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Tectonic control on the development of the Neogene–Quaternary Central Anatolian Volcanic Province, Turkey

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The Neogene–Quaternary Central Anatolian Volcanic Province (CAVP) is elongated in a north-east–south-west direction within pre-Oligocene basement in central Turkey. This study investigates the field evidence relating to the development of the CAVP.

Two dominant fault systems are recognized in the area. The first consists of the major conjugate faults in the region, namely, the right-lateral Tuzgölü and left-lateral Ecemiş fault zones, and other faults parallel to these zones. The faults in this system are mostly active and cut the CAVP almost at right angles. The second fault system trends in a N60°–70°E direction, parallel to the volcanic axis and to the alignment of the major eruption centres. These faults, which are of the normal type, are mostly buried beneath the products of recent volcanic eruptions.

The behaviour of the first system is explained with reference to the present north–south convergence that occurs in the eastern Mediterranean region. These faults, which might be reactivated palaeotectonic structures, are a response to a present day compressive stress direction of about N10°W. The second fault system, in contrast, is the product of a short-term tensional period that occurred during the Mid–Late Miocene to Pliocene. This extension is almost at right angles to the convergence. As a result, the pre-Oligocene basement in the area was fractured in a N60°–70°E direction and these fractures served as pathways for the extrusive rocks that formed the CAVP. The major eruption centres of the CAVP (i.e. the Hasandağ, Keçiboyduran and Melendiz stratovolcanoes) are located at the intersection of the major faults of these two fault systems.

KEY WORDS Volcanism Tectonism Neogene–Quaternary Central Anatolian Volcanic Province, Turkey

1. INTRODUCTION

The Central Anatolian Volcanic Province (CAVP) is a Neogene–Quaternary calc-alkaline volcanic province located in Central Anatolia, Turkey (Figure 1). It extends as a belt in a north-east–south-west direction with a long axis of about 300 km.

The age of the volcanic and volcaniclastic products within the CAVP is interpreted as Mid–Late Miocene to Recent based on radiometric age determinations from different parts of the CAVP (Innocenti *et al.* 1975; Besang *et al.* 1977; Batum 1978; Ercan *et al.* 1990; Olanca *et al.* 1992). Geochemical analyses of the CAVP display a dominantly calc-alkaline character (Innocenti *et al.* 1975; Batum 1978; Tokel *et al.* 1988; Ercan *et al.* 1990; Olanca *et al.* 1992).

Based on geochemical data, the formation of the CAVP has been attributed to upper plate extension developed over the subduction zone in the eastern Mediterranean (Innocenti *et al.* 1975; Batum 1978; Tokel *et al.* 1988). This subduction is related to the convergence between the Afro-Arabian and Eurasian plates. The first attempt to outline the nature of this extension and draw attention to the existence of the major lineaments that cut across the CAVP was the study of Pasquare *et al.* (1988). They proposed that the major volcanic centres are located at the intersection of faults of two different trends.

The objective of this study was to investigate the nature of the fault system in the area from the Mid-Miocene to Quaternary and to investigate the probable control of these faults on the development of the CAVP.

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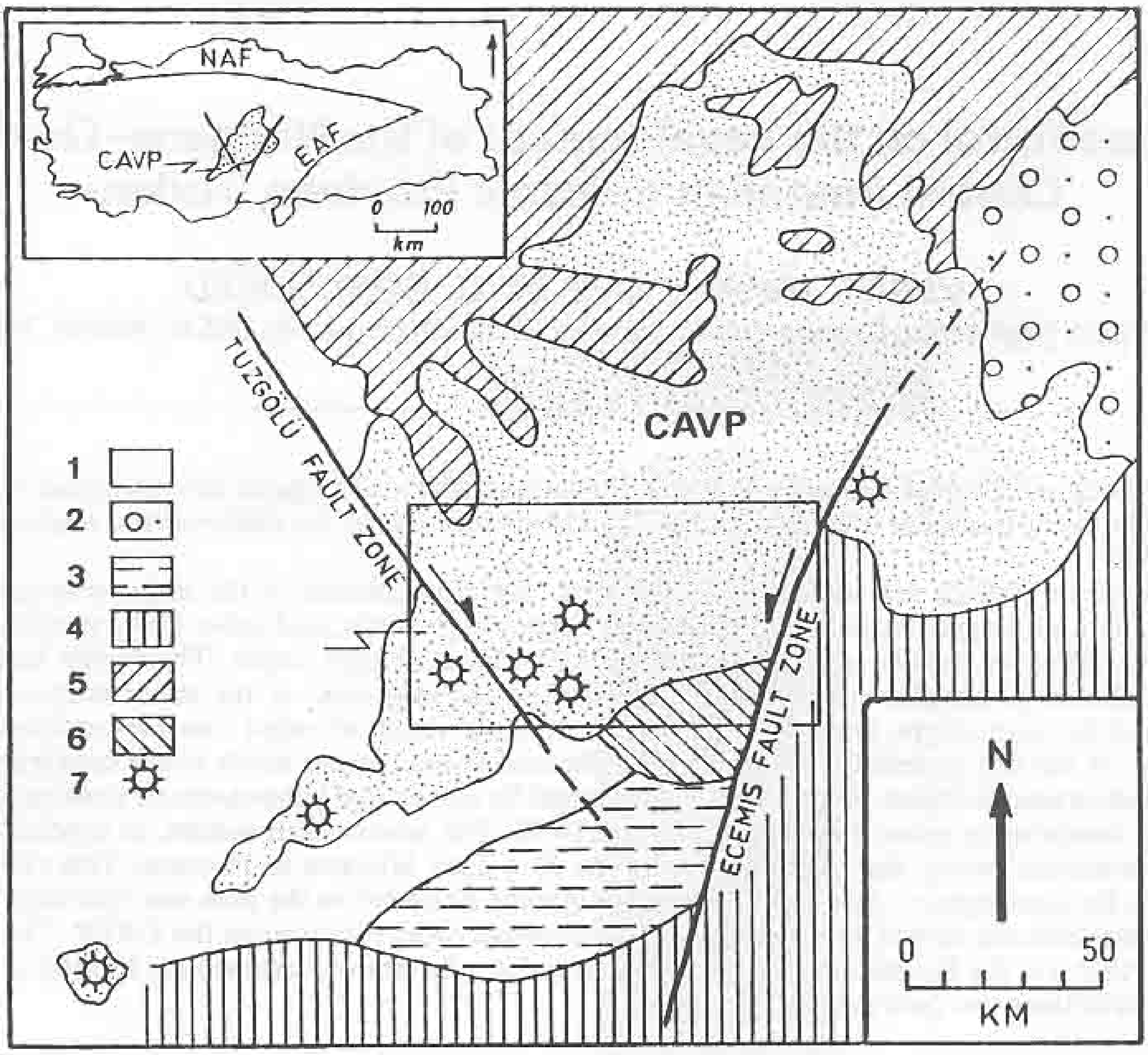

Figure 1. Simplified geological map of the Central Anatolian Volcanic Province (CAVP) and surrounding region 1 = Tuzgölü Basin; 2 = Sivas Basin; 3 = Ulukişla Basin; 4 = Taurides; 5 = Kirşehir Massif; 6 = Niğde Massif; 7 = Major eruption centres; NAF = North Anatolian Fault; EAF = East Anatolian Fault

2. REGIONAL GEOLOGY

The CAVP is situated in an area containing six tectonic units of various ages (Figure 1).

1 The Tuzgölü Basin is a sub-basin nested within the complex system of depressions of Central Anatolia. It started to evolve during the Late Cretaceous and is still a part of neotectonic Turkey (Görür *et al.* 1984).

2 The Sivas Basin, situated between the two major tectonic belts of Turkey (the Anatolides and the Pontides), was formed during the closure of the northern branch of Neotethys in the Early Tertiary and is filled with dominantly continental deposits of Eocene to Miocene age (Cater *et al.* 1991).

3 The Ulukisla Basin is composed of Late Cretaceous to Early Tertiary arc volcanics intercalated with a flyschoidal sequence. The basin is the product of northerly subduction between the Anatolides and the Pontides (Oktay 1982).

4 The Taurides constitute a major tectonic belt extending in an east–west direction and consisting of various subunits, mainly Mesozoic carbonates (Ketin 1966).

5, 6 Kirsehir and Nigde Massifs are two separate segments of the Central Anatolian Crystalline Complex (CACC). The massifs are composed of medium to high grade metamorphic rocks overthrust by Late Cretaceous ophiolites and intruded by Late Cretaceous to Palaeocene granitoids (Seymen 1981; Cöncüoğlu 1981; 1986).

3. ROCK UNITS

The rock units exposed in the area are divided into two groups (1) pre-Neogene basement rocks and (2) Neogene–Quaternary volcanics of the CAVP (Figure 2). Recent continental deposits overlie the two groups.

3a. Pre-Neogene basement rocks

Basement rocks are extensively exposed in the south-east and north-west and belong to the Nigde and Kirsehir Massifs, respectively. Small exposures of these rocks are scattered throughout the area. The basement rocks consist of Palaeozoic–Mesozoic medium to high grade metamorphic rocks, and are overthrust by Upper Cretaceous ophiolites and intruded by Upper Cretaceous–Palaeocene plutonic rocks. Eocene limestone, with negligible exposures in the studied area, forms the cover unit of the massifs. Oligo-Miocene continental clastics are observed as two narrow bands associated with the Tuzgölü and Ecemiş fault zones.

3b. Neogene–Quaternary volcanic rocks

These rocks are the products of the CAVP and cover most of the area. They consist of an undifferentiated volcaniclastic platform and nine volcanic complexes (Göncüoğlu and Toprak 1992).

The volcaniclastic platform is composed of pyroclastic and epiclastic rocks of Late Miocene to Pliocene age interstratified with continental (fluvial to lacustrine) deposits (Beekman 1966; Pasquare 1968; Innocenti *et al.* 1975) showing strong lateral and vertical facies change.

The volcanic complexes are recognized by their distinct areal distribution, eruption centres, age and composition. The major characteristics of these complexes and available age data are given in Table 1.

4. FAULTS

The faults recognized within the CAVP belong to two distinct major fault systems. One of these systems corresponds to the Tuzgölü–Ecemiş fault system trending dominantly in a north–south to north-west–south-east direction. The second fault system strikes almost parallel to the long axis of the CAVP.

4a. Tuzgölü–Ecemiş fault system

The Tuzgölü–Ecemiş fault system consists of the faults (or fault zones) that cut the CAVP almost at right angles across its long axis. The major faults are described from west to east in the following sections.

Hasandağ fault set. This is a wide fault set within the Tuzgölü Fault Zone (TFZ) and consists of several parallel to subparallel fault segments striking north-west–south-east (Figure 3). It defines the southern extension of the TFZ and plays an active part in the location of the Hasandağ composite volcano (Göncüoğlu and Toprak 1992). It is an active right-lateral strike-slip fault zone (Toprak and Göncüoğlu 1991). Evidence for the active nature of the zone is as follows (Figure 3): (1) the fault set cuts and deforms Quaternary alluvial fan deposits north-west of Altinhisar; (2) the four latest lava flows of the Hasandağ volcanics are cut and upthrown for 25–90 m west of Keçiboyduran mountain; and (3) a cinder cone (Leşkeri hill), which is dated at about 400 000 years (Olanca *et al.* 1992) is cut by one of the segments of the zone in the southern part of the area, and downthrown for about 25 m.

The Hasandağ fault set consists of faults of two dominant trends. North-west–south-east faults are concentrated around the Hasandağ stratovolcano whereas north–south striking faults are observed south of the volcano (Figure 3). The north-west–south-east faults are right-lateral strike-slip faults as evidenced by the slickensides measured at the western slope of Keçiboyduran mountain. The north–south faults,

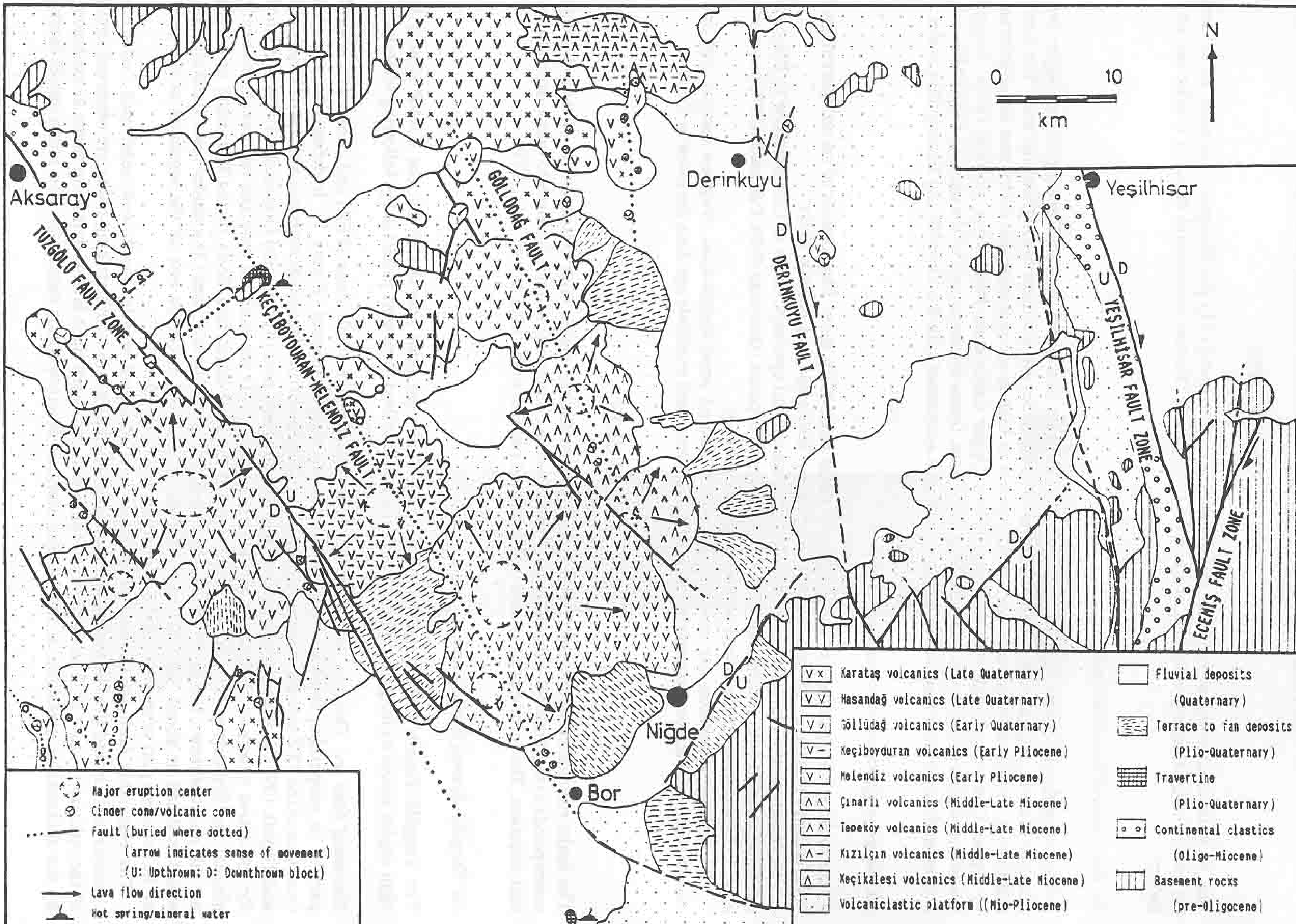

Figure 2. Geological map of the study area

Table 1.*Major characteristics of the volcanic complexes within the study area

Volcanic complex	Radiometric data (my)	Age	Dominant lithology	Type of volcano
Karataş	0·42 ± 0·04 to 0·08 ± 0·01*	Late Quaternary	Basalt	Monogenetic centres
Hasandağ	0·58 to 0·08*	Late Quaternary	Andesite–rhyodacite	Composite cone
Göllüdağ	0·9 ± 0·2 to 0·86 ± 0·1†	Early Quaternary	Rhyolite–rhyodacite	Dome
Keçiboyduran	—	Early Pliocene	Andesite	Composite cone
Melendiz	6·5 ± 0·2 to 5·1 ± 0·15‡	Early Pliocene	Andesite	Composite cone
Çınarlı	—	Mid–Late Miocene	Andesite	Composite cone(?)
Tepeköy	—	Mid–Late Miocene	Andecite–dacite	Caldera
Kızılçın	13·7 ± 0·3 to 6·5 ± 0·2†	Mid–Late Miocene	Andesite–dacrite	Caldera(?)
Keçikalesi	13·7 ± 0·3 to 12·4 ± 0·6‡	Mid–Miocene	Andesite	Caldera

* Ercan *et al.* (1990)
† Batum (1978)
‡ Besang *et al.* (1977)

on the other hand, are normal faults characterized by the alignment of cinder cones parallel to the fault trace. In the south-western part of the area, for example, 16 cones are aligned on almost north–south striking normal faults.

Keçiboyduran–Melendiz fault. This fault or fault zone is parallel to the Hasandağ fault set. It controls the locations of the Early Pliocene Melendiz and Keçiboyduran composite volcanoes. It is mostly buried under the lava and ash flows of recent volcanic eruptions. Evidence for the fault is as follows (Figure 4)

1 Volcanic-derived Plio-Quaternary conglomeratic terrace deposits are found on the western block of the fault between the Melendiz and Keçiboyduran volcanic complexes. These conglomerates are absent on the other side of the saddle-like topography formed by these stratovolcanoes. Towards the source of the conglomerates, at higher elevations, lava flows are intercalated with the conglomerates, indicating a successive development of the deposits and a gradual uplift of the north-western block.
2 A lenticular fluvial deposit is formed on the western block of the fault around Selime village. This cross-bedded and thick (> 100 m) sequence is deposited in a trough orientated in a N30°–40°W direction and ends abruptly near the fault, suggesting a depositional control of the fault. Beekman (1966) assigned a probable age of Pontian (Late Miocene) to these deposits based on the fossil remnants of an elephant.
3 Several cinder cones are concentrated on the northern flank of the Keçiboyduran and the southern flank of Melendiz volcanoes. These concentrations, as noted in other parts of the area (i.e. west of Derinkuyu (Figure 2; Toprak and Göncüoğlu 1991), usually coincide with the tensional fractures.
4 Travertine occurrences, hot springs and calcite–aragonite veins (5 cm to 2 m) are common features observed along the fault, particularly in the vicinity of Selime village. The veins are developed within Late Miocene ignimbrites and trend in a N10°–30°W direction. In a small outcrop of Eocene limestone, an *en echelon* arrangement of calcite veins was observed (inset in Figure 4). The pattern of these veins indicates a right-lateral sense consistent with a compressive stress direction of N10°–15°W. The fault may have been inactive during Pliocene to Quaternary times as it does not affect Early Pliocene Keçiboyduran and Melendiz volcanics.

Göllüdağ buried fault. The Göllüdağ fault is an inferred buried fault extending in a N25°W direction (Figure 2). The presence of the fault is indicated by the alignment of several major and minor eruption centres inconsistent with the general alignment of the centres in the area. The major centres aligned on this fault are the Tepekëy caldera (Mid–Late Miocene), the Çinarli stratovolcano (Mid–Late Miocene)

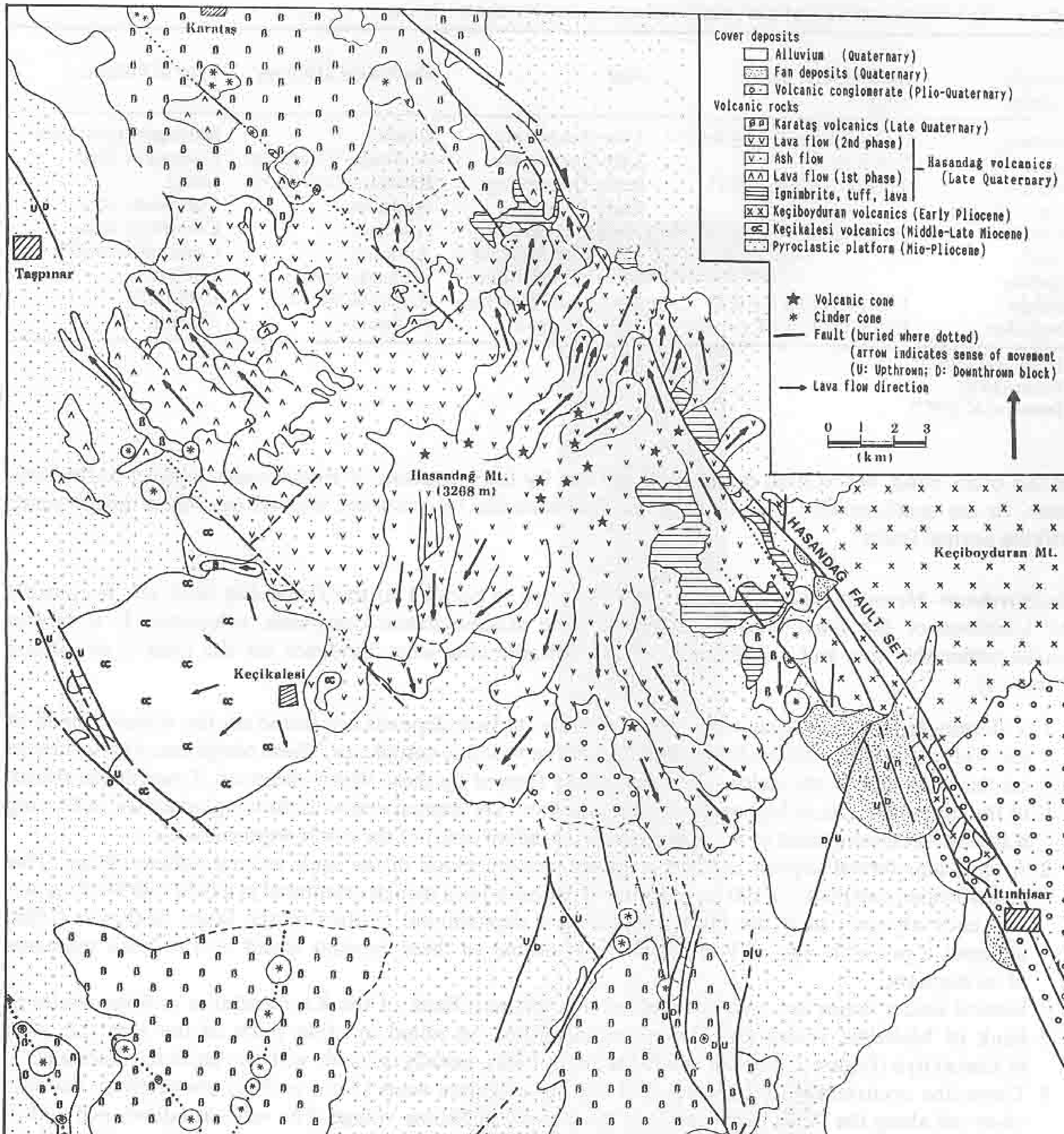

Figure 3. Geological map of the area in the vicinity of the Hasandağ fault

and the Göllüdağ rhyolitic dome (Early Quaternary). There is no sign of recent activity on the fault. Although it is suggested that it is an extensional fracture, the true nature of the movement is not evident.

Derinkuyu fault. The Derinkuyu fault strikes approximately north–south with a well exposed scarp for 20 km. It cuts and deforms volcaniclastics of Late Miocene–Pliocene age (Innocenti *et al*.1 1975). Offset streams (Figure 5) and slickensides measured along the south-central segment indicate that it is a right-lateral

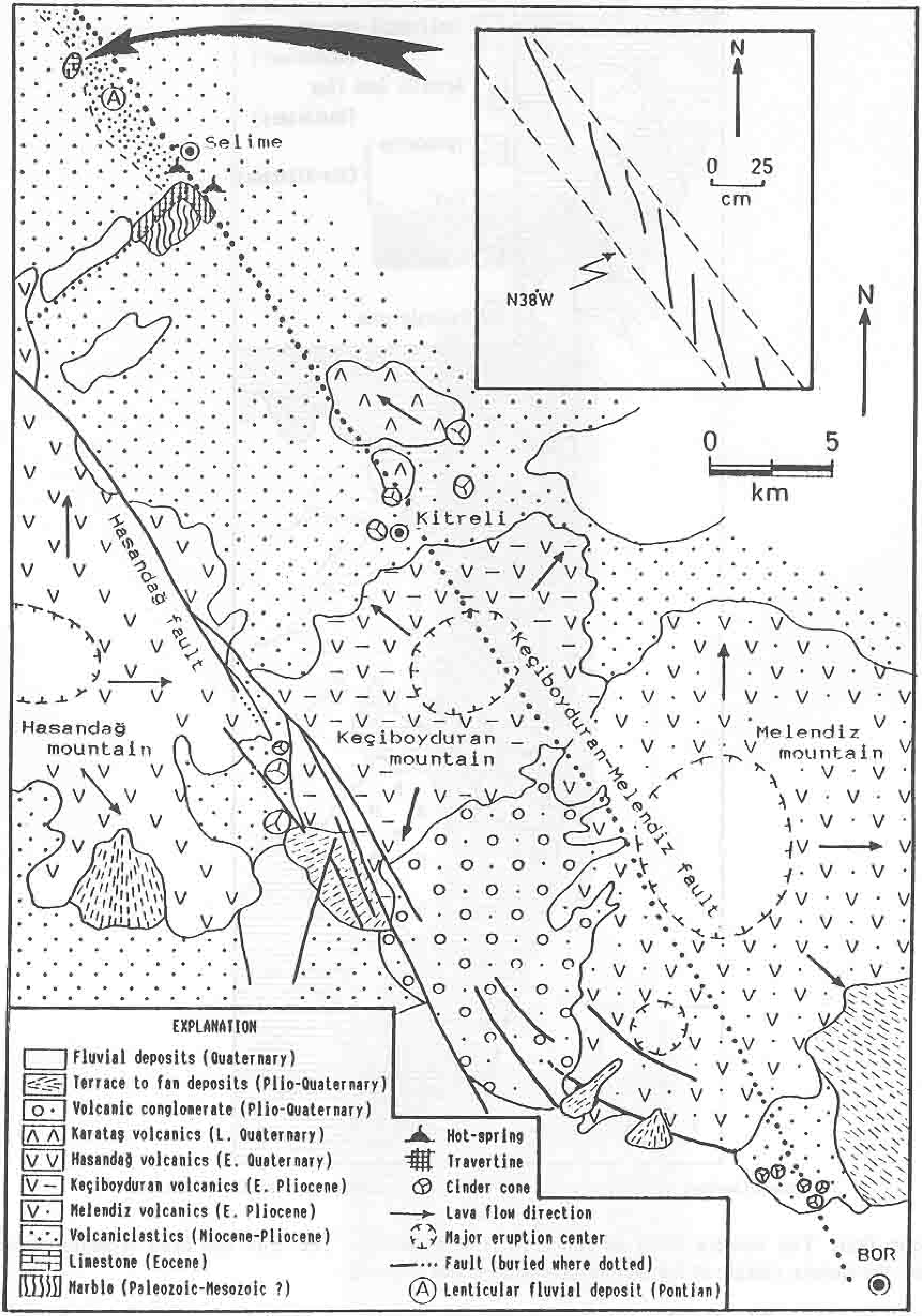

Figure 4. Geological map of the area in the vicinity of the Keçiboyduran–Melendiz fault (inset: *en echelon* calcite veins developed within Eocene limestone)

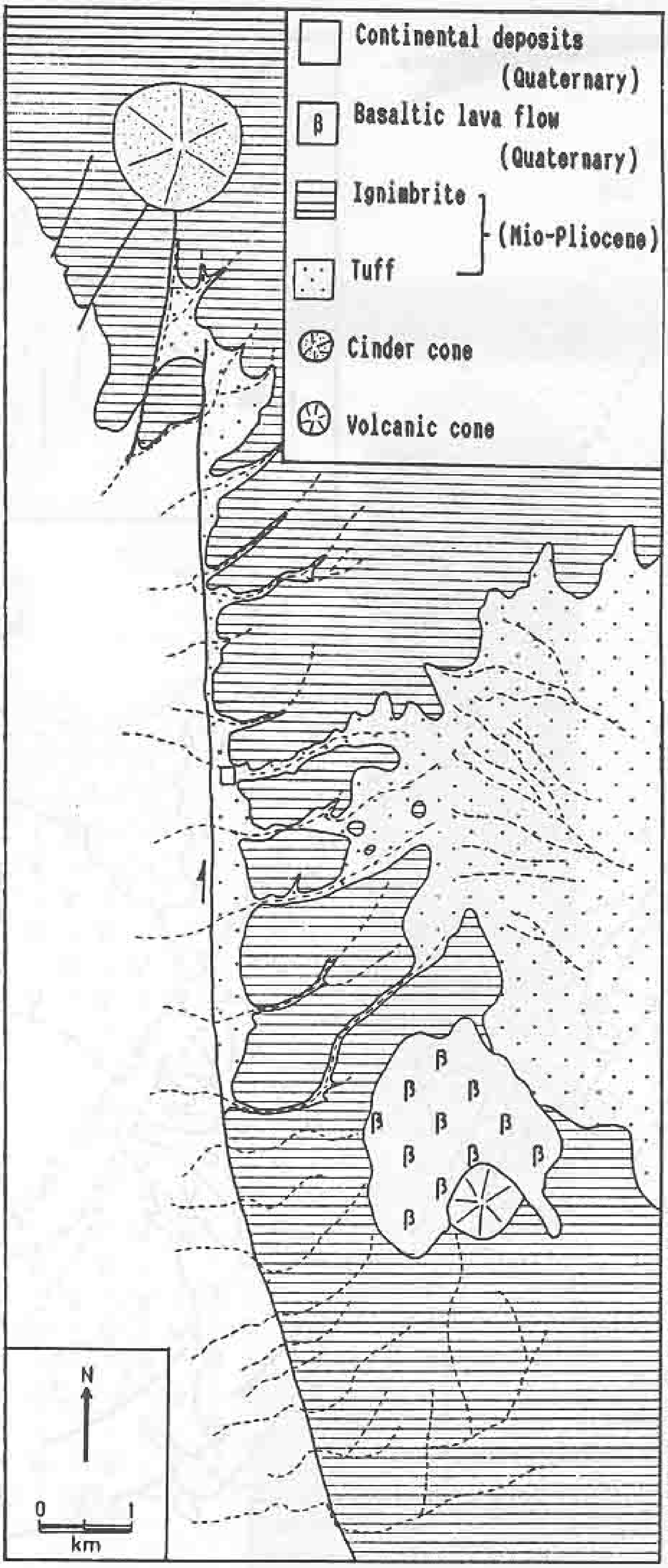

Figure 5. Geological map of the area in the vicinity of the central part of the Derinkuyu fault

strike-slip fault. The western block of the fault is downthrown. The fault has been recently active as it defines the eastern margin of the Quaternary continental deposits.

Yeşilhisar fault zone. The Yeşilhisar fault zone constitutes the western branch of the Ecemiş fault zone where it makes a horse-tail structure. The best defined fault within the zone is that which marks the

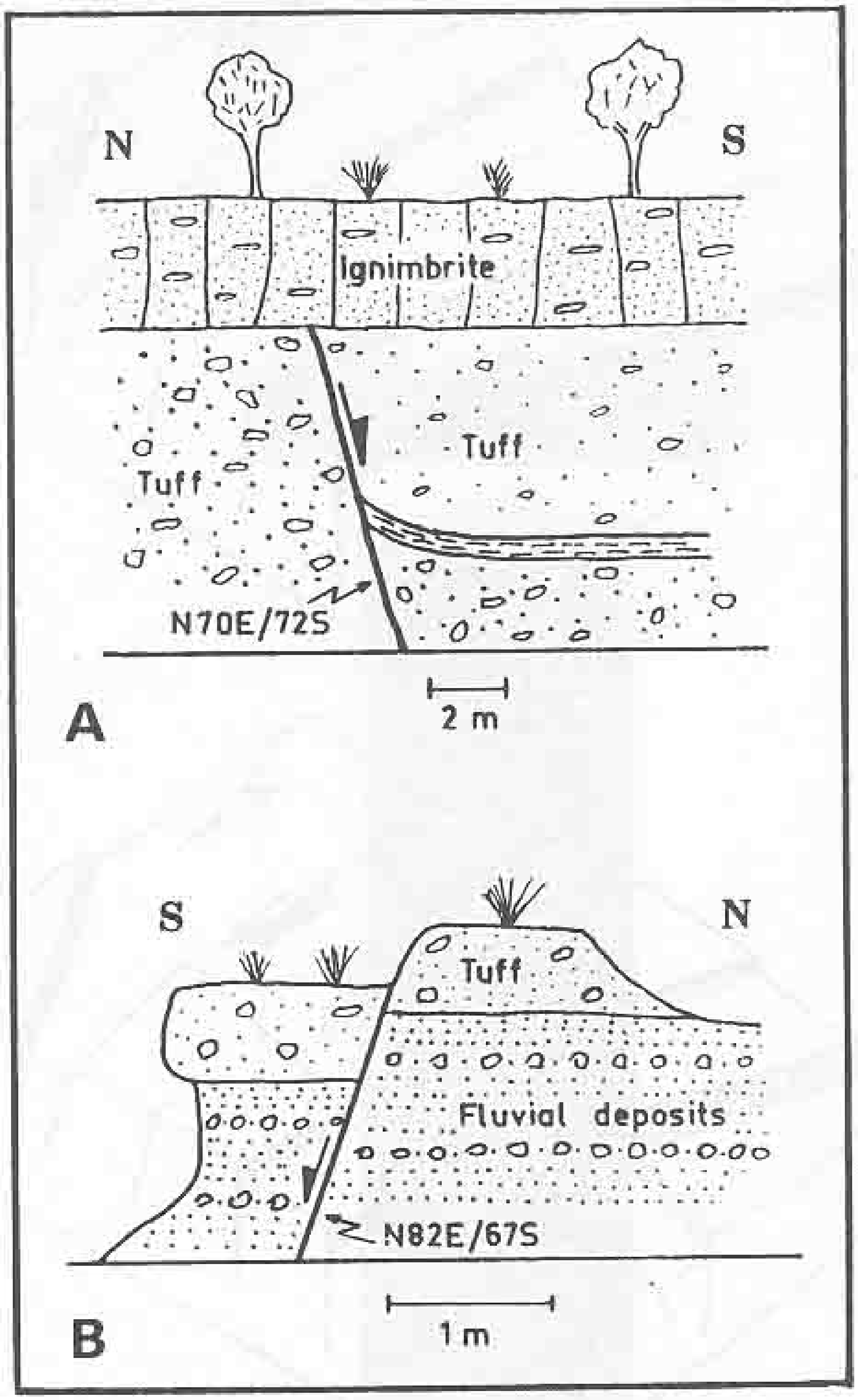

Figure 6. Extensional mesoscopic faults developed parallel to the axis of the CAVP within Mio-Pliocene volcaniclastics. (Age of ignimbrite in A is 6·5–5·5 Ma). Location: (A) 5 km north-west of Güzelyurt; (b) 4·5 km north-west of Selime

western margin of the Quaternary Yeşilhisar Basin (Figure 2). Slickensides along this fault show a right-lateral movement. Some other parallel inferred and/or buried faults at the western part of the Yeşilhisar fault zone are recognized which are responsible for the north–south alignment of basement rocks.

4b. CAVP extensional fault system (ENE–WSW trend)

The second fault system in the area trends parallel to the general axis of the CAVP. Most of the faults in this system are buried under later volcanic products. These ENE–WSW to NE–SW striking faults are normal in character and are observed extensively at the mesoscopic scale within the CAVP. They are mostly developed within volcaniclastic rocks of Mio-Pliocene age and are covered by later volcanic products. Two such faults are illustrated in Figure 6. The age of the ignimbrite in Figure 6A, which is not affected by the fault is $6{\cdot}5 \pm 0{\cdot}2$ to $5{\cdot}5 \pm 0{\cdot}2$ My (Besang *et al.* 1977), indicating that these faults were inactive after the Early Pliocene. With the exception of radial fractures developed around the Quaternary centres during their evolution, there are no field data on the faulting of recent volcanics along this trend. It is therefore suggested that this fault system is inactive at present.

Large-scale faults of this system are also exposed in the south-east of the area between the volcaniclastics and the Niğde massif (Figure 2). These *en echelon*, north-east–south-west striking faults are cut by faults

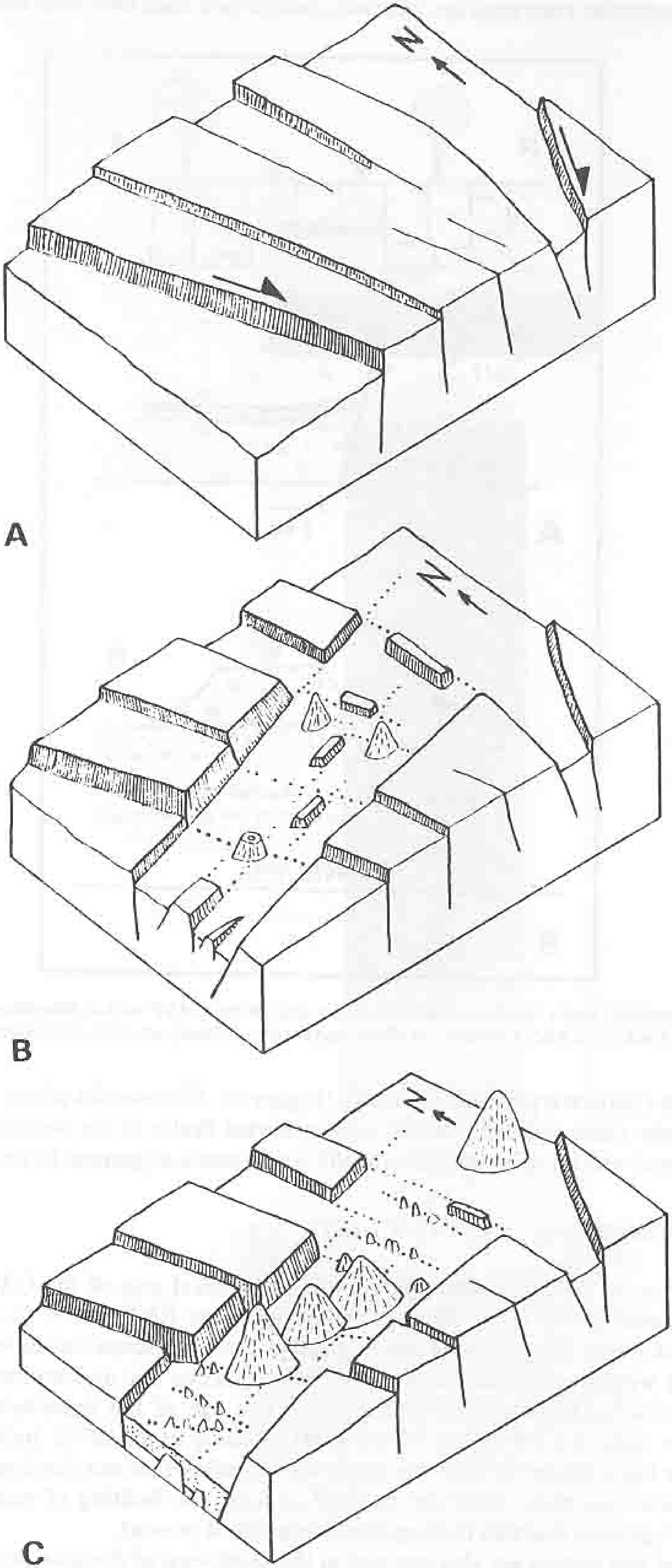

Figure 7. Development of CAVP during (A) pre-Mid-Miocene, (B) Mid-Miocene to early Pliocene and (C) Late Pliocene to Quaternary

of the Tuzgölü–Ecemiş system. The faults here are steeply northward-dipping normal faults and define the southern margin of this fault system. Fault-controlled terrace deposits are well developed at the hanging walls and are covered by Plio-Quaternary volcaniclastics. Some of the ignimbritic layers are also affected by this faulting and are uplifted above the footwall by at least 500 m, this being the minimum observed vertical throw along this fault system. Throws of this magnitude are also seen in the Tuzgölü–Ecemiş fault system, as indicated by the step-like pattern of ignimbritic layers in a north-east–south-west direction. However, the elevation differences between ignimbrites of the same north-west–south-east trending corridors suggest that the main factor in this uplift is the north-east–south-west trending system. At the northern margin of the CAVP, on the other hand, there is no evidence of significant vertical throws.

5. DEVELOPMENT OF THE CAVP

The development of the CAVP can be outlined on the basis of the ages of volcanic products exposed in the area (Table 1) and the fault systems recognized in the region. Three intervals, namely, pre-Mid-Miocene, Mid-Miocene to Early Pliocene, and Late Pliocene to Quaternary are considered to be the critical periods in the development of the CAVP (Figure 7).

5a. Pre-Mid-Miocene

The region was being deformed during this interval, mainly by conjugate faults of the Tuzgölü–Ecemiş system. Studies carried out in the Tuzgölü basin have shown that the TFZ was active during the palaeotectonic period (Uygun 1981; Görür *et al.* 1984). According to Uygun (1981) the age of the TFZ can be dated back to the Late Cretaceous. The Ecemiş fault zone, on the other hand, is believed to have initiated after the Palaeocene and before the Middle Eocene (Yetiş 1984). Although the nature of the faults before the Miocene is still not known, these faults today behave as active strike-slip faults. Oligo-Miocene continental deposits which are confined to the Tuzgölü and Ecemiş fault zones (Figure 2) suggest that the region was dissected mainly by this fault system (Figure 7A). Erol (1969) claimed that the ridges and depressions within the basement are developed in an almost north–south direction.

5b. Mid-Miocene–Early Pliocene

The oldest known products of the CAVP are the Keçikalesi (Besang *et al.* 1977) and Kizilçin (Batum 1978) volcanics, assigned to the Mid–Late Miocene. The age of two more volcanic complexes (Tepeköy and Çinarli) is also assigned to the Mid–Late Miocene based on stratigraphic and morphological data (Göncüoğlu and Toprak 1992). The distribution of these four volcanic complexes indicates that initial volcanic activity started in a belt extending in a north-east–south-west direction. This is supported by the faults parallel to this trend, most of which are buried. Therefore, during this period, the faults in a north-east–south-west direction were initiated and an extensional basin 50–60 km wide was formed (Figure 7B). This depression was filled with ignimbritic units of Late Miocene–Early Pliocene age, which are interstratified with continental (fluvial to lacustrine) deposits (Innocenti *et al.* 1975). During this period, the two fault systems were active contemporaneously, as indicated by the successive basin development on both trends (Toprak and Göncüoğlu, in press). The Keçiboyduran and Melendiz composite volcanoes were also formed during this period at the intersection of buried faults of the two systems.

5c. Late Pliocene–Quaternary

Activity of the fault system which created the CAVP depression stopped during this period. This is evident by the burial of these faults by later eruptions (Figure 6) and by the absence of deformation in Plio-Quaternary units by this system. The Tuzgölü–Ecemiş fault system, however, was active during this period.

Although not observed in the field, it is suggested that the north-east–south-west fault system was displaced by the Tuzgölü–Ecemiş fault system, based on the outcrop pattern of pre-Oligocene basement rocks in the south-east of the area (Figure 2) and on the ages of the two systems (Figure 7C). The Hasandağ composite volcano developed during this period at the intersection of the TFZ with buried north-east–south-west faults which are defined as the Sivas–Karaman lineament by Pasquare *et al.* (1988). Late Quaternary parasitic (cinder) cones were formed over north–south oriented tensional fractures, as observed at the south of Hasandağ mountain and west of Derinkuyu (Figure 2).

6. CONCLUSIONS

The Central Anatolian Volcanic Province is a belt confined between the Kirşehir massif to the north and the Niğde massif to the south in the study area. It is represented by a volcaniclastic platform and nine volcanic complexes of Mid-Miocene to Quaternary age (Figure 2). Eight of these volcanic complexes are in the form of distinct volcanic centres, as indicated by their morphology, lithology and age (Table 1). These bodies are located at the intersection of major faults. The last volcanic complex (the Quaternary Karataş volcanics), which is composed of discrete outcrops scattered throughout the area, used north–south extensional fractures to reach the surface.

Two fault systems are recognized within the CAVP. The first is the product of north–south compression. This system is represented by the conjugate right-lateral Tuzgölü and left-lateral Ecemiş strike-slip fault zones. Other major faults within this system are the Keçiboyduran–Melendiz, Göllüdağ, Derinkuyu and Yeşilhisar faults. Most of these faults (some of which could be reactivated faults of the palaeotectonic period) are still active and indicate a compressive stress direction of about N10°W.

The second fault system is characterized by normal faults which are parallel to the alignment of major volcanic centres (N60°–70°E). Faults of this system are mostly buried and not active at present. A prominent vertical throw along this system is observed in the vicinity of Niğde where the southern block (Niğde Massif) is upthrown for about 500 m.

The nature and the age of the two fault system suggests the following three stages in the development of the CAVP (Figure 7). (1) During pre-Mid-Miocene time the region was deformed mainly by the conjugate Tuzgölü and Ecemiş fault system. This is indicated by the ridges and depressions formed within basement rocks. (2) During the Mid-Miocene–Early Pliocene, the second fault system (north-east–south-west trend) was initiated and the main depression of the CAVP was formed. Most of the volcanic centres were formed at the intersection of faults of the first and second systems. (3) During Late Pliocene–Quaternary time, the activity on the second fault system stopped and these faults were buried beneath later eruptions.

The main event during the development of the CAVP is the stretching of the CACC and its division into two geographically distinct realms (the Kirşehir and Niğde Massifs). Scattered small outcrops of the CACC within the CAVP are evidence of this mechanism.

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