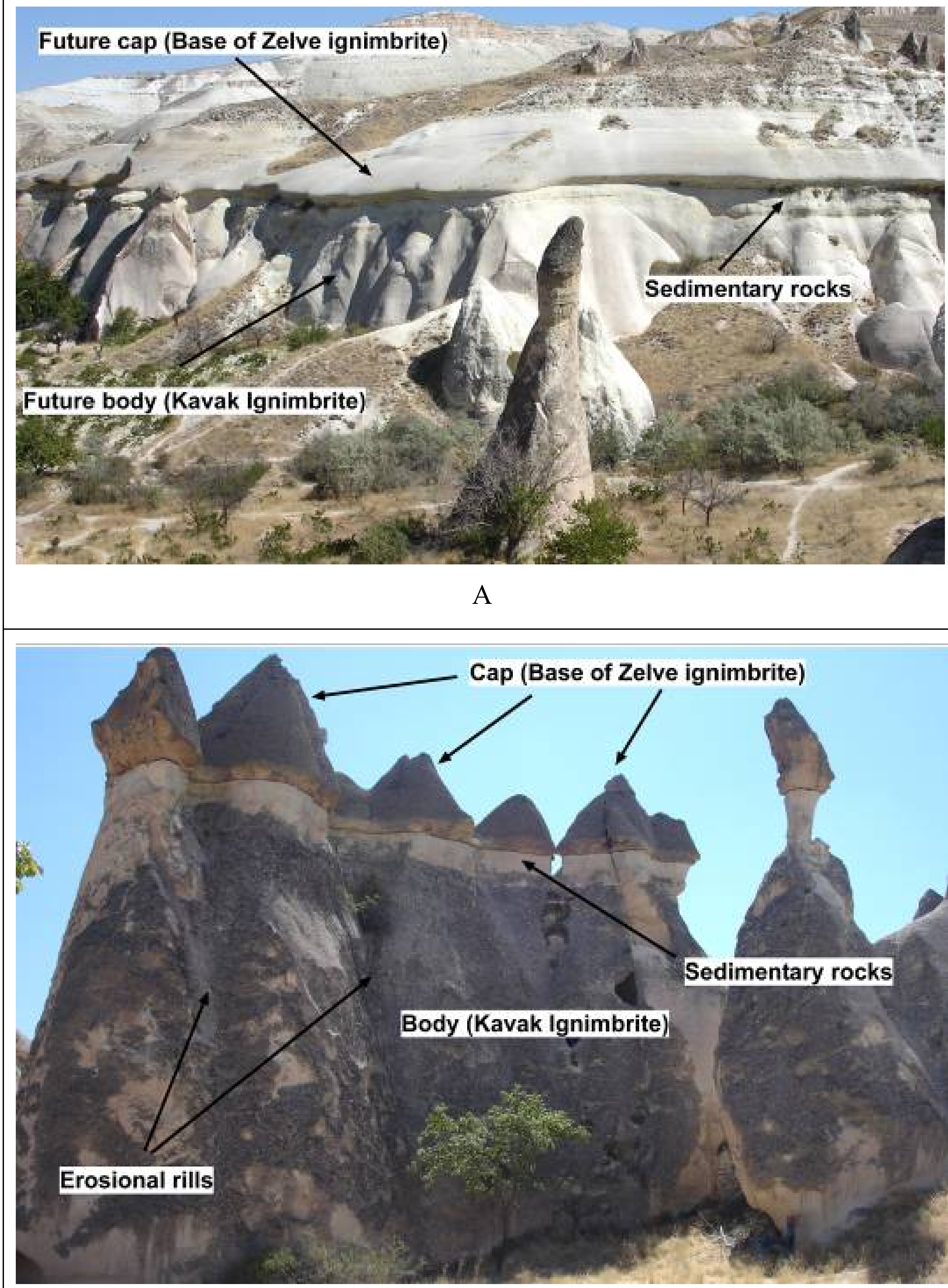
In the late stage, smaller fairy chimneys are formed by disintegration of the initial cap and columnar separation of underlying sedimentary sequence.These new fairy chimneys are mostly made up of sedimentary rocks with a small cap which is the remnant of the initial large cap. The shape of the chimney is cylindrical (Figure 6.10-C, Figure 6.11-C).

Kavak-Zelve transition fairy chimneys have a distinct feature that differs it from other chimneys (Figure 5.13). This feature is that the chimneys has a cap and a body both composed of ignimbrites. The cap is formed by the basal part of Zelve Ignimbrite and the body by the upper part of Kavak Ignimbrite. The thin sedimentary layer in between is considered to be a part of the body. Both the cap and the body have conical shapes.

Figure 6.13-A shows the initial development of this fairy chimney at the footslopes. There is no joint developed either in the cap nor in the body. The erosion starts first in the body in the form of vertical rills. Later, these rills extend upward and starts to shape the cap (Figure 6.13-B). Sometimes the erosion in the cap can occur so that there are more than one cap above the body. This is a common feature observed particularly in the Paşabağı area (S of Zelve village) indicating that the erosion of the body and the cap may occur independently from each other.

Zelve fairy chimneys are totally developed within the Zelve Ignimbrite. Therefore, there is not a cap in this ignimbrite as it is observed in Kavak or Kavak-Zelve transition fairy chimneys. A different feature, however, in this ignimbrite is observed which is the existence of gas-escape pipes associated with the chimneys. The field observations suggest that the fairy chimneys are not developed if these pipes are missed. Best examples of chimney-free Zelve outcrops are observed at the southern slopes of Derbent valley (Figure 6.14-A). The erosion of the Zelve Ignimbrite in this area occurs in the form of "sweeping curves" that produces conical structures to some extend but never produces individual fairy-chimneys.

The chimney-bearing areas on the other hand, observed on the northern side of the same valley is characterized by extensive gas escaping structures. These dark, lithic-rich pipes are gas segregation structures that provide direct routes for the degassing of ignimbrite (Figure 6.14). The escaping gases cause fragments of different sizes and densities to push apart from one another. Most of the finer material, however, has been blown out of the pipes (elutriated) by the escaping gas (fines depleted). This process cements the interstitial fragments so that the pipes are often resistant to erosion. Therefore, in the Zelve Ignimbrite presence of these pipes results in a



A

B

Figure 6.13. Development of fairy chimneys in Kavak-Zelve transition. A) Chimneys initially formed at the footslope, B) Fairy chimneys in their mature stage

A

B

Figure 6.14. Fairy chimneys developed in Zelve Ignimbrite (Derbent valley, vicinity of Zelve village). A) Area with no gas escape pipes, B) Area with pipes where chimneys are developed.

differential erosion between nonwelded part of the ignimbrite and the pipe dominating parts. They mostly form the cap parts of the fairy chimneys and also observed in the body parts. In some cases the surrounding material is totally eroded and only the pipes exist as vertical chimneys (Figure 6.15). Such structures, however, are not classified as fairy chimney and not measured for the analysis.

Figure 6.15. Gas escape pipes in the Zelve Ignimbrite (Devrent valley) forming cylindrical bodies due erosion of surrounding nonwelded parts.

The shape of the Zelve fairy chimney although in general is conical, it has the most irregular shape compared with other fairy chimneys. The main reason for this is the location of the gas pipe over the chimney.

Cemilköy fairy chimneys are totally developed within the Cemilköy Ignimbrite. They have almost perfect conical shape. Erosion of this chimney is similar to the erosion of other ignimbrites as the erosion first initiates along vertical rills that starts to separate individual chimneys from each each other. One distinguishing feature of this chimney, however, is the nature and the origin of their caps. The caps of these chimneys belong to the blocks of Kızılkaya Ignimbrite which is stratigraphically at the top of the Ürgüp Formation. Figure 6.16-A shows the Kızılkaya Ignimbrite at the top of the sequence at the background. All figures (Figures 6.16-A-B-C) illustrates the Kızılkaya blocks both as cap and as loose material on the ground. Most of the fairy chimneys of this ignimbrite are associated with these caps suggesting that these fallen blocks controlled the location of the fairy chimney as the erosion in this area occur.

Lithology: The most prominent factor in the formation of the fairy chimneys is their rock types. The fairy chimneys were developed only within the nonwelded ignimbrites in the region. Although the whole sequence (Ürgüp formation) is composed of alternation of volcanic and sedimentary layers, no fairy chimney development is observed in the sedimentary rocks (Çökek Member) nor in lava flows (Damsa and Topuzdağ Basalts) and welded ignimbrites (Sarımaden Tepe and Kızılkaya Ignimbrites). Sedimentary rocks sometimes are observed within the fairy chimneys only if they form the base of the chimney (as in the case of the Kavak Ignimbrite) or sandviched between two ignimbrite layers (as in the case of Kavak-Zelve transition). This sedimentary layer forms the body of the chimney in Kavak Ignimbrite if the erosion continued downward to expose the sedimentary layer. In this case the body is distinct with its cylindrical shape.

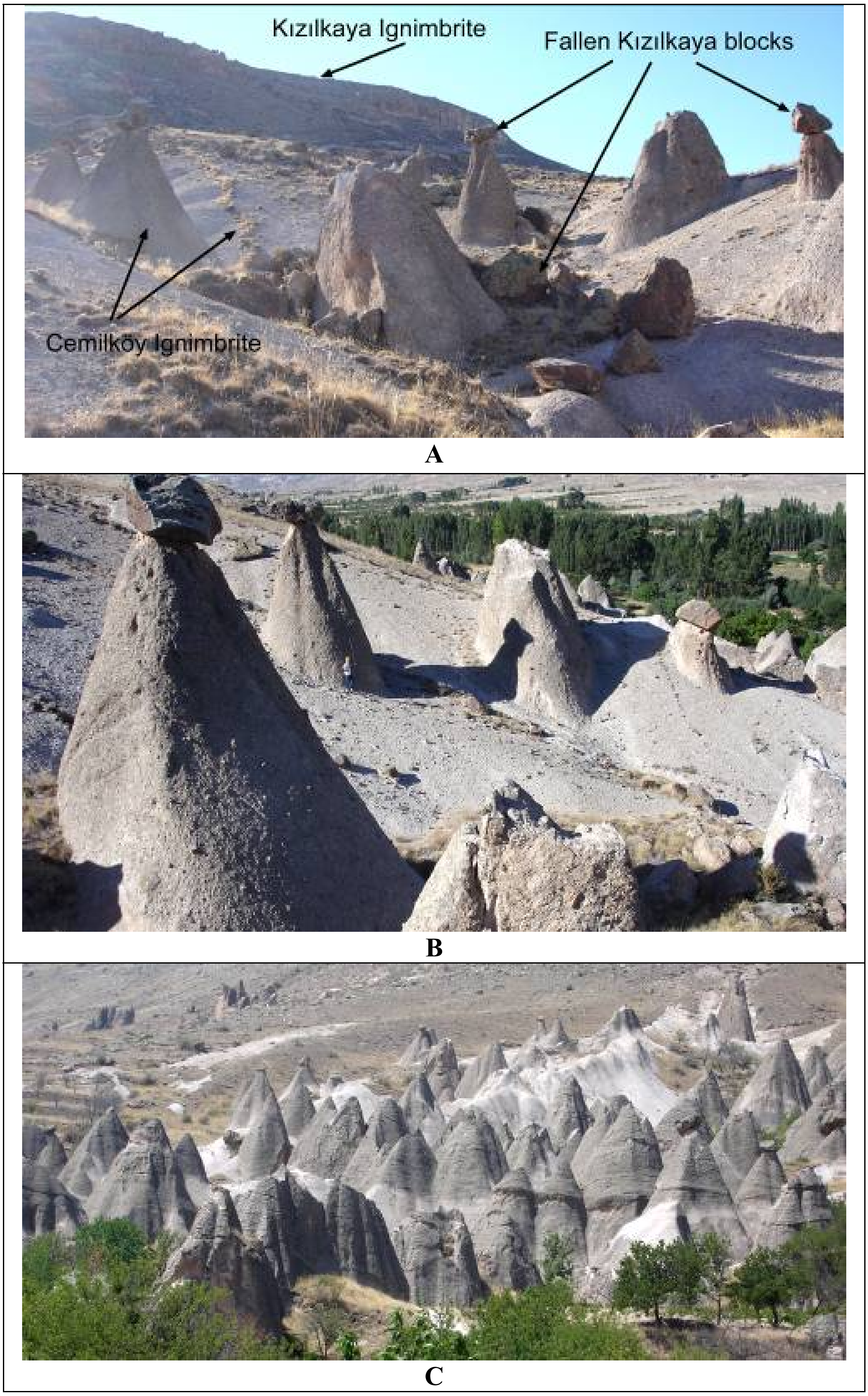


Figure 6.16. Blocks of Kızılkaya ignimbrite as observed as caps over the Cemilköy fairy chimneys.

Mineralogical and geochemical characteristics of these ignimbrites are investigated to seek a possible relationship between the lithology and the formation of the fairy chimney. The analyses carried out for all ignimbrites in the region are mentioned in the first chapter. Temel (1992) classified all ignimbrites as "rhyolitic-rhyodacitic in composition" and plot in high-K calc-alkaline field. Comparison of major elements suggests that there are no significant differences between the fairy chimney bearing and other ignimbrites. Therefore, the composition based on minerals and major elements is not expected to influence the formation of fairy chimneys.

Trace elements, on the other hand, although in general show consistent values, it may be quite different as in the case of Sr and V. This difference, however, is not supposed to be responsible for the formation and the difference between the fairy chimneys.

Welding and cooling joints: Welding is one of the most prominent property of ignimbrites. To quantify the "welding" two enginerring properties, namely density and porosity (Streck and Grunder, 2003) and/or "physical properties and specific macroscopic or microscopic textural characteristics" (Quane and Russell, 2005) can be used. The classes/ranks of different ignimbrites are tabulated in Tables 2.4 and 2.5.

Engineering properties of the Kavak and Zelve Ignimbrites were studied by Erguvanlı and Yüzer (1977), Erdoğan (1986), Erguvanlı et al (1989), Topal (1995) and Aydan and Ulusay (2003). There is no published engineering data on the Cemilköy Ignimbrite. Therefore, engineering properties for the Cemilköy Ignimbrite are identified in this study. Samples collected from the Cemilköy Ignimbrite were analyzed in the Rock Mechanics Laboratory of the Mining Engineering Department of METU. Five cylindrical specimens of the Cemilköy Ignimbrite were used for the tests. The details of the test results are given in the Appendix H. Dry and saturated unit weight, effective porosity and uniaxial compressive strength of the Cemilköy Ignimbrite were determined. Results of these tests together with other two ignimbrites taken form Aydan and Ulusay (2003) are shown in Table 6.6.

Table 6.6. Engineering properties of the fairy chimney bearing ignimbrites. Data for the Kavak and Zelve Ignimbrites are from Aydan and Ulusay (2003). Analyses for the Cemilköy Ignimbrite is made in this study.

Ignimbrite	Dry Unit Weight (kN/m^3)	Saturated Unit Weight (kN/m^3)	Effective porosity (%)	Uniaxial Compressive Strength, vertical (Mpa)
Cemilköy	13,00	16,7	37,9	5,59
Zelve	13,00	14,52	35.2	4,00
Kavak	14,25	17,03	32.8	6,45

Considering the Temel's study (1992) and classification scheme (Streck and Grunder, 2003; Quane and Russell, 2005) all the fairy chimney bearing ignimbrites in the area are nonwelded. Therefore, closely-spaced systematic development of cooling joints is not expected in these non-welded ignimbrites. Examples of densely welded ignimbrites in the area are Kızılkaya and Valibaba characterized by dense joints (Figure 6.17). These ignimbrites are well-known with their closely-spaced vertical joints. These ignimbrites do not produce fairy-chimney because of their high resistance to the weathering. Their erosion take place in the form of falling (toppling) of rock slabs which are accumulated at the slope of the cliffs. Talus-like deposits formed by toppling of Kızılkaya Ignimbrite is very common in the area (Figure 6.17).

Emre and Güner (1985) and Topal (1995) claimed that joints play important role on the formation of the fairy chimneys. The model suggested by Topal is illustrated in Figure 2.5. Topal (1995) suggested the joints to be the key parameter for the formation of fairy chimneys in the Kavak Ignimbrite, such observation was not made in this study. Although there are joints developed within Kavak, Zelve and Cemilköy Ignimbrites in the area, in some cases these joints cut across the fairy chimney as best illustrated in the case of the Cemilköy Ignimbrite.

It can be concluded that i) fairy chimney bearing ignimbrites of this study are non welded and therefore are subjected to weathering and erosion which is important in the formation of chimney, ii) direct effect of the joints on the formation and shaping of the chimney was not observed during this study.

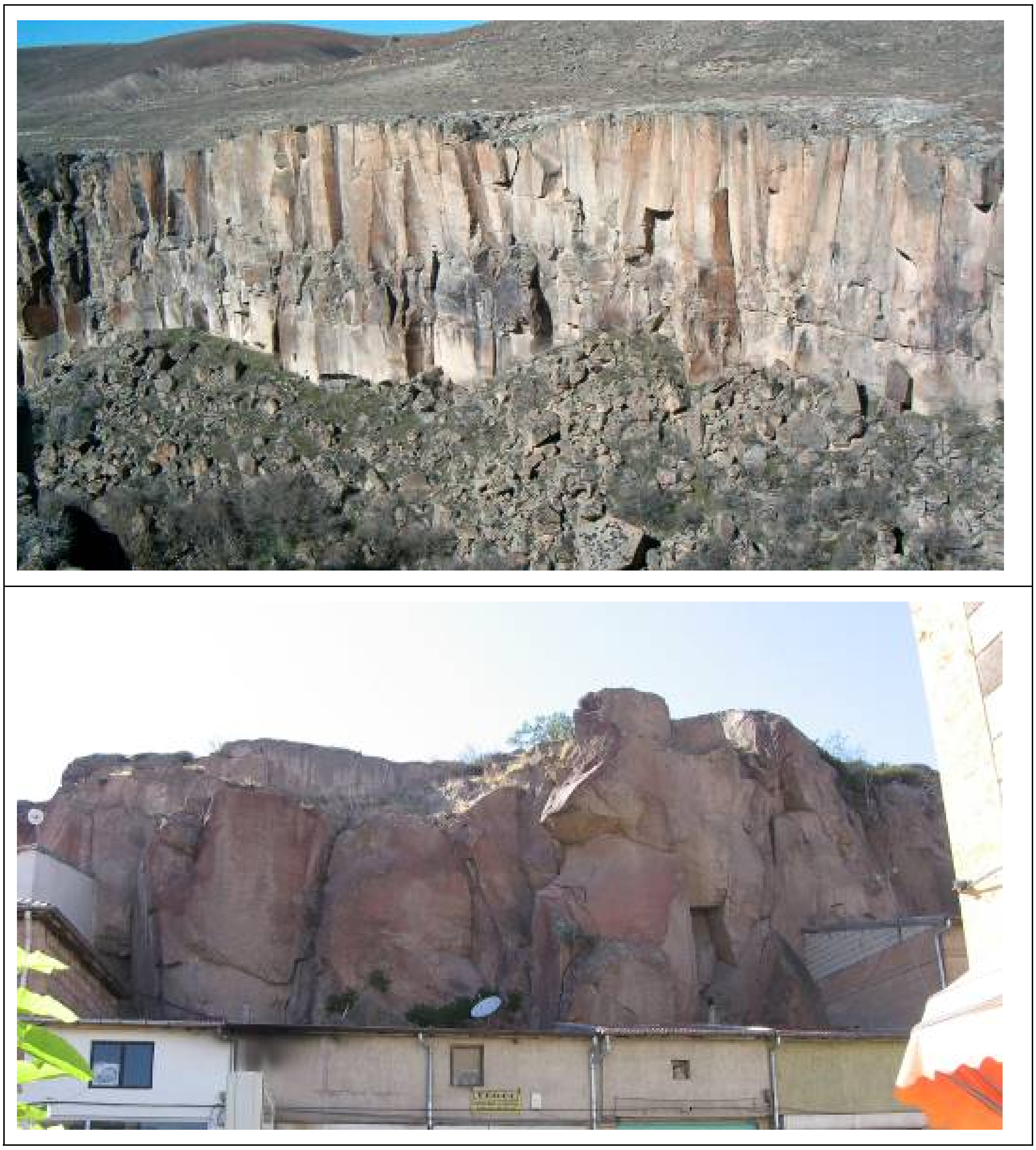


Figure 6.17. Views of Kızılkaya (above) and Valibaba (below) Ignimbrites characterized by closely-spaced vertical joints. Fairy chimneys were not developed in these ignimbrites.

Thickness of ignimbrite and topographic slope: Thickness of the ignimbrite is one of the main factors that controls development of the suitable slope. A thin ignimbrite (whether welded or nonwelded) will produce a steep slope since the outcrop width is short (Figure 6.18-A). As the thickness increases the outcrop width also increases resulting in gentler slope. The maximum slope values for Kavak, Zelve and Cemilköy are identified as 17°, 13° and 23° (Figure 6.9). This slope is controlled mainly by two factors: i) degree of welding, and ii) thickness of ignimbrite.

For the ignimbrites exposed in the area, the welded Kızılkaya Ignimbrite, can not produce a suitable slope because of falling of rock masses which always forms steep cliffs (Figure 6.18-A). Nonwelded thin ignimbrites, such as Tahar and Gördeles, again can not produce a suitable slope because of its thickness. The slope developed on such ignimbrites with a short “outcrop width” which is not enough to form fairy chimneys.

Location of the fairy chimneys within the ignimbrite has different characteristics in different ignimbrites. As seen in Table 6.7, fairy chimney was developed in certain section of the ignimbrite. This is about 60 to 80 % of Cemilköy, 50-80 % of Zelve Ignimbrites. For Kavak this ratio is smaller. The total thickness of the Kavak Ignimbrite is 120 m, however, only the upper 50 m of this section is studied in the area. Therefore, fairy chimney producing section of the Kavak Ignimbrite is about 60-90 %.

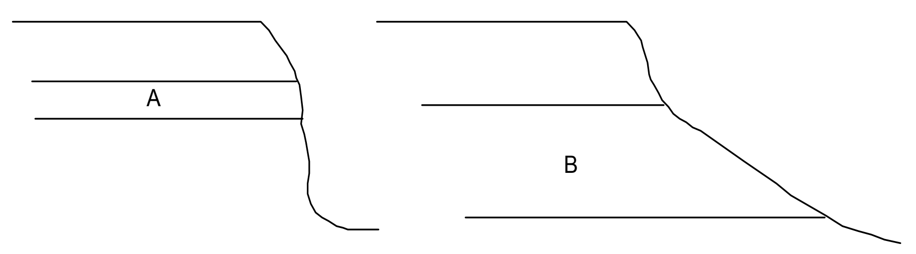


Figure 6.18. Effect of welded or thin nonwelded ignimbrite on the topographic slope

Table 6.7. Geological properties of fairy chimney producing ignimbrites

Ignimbrite	Thickness (m)		Elevation (m)	Age (Ma)	Dip
	Whole layer	Fairy-chimney developed layer			
Cemilköy	100	60-80	1250-1350	7.6	0-7
Zelve	60	30-50	1050-1150	8.5	0-7
Kavak	120	30-50	1050-1150	9	0-7

Field observations suggest that locations of the Zelve and Cemilköy fairy chimneys by overlapping at different elevations (Figure 6.19). Therefore, these chimneys are observed over a slope one on top of the other. The Kavak fairy chimneys follow a certain stratigraphic level and are all exposed at the same location within the ignimbrite (Figure 6.19).

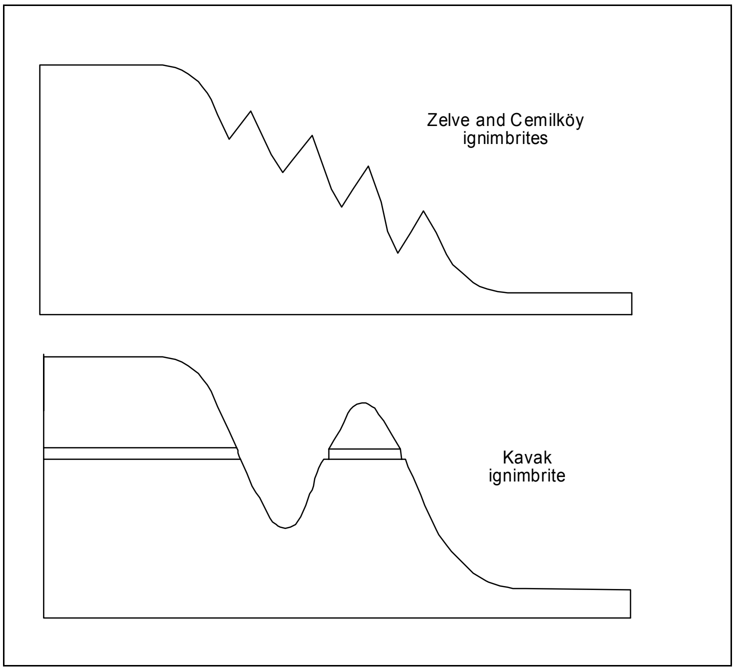


Figure 6.19. Sketch cross-sections showing location of the fairy chimneys developed within the ignimbrites.

Dip of strata: The dip amounts of fairy chimney bearing ignimbrites are gentle with maximum amount of 7 degrees (Table 6.7). According to Emre and Güner (1985) the dip of the strata influences the symmetry of the fairy chimneys. If the dip is horizontal the fairy chimneys are symmetric; if the dip is not horizontal fairy chimneys are asymmetric. The dip variation in the area is not suitable to test this hypethesis since almost all the measurement sites have nearly the same dip amounts. The asymmetry identified in this study is related to the erosional activity as illustrated in Figures 6.5 and 6.6. All three fairy chimneys are slightly assymetric with steep slope facing the upslope. This asymmetry therefore is not a property of the chimney when it was initially formed, on the contrary it is a secondary feature gained during erosion of the chimney.

6.4. Model for Development of Fairy Chimneys

In this section an attempt will be made to model fairy chimney development within the ignimbrites. This model comprises a synthesis of all parameters discussed in the previous section.

According to the model the formation of the fairy chimneys occurs in two stages:

Stage 1: Development of a suitable landform

Stage 2: Formation and shaping of the fairy chimneys on this landform

In the first stage a suitable landform should be produced where future fairy chimneys can develop. Although this is due to the erosion of the land, three dominant factors play roles to shape the landform. These are dergree of welding, thickness of the ignimbrite and amount of topographic slope.

Welding controls the mode of erosion. If the ignimbrite is welded the erosion occurs in the form of rock falling along the cooling joints which are main elements of welded ignimbrite. Therefore, the erosion will always produce steep slopes where fairy chimneys are not developed. Kızılkaya and Sarımaden Tepe Ignimbrites are examples of such welded units that do not produce fairy chimneys.

Thickness of the ignimbritic layer is important because the outcrop width is direcly aassociated with the thickness. A thin ignimbrite can not generate a suitable surface with a considerable length of outcrop. Tahar, Gördeles and Kızılkaya Ignimbrites have thicknesses not more than a few tens of meters. Although, Tahar and Gördeles Ignimbrites are nonwelded and are suitable for the generation of fairy chimneys, their thickness is not enough to form a suitable outcrop width.

The last factor is the topographic slope which is the last product of several factors including welding, thickness etc. If the slope amount is too high, the fairy chimney are not developed due to the type of erosion here that will occur in the form of falling. If the slope is too low, that means the area is transformed into a flood plain indicating the old stage of the fairy chimneys where previously developed fairy chimneys are eroded.

In the second stage, several factors contribute to the shaping of the fairy chimneys. Initial cone like erosion of the ignimbrites is due to the sweeping curves developed in these lithologies. These curves, however, are not alone responsible fort he form, shape and size of the fairy chimneys. Several other factors factors play certain roles in this stage. These factors can be different for different fairy chimneys. For example, presence of gas escape pipes for Zelve fairy chimneys and fallen Kızılkaya blocks for Cemilköy fairy chimneys seem to be important in the development of these chimneys. For Kavak chimneys, the exposure of the underlying sedimentary units to the surface triggers disintigration “only cap” type conical fairy chimneys into smaller cylindrical “body type” chimneys. For Kavak-Zelve transition fairy chimneys, the base of Zelve Ignimbrite forms a cap in this type fairy chimney which is systematically formed and is unique for these chimneys.

CHAPTER 7

CONCLUSIONS

Following conclusions are derived from this study which is carried out on the fairy chimneys developed within the ignmbrites of Cappadocian region:

1. The fairy chimneys were systematically developed at four stratigraphic levels of the Ürgüp Formation which are, from bottom to top, Kavak Ignimbrite, Kavak-Zelve transition, Zelve Ignimbrite and Cemilköy Ignimbrite. Other ignimbrites (at least five more) do not produce fairy chimneys or produce only locally as in Tahar and Gördeles Ignimbrites.

2. The Zelve and Cemilköy fairy chimneys were totally developed within the ignimbrites. The Kavak and Kavak-Zelve fairy chimneys were formed within two ignimbritic layers with a sedimentary layer in between.

3. Depending on the degree of erosion the fairy chimneys are classified into two as "only cap" and "cap+body". Zelve and Cemilköy fairy chimneys are examples of conical "only cap" type. Kavak ignimbrite may exist in the form of conical "only cap" type if underlying sedimentary rocks are not exposed to the surface. If they are exposed to the surface then a cylindrical body will be formed benath the cap. The Kavak-Zelve transition fairy chimneys, on the other hand, have a body made up of Kavak Ignimbrite and a cap made up of the basal part of the Zelve Ignimbrite with a thin sedimentary layer in between. Both cap and body are conical.

4. Data taken in the field and measured from the photographs taken in two directions yield following conlusions on the morhological features of the fairy chimneys:

- Slopes of the fairy chimneys measured in four direction indicate that the Zelve chimneys are steeper than others. Average slope values for the Kavak, Zelve and Cemilköy fairy chimneys are 60°, 70° and 60°. In all fairy chimneys a slight asymmetry is observed with the steep slope facing upslope of topography.

- The fairy chimneys were developed in conical form especially when they are formed in ignimbrite. A cylindrical shape can also be observed for the part of the chimney if developed in the intercalated continental sediments.

5. Analysis of the slope amount of the topography determined from digital topographic map at 1/25.000 scale indicate that the most suitable slope intervals for chimney development Kavak, Zelve and Cemilköy are 4°-17°, 2°-13° and 8°-23°, respectively.

6. Evolution of the chimneys occurs in two stage. The first stage is the formation of a suitable surface over which the fairy chimneys are formed. Three main factors that control the formation this surface are degree of welding, thickness of the ignimbrite and amount of topographic slope. In the second stage several other factors play roles to shape the fairy chimneys.

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APPENDIX A

Table A: Fairy chimney measurements in Kavak Ignimbrite

No	x	y	BODY			CAP						
			D1	D2	H	S1	S2	S3	S4	D3	D4	h
1	2320.38	1116.15	10.9	22.60	9.00	70	63	57	56	11.20	23.00	21.00
2	2329.15	1147.74	11.5	22.20	7.90	67	55	68	71	9.80	18.30	8.00
3	2366.00	1133.70	5.5	9.10	2.70	66	60	65	67	5.70	7.60	8.60
4	2297.57	1189.85	13.7	10.50	5.50	66	73	61	63	10.50	9.10	9.30
5	2392.32	1193.36	10.9	15.00	5.90	67	57	55	61	10.40	15.00	12.20
6	2373.02	1189.85				71	69	76	71	11.60	11.50	16.20
7	2348.46	1203.89	10.50	18.60	5.50	67	70	68	70	11.40	18.50	14.60
8	2467.78	1219.68										
9	2478.31	1235.47										
10	2374.78	1258.28										
11	2402.85	1268.81										
12	2237.91	1244.25	10.00	11.50	8.60	60	67	61	73	6.40	8.50	8.00
13	2260.72	1270.57										
14	2262.47	1312.68	8.50	9.00	8.10	68	53	63	67	9.10	7.70	6.10
15	2273.00	1346.02	5.0	5.00	6.20	78	52	73	54	5.30	4.60	5.70
16	2274.76	1098.60	14.40	12.70	4.40	64	67	65	68	12.20	11.10	16.10
17	2253.70	1123.17	17.5	20.30	7.50	61	66	61	60	14.80	18.60	16.10
18	2218.61	1161.77	10.30	13.50	8.70	70	65	60	55	8.10	10.20	9.20
19	2181.76	1188.10	8.20	9.50	11.00	71	69	70	60	5.50	7.00	6.80
20	2109.81	1230.21	5.80	10.00	13.30	71	79	66	63	1.60	3.10	1.70
21	2087.00	1186.34	10.00	8.20	14.00	69	71	70	62	5.50	4.90	3.70
22	2079.98	1142.47	13.70	11.00	4.20	70	73	67	73	10.00	10.50	14.50
23	2169.47	1052.98										
24	2234.40	1049.47	14.10	8.60	6.80	72	60	70	52	12.70	8.20	10.50
25	2153.68	1000.34										
26	2155.44	1082.81										
27	2164.21	1110.89	14.50	15.50	4.60	62	60	44	50	11.80	12.70	12.20
28	2160.70	1098.60	5.20	15.70	5.90	70	54	51	74	16.10	11.80	14.20
29	2088.76	967.00										
30	2034.36	981.04	12.30	11.40	3.30	55	62	60	50	11.50	11.40	11.10
31	1962.42	998.59	8.80	10.00	7.30	71	80	60	63	10.00	8.80	8.50
32	1988.74	921.38	10.40	14.40	8.00	50	54	63	68	9.80	12.50	17.00
33	2037.87	896.81				57	59	56	69	9.40	12.80	19.20
34	2044.89	858.21				61	70	62	69	13.30	18.60	20.00
35	1985.23	879.26	19.00	16.00	7.50	45	55	55	48	17.00	14.00	16.70
36	1908.02	851.19				71	53	50	60	13.80	8.70	18.80
37	1879.95	821.36				68	61	65	45	13.20	12.50	19.50
38	1893.98	742.40				60	65	53	62	16.20	16.10	15.00
39	1871.17	703.79				65	67	60	50	15.70	15.40	15.20
40	1937.85	693.26										
41	1848.36	695.02										
42	1893.98	651.15				55	60	65	57	14.10	13.50	10.90

Table A (continued)

No	x	y	BODY			CAP						
			D1	D2	H	S1	S2	S3	S4	D3	D4	h
43	1825.55	693.26				65	68	62	55	8.20	13.60	11.20
44	1818.53	656.41				61	66	60	53	12.50	14.00	12.50
45	1822.04	740.64				60	65	68	61	11.60	13.80	11.50
46	1800.98	733.62				72	65	60	56	12.70	16.00	15.90
47	1772.91	726.60				53	57	75	77	10.60	8.90	12.20
48	1751.85	684.49				60	66	55	65	12.50	12.70	12.70
49	1646.57	684.49	13.10	12.40	8.30	70	60	56	50	13.10	9.00	11.10
50	1692.19	633.60	11.60	7.20	6.00	50	65	70	55	13.90	10.30	12.10
51	1629.02	835.40	15.40	8.10	6.30	70	60	50	57	7.70	12.70	10.90
52	1636.04	907.34	14.00	5.60	11.80	62	45	60	55	13.00	14.10	11.20
53	1465.83	724.85										
54	1448.28	714.32										
55	1399.15	740.64	9.20	9.60	11.50	57	50	58	52	6.50	7.70	4.50
56	1325.45	779.25	8.10	8.80	12.00	68	55	48	62	5.00	6.90	3.30
57	1376.34	561.66										
58	1346.51	512.53										
59	1279.83	484.45	7.20	5.60	10.80	56	60	59	55	5.20	3.80	4.40
60	1365.81	344.07	11.00	15.80	3.50	63	77	56	53	8.70	15.20	14.50
61	1251.75	503.75	8.10	6.90	9.60	62	50	50	57	8.50	6.40	6.50
62	1258.77	514.28										
63	1279.83	602.02										
64	1164.02	554.64	15.00	20.00	1.30	67	50	52	49	13.00	18.40	15.00
65	1164.02	587.98				45	60	61	43	17.70	19.60	14.20
66	1167.53	619.57										
67	1106.11	789.77										
68	1155.25	795.04										
69	1171.04	793.28	10.40	19.30	7.30	60	56	45	50	8.20	14.40	7.60
70	1060.49	535.34	13.50	13.70	15.70	55	60	65	70	10.70	8.90	11.40
71	1016.62	493.23	10.80	14.30	15.20	58	62	57	70	7.70	6.90	7.60
72	1030.66	593.24	9.80	11.20	23.50	65	68	63	70	5.00	4.80	5.00
73	1041.19	609.04	7.80	10.50	12.20	68	60	62	70	6.90	9.00	7.20
74	927.13	417.77	5.50	15.40	5.80	71	65	56	51	4.00	11.70	8.60
75	600.75	633.60				65	56	60	55	12.80	10.00	12.60
76	513.02	696.77	12.80	19.30	20.70	70	60	65	58	2.70	2.90	2.70
77	465.64	714.32	10.80	16.80	17.00	50	55	50	62	3.30	5.90	4.10
78	439.32	721.34	10.40	18.90	12.20	58	50	55	52	3.20	5.80	4.20
79	516.53	779.25	8.90	10.00	14.40	50	58	53	70	7.80	8.30	5.30
80	420.02	810.83	9.40	12.00	6.50	50	60	55	67	8.70	9.50	8.30
81	416.51	793.28										
82	395.45	807.32	6.50	7.20	8.50	64	68	62	58	5.00	7.20	5.20
83	437.56	637.11										
84	365.62	645.89	3.00	5.80	3.50	62	50	65	60	4.00	4.10	3.50

Table A (continued)

No	x	y	BODY			CAP						
			D1	D2	H	S1	S2	S3	S4	D3	D4	h
85	321.75	731.87	8.70	10.10	10.00	50	60	60	66	5.90	10.70	12.80
86	302.45	731.87										
87	304.21	756.43	14.10	14.50	4.20	59	57	62	60	13.20	14.00	12.80
88	569.17	868.74	7.00	8.30	6.70	57	56	63	56	6.80	6.00	4.80
89	630.58	858.21	10.50	10.20	15.70	70	65	56	60	8.60	8.80	10.60
90	570.92	1016.13	7.80	8.30	17.00	62	60	50	56	4.20	4.00	3.50
91	621.81	1047.72	10.60	11.30	18.10	57	48	63	55	3.90	6.30	4.70
92	448.09	565.17										
93	427.04	568.68	10.50	15.70	27.00							
94	241.04	458.13	11.80	17.40	15.90	55	63	72	57	2.90	3.10	3.00
95	267.36	482.70										
96	193.66	426.55	15.30	23.30	18.70	56	65	72	65	2.10	3.10	1.40
97	141.02	396.72	14.40	16.50	15.90	55	60	64	62	2.80	4.40	1.10
98	158.56	363.38	8.40	11.30	12.30	67	62	73	50	1.80	1.10	0.70
99	137.51	470.41	13.70	24.40	15.90	57	50	60	58	3.50	4.50	3.40
100	155.05	489.72	15.00	20.60	12.30	59	55	56	66	4.80	6.90	5.00
101	162.07	533.58	5.30	15.00	20.00	60	63	53	44	5.50	9.30	6.00
102	104.17	528.32	12.10	15.00	18.80	60	55	64	64	7.40	7.80	6.70
103	207.70	672.21										
104	195.41	331.79				72	67	60	48	10.50	24.50	18.50
105	62.05	338.81				57	65	49	48	10.00	31.70	21.80
106	155.05	187.90				68	69	52	53	9.60	25.50	17.50
107	602.51	1116.15	13.30	14.40	13.60	65	64	60	60	11.80	12.50	12.20
108	621.81	1138.96	11.50	18.90	10.10	60	68	62	58	9.00	15.00	6.50
109	655.15	1144.23	20.00	9.60	5.70	60	62	58	68	18.60	8.80	16.00
110	686.73	1119.66	16.00	13.30	11.70	60	60	70	67	13.60	13.10	15.50
111	634.09	1200.38	13.30	20.70	14.00	62	75	60	65	13.00	19.30	17.80
112	476.17	1189.85	12.50	21.20	13.50	57	50	50	60	10.00	19.70	10.20
113	497.22	1244.25										
114	800.79	1193.36	8.80	5.00	8.20	62	68	55	60	7.90	4.20	7.60
115	799.04	1181.08	5.00	3.50	11.00	70	65	52	62	3.20	5.40	6.80
116	746.40	1217.93										
117	760.43	1240.74	11.10	20.00	5.90	60	70	55	57	10.80	18.90	17.80
118	723.58	1284.60				55	60	57	52	10.00	18.50	18.50
119	651.64	1310.93				70	60	60	48	13.00	30.50	20.00
120	735.87	1337.25										
121	716.56	1651.34										
122	737.62	1642.57				65	72	55	60	13.30	21.20	22.50
123	790.26	1612.74				48	52	40	50	11.50	12.50	18.00
124	804.30	1639.06										
125	820.09	1609.23				65	60	58	60	16.20	16.70	15.60
126	827.11	1649.59				65	62	48	60	10.70	9.00	10.30

Table A (continued)

No	x	y	BODY			CAP						
			D1	D2	H	S1	S2	S3	S4	D3	D4	h
127	793.77	1705.74				50	60	60	70	15.00	31.50	28.30
128	853.43	1610.98				51	60	50	60	20.00	19.00	19.10
129	888.53	1595.19				56	58	56	60	12.40	19.10	15.80
130	881.51	1575.89				52	56	64	68	8.90	14.80	12.50
131	918.36	1486.40				59	53	60	70	20.50	22.30	21.10
132	909.58	1537.28				54	58	63	60	18.90	13.80	15.00
133	1000.83	1507.45				65	67	57	62	9.70	15.40	12.90
134	951.70	1417.96										
135	1064.00	1451.30										
136	1044.70	1437.27										
137	1404.42	1379.36	11.40	16.40	1.81	55	49	54	60	11.50	14.50	13.30
138	1299.13	1493.42				52	55	52	68	9.70	12.50	11.10
139	1306.15	1540.79				60	47	54	60	17.40	20.00	16.00
140	1416.70	1540.79				54	59	59	49	16.40	17.70	16.50
141	1434.25	1539.04				68	62	56	70	15.20	13.60	13.90
142	1437.76	1526.76				65	53	57	52	11.70	13.50	10.70
143	1427.23	1507.45										
144	1436.00	1453.06				52	50	63	52	8.40	10.90	10.60
145	1453.55	1468.85				51	52	51	60	15.40	16.20	13.10

APPENDIX B

Table B: Fairy chimney measurements in Kavak-Zelve transition

No	BODY			CAP						
	D1	D2	H	S1	S2	S3	S4	D3	D4	h
1	10.0	8.5	11.7	60	65	60	50	5.4	5.2	3.6
2	3.3	7.4	8.5	60	65	50	60	3.4	3.5	3.3
3	6.6	6.3	9.7	55	58	63	60	3.6	4.5	4.4
4	7.1	6.4	10.3	60	58	58	65	3.0	3.5	2.5
5	7.9	7.7	9.6	54	50	57	59	4.2	3.7	2.1
6	4.3	7.5	10.7	52	59	55	65	3.6	3.8	2.9
7	6.5	6.6	16.0	65	54	60	68	2.9	2.9	2.1
8	6.4	9.3	9.6	50	60	56	60	1.3	1.8	0.9
9	5.6	7.5	13.3	40	55	54	49	1.4	1.7	2.5
10	4.4	5.9	14.5	45	70	40	60	1.8	2.4	1.1
11	3.0	5.0	15.1	45	60	51	51	1.1	1.9	1.2
12	6.4	7.5	13.5	50	60	45	67	4.2	4.6	3.0
13	8.0	7.0	13.5	55	61	57	60	3.5	4.0	3.1
14	7.8	9.1	9.5	55	70	65	62			
15	9.2	10.0	17.9	72	63	65	70	1.5	2.7	1.4
16	7.0	9.5	8.6	59	64	57	60			
17	7.7	8.0	16.0	62	68	50	58	3.3	3.9	2.0
18	13.5	11.5	14.2	62	65	48	57	5.0	3.5	2.0
19	7.6	8.7	12.5	50	54	50	67	1.9	2.2	2.7
20	5.3	9.7	11.1	65	67	60	67	1.1	1.2	0.7
21	12.5	14.3	8.8	57	50	45	50	10.6	13.0	6.2
22	6.5	5.0	11.0	50	75	65	67	3.2	2.9	3.5
23	5.0	6.4	9.6	57	77	60	50	3.3	3.7	4.0
24	11.6	7.0	10.7	60	54	51	62	6.0	4.3	2.9
25	7.2	8.0	11.0	57	60	53	56	4.6	4.0	2.7
26	5.5	5.9	13.7	53	57	57	66	1.9	1.9	2.8
27	7.8	6.7	14.7	57	60	50	60	5.3	4.8	2.9
28	8.2	13.5	16.0	45	58	57	59	1.9	2.4	1.5
29	12.8	10.0	14.1	53	60	57	60	4.4	3.9	2.5
30	6.7	7.3	9.7	52	55	50	55	4.1	3.7	2.9

APPENDIX C

Table C: Fairy chimney measurements in Zelve Ignimbrite (Site-1)

NO	S1	S2	S3	S4	D1	D2	H
1	70	50	60	70	4	4.5	3.2
2	87	80	70	87	2.6	2.9	4
3	81	84	65	70	1.2	1.7	5.2
4	65	82	50	75	1.8	3.1	3.1
5	80	85	64	84	1.8	4.6	4.8
6	70	71	68	81	3	3.2	5.4
7	65	67	68	54	4	5	5.3
8	72	82	67	72	1.9	3.1	6
9	80	80	60	77	2.9	3.8	7.1
10	71	73	70	56	3	4.7	5
11	80	83	74	69	2.1	2.5	6.6
12	80	75	76	80	2.8	2.2	4.5
13	72	63	70	72	5	3.4	5.5
14	80	78	77	74	3.2	3.5	5.9
15	87	81	73	77	1	1.9	3.4
16	85	81	70	65	1.2	2.9	3.4
17	85	82	84	87	1.5	1.8	3.5
18	85	80	83	85	1.2	2.2	3.7
19	75	70	60	67	2.4	4.9	5.5
20	60	83	55	80	2.8	5.3	5.2
21	88	77	80	89	0.8	1	2.7
22	83	80	80	83	2	2.3	5.7
23	78	62	70	58	3.3	5.7	6.3
24	62	60	82	78	2.6	2.4	5.4
25	65	70	64	65	2.2	2.8	3.4
26	75	73	58	75	4	4.3	4
27	63	70	73	67	6.6	7.7	8.7
28	69	62	55	57	4.5	5.5	6
29	69	61	63	68	3.7	4.8	4.3
30	70	69	70	60	2.8	3.6	4.6
31	61	78	70	80	2.6	2	4.5
32	63	70	60	70	3.6	4.9	4.9
33	77	75	65	73	3.8	6.5	8.4
34	72	66	54	53	3	5.8	5.2
35	75	67	61	76	5.7	6.1	9
36	65	80	62	75	5.2	6.6	7.5
37	73	78	62	70	2.2	3	5.5
38	67	70	58	68	4.2	4.4	5.4
39	70	65	55	60	3.2	5.1	5.4
40	52	60	52	61	7	10	11.8
41	65	70	71	72	4.8	5	8.9
42	68	66	56	60	7.7	11.4	8.3
43	70	60	60	61	10.3	10.6	12
44	65	70	71	64	7.9	8.6	10.4
45	70	76	70	70	10.3	10.8	15.1

APPENDIX D

Table D: Fairy chimney measurements in Zelve Ignimbrite (Site-2)

NO	S1	S2	S3	S4	D1	D2	H
1	65	55	48	67	7.7	8.7	13.8
2	62	60	59	60	8.4	10	8.9
3	61	60	61	61	8	9.5	8.8
4	76	66	70	80	3	4.6	6
5	74	69	65	62	5.3	5.4	8.6
6	82	88	72	73	0.8	0.9	2.7
7	77	76	80	78	1.9	2.4	3.6
8	60	58	62	75	7.7	5.9	5.8
9	72	70	72	71	2.9	2.9	4.3
10	70	65	63	76	7.8	5.4	7.4
11	75	73	75	80	2.1	1.7	4.6
12	75	80	78	78	2.5	2.8	5.2
13	64	65	55	55	6.8	7.8	5.9
14	70	71	62	56	2.4	3.1	4.1
15	68	68	61	62	8.3	12	17
16	80	85	75	72	8	10	18
17	61	59	63	70	15	14.4	18.5
18	75	70	67	70	10	10.7	17.6
19	80	75	74	76	4	5.4	11.1
20	77	76	60	65	5.2	6	15
21	66	61	66	68	6.1	12.2	18.4
22	67	70	63	66	8.8	14.4	20.5
23	60	57	60	75	9.2	5.5	15
24	60	58	50	55	11.8	14.4	11.8
25	75	70	55	62	2.1	4.9	4.3
26	68	70	71	68	4.5	4.6	5.7
27	65	58	63	60	5.9	5.9	6.6
28	68	62	57	67	5.5	5.8	6.1
29	68	67	67	70	3.7	3.9	5.8
30	80	71	75	70	1.4	1.8	4
31	65	60	58	60	5.7	5.9	5.8
32	73	71	68	70	2.4	4.6	6.2
33	79	78	73	87	1.8	1.7	4.1
34	65	53	57	65	10.8	12	10.6
35	52	71	47	55	5.3	11.1	8
36	62	53	60	70	4.3	5.4	5
37	60	82	70	83	3.4	3.5	8
38	60	58	59	65	3.9	4.2	4.2
39	61	59	70	65	6.3	4.9	6.5
40	70	65	51	51	7.4	7.7	10.5
41	65	74	68	55	8.3	7.3	14.7
42	55	60	80	70	5.7	7.9	15
43	60	70	63	70	2.6	3	4.5
44	53	50	62	67	9.1	9.2	9.2
45	59	54	60	65	5.9	6	5.4

APPENDIX E

Table E: Fairy chimney measurements in Cemilköy Ignimbrite (Site-1)

NO	S1	S2	S3	S4	D1	D2	HEIGHT	CAP
1	55	60	35	30	9.3	17.3	9.0	
2	30	32	40	30	9.1	14.7	8.8	
3	50	60	53	47	10.0	14.1	9.5	
4	55	60	60	50	10.0	13.3	9.2	
5	55	58	55	45	6.7	9.5	7.0	
6	50	60	60	52	8.8	6.1	5.5	
7	53	60	50	60	6.2	7.2	6.8	
8	60	57	48	50	6.5	7.5	5.7	yes
9	47	55	40	47	4.8	6.3	4.0	
10	50	45	42	40	7.2	11.5	6.2	
11	67	65	60	64	4.1	6.5	7.0	yes
12	50	48	40	57	16.0	14.2	12.0	
13	70	67	58	63	8.8	10.0	9.8	yes
14	61	59	55	65	5.5	7.5	5.5	
15	53	58	52	62	6.3	6.6	5.5	
16	55	50	55	60	8.8	13.0	8.5	
17	68	60	53	62	12.0	12.2	10.0	
18	56	48	50	68	7.3	5.5	6.5	
19	75	68	65	75	2.8	3.4	4.6	
20	58	52	62	56	9.1	8.7	7.8	
21	65	55	50	55	11.2	13.3	10.8	
22	65	50	62	64	11.3	13.8	13.5	
23	55	60	62	58	10.0	10.5	8.8	
24	58	65	58	53	8.2	8.6	8.8	
25	55	60	62	60	6.6	7.7	6.7	
26	63	62	71	68	6.5	7.5	8.8	yes
27	57	60	63	66	8.8	8.3	10.5	
28	55	60	55	65	8.8	12.2	9.5	
29	59	61	60	54	10.5	11.8	11.0	
30	60	60	55	66	16.4	13.3	13.0	
31	63	64	56	61	6.3	7.9	5.8	yes
32	50	45	40	50	11.5	12.3	14.2	
33	55	58	55	50	15.7	15.3	12.7	
34	50	40	48	53	14.5	18.0	14.0	
35	60	60	55	60	14.6	17.8	11.4	
36	67	55	50	65	13.1	13.8	13.4	
37	60	62	65	67	16.4	14.1	13.5	
38	58	53	63	70	11.0	15.0	13.1	
39	67	62	59	63	7.8	9.1	7.8	
40	55	60	57	64	8.8	7.9	10.0	
41	60	55	63	68	13.5	8.5	8.9	
42	62	60	55	60	10.0	8.5	9.2	yes
43	62	68	48	42	7.0	8.7	6.6	
44	67	66	69	64	7.1	8.8	8.7	yes
45	56	56	63	60	9.0	11.3	10.6	

APPENDIX F

Table F: Fairy chimney measurements in Cemilköy Ignimbrite (Site-2)

NO	S1	S2	S3	S4	D1	D2	H	CAP
1	60	60	80	60	8.1	5.7	7.7	
2	50	62	67	59	10.1	8.2	7.0	
3	58	60	58	61	6.6	5.0	6.0	
4	70	72	60	68	7.0	6.5	9.8	
5	60	58	47	51	4.8	6.4	4.1	
6	60	69	51	55	10.0	10.8	8.6	
7	65	67	50	68	3.7	3.8	2.9	yes
8	67	75	60	65	4.2	6.0	4.3	yes
9	70	74	67	70	3.5	4.4	4.6	yes
10	67	57	52	72	6.9	6.8	6.8	yes
11	50	65	49	65	13.6	9.2	8.3	
12	65	70	64	46	6.6	11.7	8.9	yes
13	61	57	60	52	7.0	10.0	7.9	
14	60	48	40	62	6.5	9.6	5.1	
15	61	68	60	70	5.5	7.4	9.7	
16	67	60	60	63	5.0	5.6	4.8	yes
17	62	60	48	57	8.5	14.0	8.5	
18	58	63	62	60	13.1	13.6	11.3	
19	73	58	57	53	12.8	17.9	12.3	
20	58	58	50	50	7.2	7.4	6.7	
21	45	50	55	60	8.1	11.7	10.8	
22	61	63	50	62	13.8	12.8	13.8	
23	55	60	58	65	10.4	10.0	8.2	
24	60	67	65	55	10.0	8.3	9.7	
25	63	68	65	60	7.1	8.0	7.2	
26	63	65	68	70	6.4	7.8	8.5	yes
27	60	65	65	70	9.1	8.3	10.5	
28	58	60	50	63	8.5	12.7	9.2	
29	62	52	57	60	13.9	11.1	10.5	
30	62	62	60	68	16.0	14.2	13.3	
31	63	65	58	60	6.7	7.9	6.0	yes
32	60	65	56	61	6.6	10.0	7.5	
33	67	72	62	65	4.5	8.8	6.2	
34	60	62	60	63	5.9	6.4	7.1	
35	67	65	56	58	7.1	9.2	6.6	yes
36	68	65	70	63	10.6	9.2	7.3	yes
37	61	68	56	58	7.4	10.0	6.5	
38	74	80	65	62	3.6	6.6	6.2	
39	57	60	60	52	6.8	7.3	4.8	
40	65	55	60	55	7.6	7.9	7.5	
41	70	60	56	58	11.5	11.0	10.0	yes
42	60	63	60	62	6.3	4.6	5.5	yes
43	60	58	62	64	6.3	6.3	5.1	
44	75	60	60	70	6.1	8.5	7.4	yes
45	60	67	62	80	6.4	5.6	6.0	yes

APPENDIX G

Table G: Fairy chimney distance measurements

No	Cemil-1	Cemil-2	Zelve-1	Zelve-2
1	9.1	11.2	4.0	6.6
2	11.2	16.8	5.4	5.9
3	14.2	14.2	3.3	6.2
4	14.1	11.6	6.5	7.1
5	13.5	12.1	6.2	4.8
6	10.5	5.4	5.4	5.4
7	7.1	4.7	3.9	7.3
8	4.5	20.6	3.7	4.2
9	10.4	16.8	4.1	6.9
10	14.2	6.9	3.9	5.1
11	14.3	7.6	5.9	6.5
12	11.5	9.4	3.1	5.2
13	10.9	10.9	4.4	6.3
14	9.8	8.9	3.6	7.0
15	10.5	6.4	3.2	7.2
16	14.7	7.6	5.3	6.4
17	20.4	10.3	5.2	5.1
18	18.8	12.8	3.1	6.6
19	17.9	10.7	3.7	4.4
20	14.1	13.4	5.5	4.9
21	10.4	9.6	7.5	6.2
22	8.6	10.4	3.3	5.3
23	8.8	12.2	4.9	5.7
24	9.1	11.7	4.2	7.6
25	13.6	13.4	8.6	5.2
26	10.6	14.8	5.8	4.9
27	12.1	12.8	6.9	6.6
28	10.9	13.1	6.1	4.1
29	10.7	12.4	3.5	5.5
30	12.1	12.3	4.7	4.8
31	7.8	8.6	3.8	4.2
32	10.4	8.8	8.1	7.2
33	18.5	13.6	4.6	5.4
34	12.1	8.3	5.7	3.8
35	9.1	9.3	6.2	4.7
36	10.2	8.1	7.7	6.2
37	9.9	8.6	5.1	4.6
38	13.7	10.5	8.3	5.9
39	16.8	5.7	5.4	5.1
40	7.2	10.8	6.4	4.3
41	13.2	7.9	5.5	3.7
42	15.9	14.0	7.1	7.1
43	14.2	9.5	4.0	6.1
44	16.3	8.6	5.8	4.6
45	15.8	12.7	4.2	5.3
46	14.5	12.4	6.7	6.6
47	10.8	11.3	5.2	5.4
48	11.7	11.5	4.4	5.9
49	14.9	17.1	7.1	4.7
50	13.8	10.4	6.8	6.3

APPENDIX H

Table H: Engineering properties of Cemilköy Ignimbrite

Sample No	Length (mm)	Diameter (mm)	Failure load (kg)	Uniaxial Compressive strength (kg/cm2)	Uniaxial Compressive strength Mpa
1	90,32	40,20	600,00	47,27	4,64
2	89,66	40,50	600,00	46,57	4,57
3	92,09	40,14	550,00	43,46	4,26
4	90,89	40,60	950,00	73,38	7,20
5	93,79	40,35	950,00	74,29	7,29
			Average	**57,00**	**5,59**
			Std. Dev.	**15,44**	**1,51**

Sample No	Length (mm)	Diameter (mm)	Dry weight (gr)	Dry weight (gr)	Dry unit weight (gr/cm3)	Saturated unit weight (gr/cm3)	Specific gravity (gr/cm3)	Volume cm3	Porosity (%)	Water absorption by weight (%)
1	90,32	40,20	146,5	189,76	1,28	1,66	2,05	114,64	37,74	29,53
2	89,66	40,50	149,18	193,59	1,29	1,68	2,10	115,50	38,45	29,77
3	92,09	40,14	146,37	191,58	1,26	1,64	2,05	116,54	38,80	30,89
4	90,89	40,60	156,46	197,73	1,33	1,68	2,05	117,67	35,07	26,38
5	93,79	40,35	162,78	205,26	1,36	1,71	2,10	119,93	35,42	26,10
				Average	**1,30**	**1,67**	**2,07**		**37,09**	**28,53**
				Std. Dev.	**0,04**	**0,03**	**0,03**		**1,73**	**2,16**

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WORK EXPERIENCE

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FOREIGN LANGUAGES

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