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Miocene Synvolcanic Alluvial Sedimentation in Lignite-bearing Soma Basin, Western Turkey

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Abstract: Calcalkaline volcanism and volcaniclastic deposition controlled considerable mode of late Miocene sedimentation and basinal development of the lignite-bearing Soma basin in western Turkey.

The volcanism-induced Deniş Formation, overlying the Soma Formation discordantly, is represented by two rock assemblages: 1) In the depositional axis of the basin, green, fine-grained sandstone dominated alluvial-lacustrine deposits and, 2) In the northern margin of te basin, syn-eruptive volcaniclastic apron deposits which are mainly composed of fine and coarse-grained volcaniclastic/pyroclastic rocks and lavas. The primary volcanic rocks surrounding probably low-relief volcanoes representing near-vent assemblage are composed mainly of andesitic, rhyolitic and basaltic lavas and pyroclastics. These volcanic rocks show a complex transformation to syn-eruptive debris flow and hyperconcentrated stream/flood flow processed volcaniclastic apron deposits.

The debris flow dominated volcaniclastic apron deposits extend as much as 20-25 km from the multi-vent and low-relief volcanoes. The gradational lithofacies assemblages within the volcaniclastic apron deposits show a proximal to distal change from massive, coarse volcaniclastics to thickly-to thinly bedded, fine-grained ones, and from poor channelized to unchannelized flows. From proximal to distal parts of the apron system, the abundance of debris flow deposits decrease and of hyperconcentrated flood-flow deposits increase gradually. Pyroclastic fallout products like pumices representing explosive volcanism, were spread widely within the basin. Due to the rapid sedimentary processes, huge amounts of unconsolidated volcanic detritus were filled probably fault-controlled topographic lows of the basement rocks and green fine-grained alluvial deposits.

The distal volcaniclastic apron deposits are represented coarse-to fine-grained tuffaceous sandstones and they are disturbed or cutted by subvolcanic bodies and covered locally by thin brecciated basalt lavas.

Key Words: Deniş Formation, lignite, volcaniclastic apron deposits, Turkey

Linyit İçeren Soma Havzasında (Batı Anadolu) Miyosen Volkanizmasıyla Eşzamanlı Çökelme

Özet: Kalk-alkalin volkanizma ve volcaniklastik birikim, Batı Anadolu'da linyit içeren Soma havzasındaki geç Miyosen tortullaşmasını ve havza gelişimini önemli ölçüde kontrol etmiştir.

Soma Formasyonunu uyumsuz olarak üzerleyen volkanizma denetimli Deniş Formasyonu başlıca iki kaya topluluğu ile temsil edilir; 1) havzanın çökelme ekseninde, volkanik kökenli yeşilimsi ince taneli kumtaşlarının baskın olduğu alüvyonal-gölsel çökeller ve 2) havzanın kuzey kenarında, başlıca ince ve kaba taneli volkaniklastik/piroklakstik kayalar ile lavlardan oluşan püskürmeli volkanizma ile eş oluşumlu volkaniklastik apron çökelleri. Olasılıkla az engebeli volkanlar çevresindeki ve çıkış merkezlerine yakın birincil volkanik kaya topluluğu başlıca andezit, riyolit ve bazalt lavları ve piroklastiklerden oluşur. Bu birincil volkanik kayalar, volkanik püskürmelerle eş oluşumlu döküntü akması ve yeşilimsi alüvyonal-gölsel çökellere geçişli ve aşırı tortıl yüklü taşkın akmalarıyla işlenmiş volkaniklastik apron çökellerine karmaşık bir dönüşüm gösterir.

Egemen olarak döküntü akmalarıyla işlenmiş yakınsak volkaniklastik apron çökelleri az engebeli volkanlardan 20-25 km kadar uzağa yayılmıştır. Volkaniklastik apron çökellerinin birbirleriyle geçişli litofasiyes toplulukları, masif, kaba volkaniklastiklerden kalın-ince katmanlı ve ince taneli olanlarına ve az kanallıdan kanallanmamış akma özellikleriyle yakınsaktan (kaynağa yakın) ıraksağa (kaynaktan uzak) bir değişim gösterir. Apron sisteminin yakınsaktan ıraksak bölümlerine doğru, döküntü akması çökellerinin bolluğu azalır, aşırı tortul yüklü taşkın akması çökelleri dereceli olarak artar. Pümis parçaları gibi patlamalı volkanizmayı temsil eden piroklastik ürünler havza içinde geniş yayılım sunar. Ani çökelme işlevlerine bağlı olarak büyük miktarlardaki tutturulmamış volkanik kırıntılar, olasılıkla fay kontrollü temel kayalar ile yeşilimsi ince taneli alüvyonal-gölsel çökellerin oluşturduğu topoğrafik düzlükleri doldurmuştur.

Iraksak volkaniklastik apron ve alüvyal düzlük çökelleri kaba-ince taneli tüflü kumtaşları ile temsil edilir. Bu çökeller, subvolkanik kütleler ile kesilmiş ve yersel olarak breşlenmiş bazalt lavları ile örtülmüştür.

ntroduction

Over the last ten years, the influence of volcanism on epositional systems and remobilization of pyroclastic etritus have gained interest from sedimentologists and ther geologists (e.g. Vessel and Davies, 1981; Mathisen nd Vondra, 1983; Smith, 1986, 1987 a, b, 1988 a, b, 991; Palmer and Walton, 1990; Waresback and urbeville, 1990; White and Robinson, 1992; Cole and idgway, 1993; Haughton, 1993; Stollhofen and tanistreet, 1994; Bahk and Chough, 1996; Nakayama nd Yoshikawa, 1997). The large volumes of pyroclastic materials originated from explosive volcanic centres are apidly transported into the surrounding environment nd are deposited as volcaniclastic sequences displaying ifferent facies characters from those of non-volcaniclasc sequences. Smith (1986) and Smith and Lowe (1991) ave pointed out the importance of some sedimentary crieria of high sediment-concentration flows (hyperconcenrated flows; intermediate flows between debris flows nd normal stream flows) for distinguishing characteriscs of the linear or irregular aprons of volcaniclastic sedments that commonly developed adjacent to the volcanic entres and/or terranes.

In western Anatolia, Neogene sedimentation was trongly infuenced by extensional tectonism. In addition, olcanism-induced sedimentation is a typical characteristic f Neogene sedimentary basins of northwestern Anatolia. he Soma lignite-bearing basin, one of these sedimentary asins, consists of Soma Formation and the volcanism-nduced Deniş Formation named previously by Nebert 1978), and three mineable lignite seams. The Soma ormation underlying the Deniş Formation is mainly comosed of alluvial, carbonate-dominated (marlstone and mestone) deposits and two lignite seams.

The Deniş Formation consists of volcaniclastic debris hat agraded primarily in response to explosive volcanism urrounding the Soma basin and is characterized by ebris-flow and hyperconcentrated stream/flood-flow eposits extending tens of kilometres from the probable olcanic sources. The Deniş formation comprises two main volcaniclastic rock assemblalges; 1) volcanogenic reen fine-grained sandstone-dominated alluvial-lacusrine deposits derived from pre-existing volcanic rocks by ormal sedimentary processes and, 2) reworked synerupve tuffaceous volcaniclastic apron deposits.

The purpose of this paper is to determine the stratiraphic position and describe facies characteristics of the olcaniclastic apron deposits (described as an informal ock unit p_2 by Nebert, 1978) and influence of the synolcanic eruptions to the deposition of the lignite-bearing Soma basin. The volcanogenic green allluvial deposits of the Deniş Formation will be discussed in detail in İnci (in prep.).

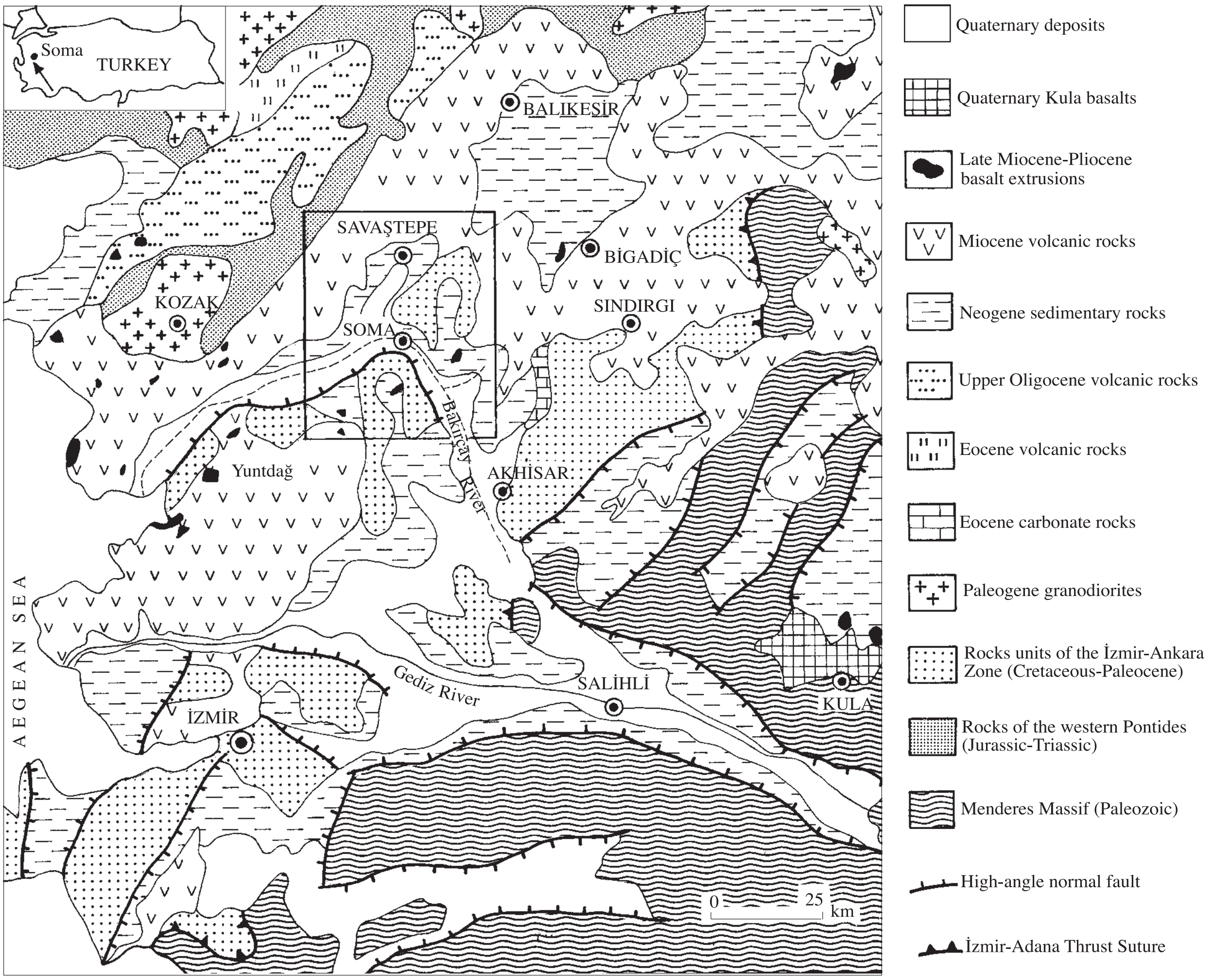
The depositional characteristics of volcaniclastic apron deposits of the Miocene Deniş Formation are significant for several reasons. First, syn-eruptive volcaniclastic sequences in Neogene basins within or adjacent to volcanic terranes of northwestern Anatolia have not been distinguished completely from other deposits. These types of deposits give information about eruption style, some volcanic synrift phases and relative stratigraphic age of the volcanism in western Anatolia. Secondly, the Bigadiç basin located northeast of the Soma basin, includes borate horizons alternating with syn-eruptive rhyolitic/dasitic tuffaceous units (Helvacı, 1995). Syn-eruptive volcaniclastic sequences of the Soma basin may compare with the borate-bearing sequence of Bigadiç basin and they may be a guide for borate explorations in the region. Thirdly, in coal-depositing basins adjacent to volcanic terranes, because of erosive effect and rapid deposition of the vocaniclastic sediments, the coal-forming peats may be eroded or buried by volcaniclastic deposition. Therefore, syn-eruptive volcaniclastic deposits should be taken into consideration for coal explorations and basin analysis.

Methods and Terminology

This study is based on stratigraphic and depositional characteristics of the volcaniclastic apron deposits of the Deniş Formation. Section and outcrop descriptions include grain size, visual estimates of clast concentration, and types of individual beds.

The term volcaniclastic apron is used in the literature in sense of a linear, blanket-like or irregular alluvial morphology that developed adjacent to high or low-standing volcanoes, volcanic centres, volcanic terranes in response to volcanic activities and, they include primary pyroclastic rocks and lavas, resedimented volcaniclastic and volcanogenic sedimentary deposits. The volcaniclastic aprons usually occur within subsiding arc graben depressions (Riggs and Busby-Spera, 1990) and/or, retroarc or intra-arc foreland basins (Orton, 1996). In this paper, the term volcaniclastic apron is used to express the coarse to fine-grained syneruptive volcaniclastic alluvial deposits for previously described as “tuff-marn serie, p_2 “ by Nebert (1978). This volcaniclastic rock assemblage, covered by younger deposits in most localities, lies betweeen Bergama and Gelenbe along the southern slope of the volcanic complex in the Balıkesir district. In surrounding of Soma, six well-exposed sections of these volcaniclastic deposits were examined.

There has been variable use of certain terms to escribe volcanic rocks in nomenclature. The term pyroclastic has been used for volcaniclastic deposits consisting f volcanically produced and fragmented clasts (pyroclast) nd which were deposited by primary volcanic processes Cas and Wright, 1987; Cas, 1991; McPhie et al., 1993; Orton, 1996). The term "tuff" is commonly used as pyroclastics finer than 2 mm, (volcanic ash) or lithified equivlent of these pyroclastics, or if it is coarser than 2 mm, breccia, tuff breccia or lapili tuff (Fisher and Schmincke, 984; McPhie et al., 1993). In this paper, tuffaceous andstone has been used for a volcaniclastic rock containing between 25 % and 50 % or more of pyroclast (finer than 2 mm) that was volcanically produced/fragmented and/or re-sedimented during syn-eruptive periods. Pumice is highly vesicular glass or fragment riddled with gas holes and is a product of explosive volcanism (McPhie et al., 1993; Scarth, 1994; Orton, 1996). Syn-eruptive volcaniclastic deposits used in this paper are resedimented volcaniclastic deposits by debris and hyperconcentrated flows and ash-fall processes that occured penecontemporaneously with or immediately after volcanic eruptions as described in detail in Orton (1996).



igure 1. Geological map of northwestern Anatolia.

eological Setting

The Miocene Soma coal basin is located at the north-rn side of the Western Anatolian graben complex and the asin fill discordantly overlies the rocks of the İzmir-nkara tectonic zone (squared area in Fig. 1). The rocks f this zone, first defined by Brinkmann (1976), consist mainly of turbidites, ultramafic rocks, sub-marine olcanic rocks and deep-marine deposits interpreted as a ranch of the Tethyan ocean opened during the middle-te Triassic (e.g. Güvenç and Konuk, 1981; Özgül, 1984; engör et al., 1985; Okay, 1989). The Western Anatolian raben complex developed on the Menderes massif and zmir-Ankara zone during the Miocene through uaternary periods. The Menderes massif consists of neiss, very thick mica-schists and platform-type marble uccession (e.g. Konak et al., 1987; Candan, 1993). To he east and south of İzmir, the rocks of the İzmir-Ankara one, named previously as the Bornova Melange was hrust over the Menderes massif during the Late Eocene. uring this overthrusting, the Lower Tertiary rocks were robably broke up and eroded. Therefore, only a few outcrops of the Lower Tertiary rocks can be observed to the east of the town of Soma (Figs. 1 and 2).

Most of the previous studies on Tertiary volcanism in western Turkey (e.g. Borsi et al., 1972; Krushensky, 1976; Innocenti et al., 1977; Fytikas et al., 1984; Ercan and Günay, 1984; Şengör et al; 1984; Ercan et al., 1985 Genç and Yılmaz, 1997) point out four different periods of volcanism; 1) Eocene-Oligocene calc-alkaline volcanism, 2) Miocene-Pliocene calc-alkaline volcanism, 3) Pliocene-present day island-arc volcanism and, 4) Quaternary basaltic volcanism (Fig. 1).

Products of the Miocene-Pliocene calc-alkaline volcanism filled up Soma and other Neogene sedimentary basins of western and northwestern Turkey. The Soma coal basin developed through late Miocene to Quaternary periods between two volcanic terranes, whose deposits consist mainly of andesitic, rhyolitic, basaltic rocks and lahars erupted from volcanoes ad fissure vents with related intra-continental rifting and block faulting (e.g. Ercan et al., 1985).

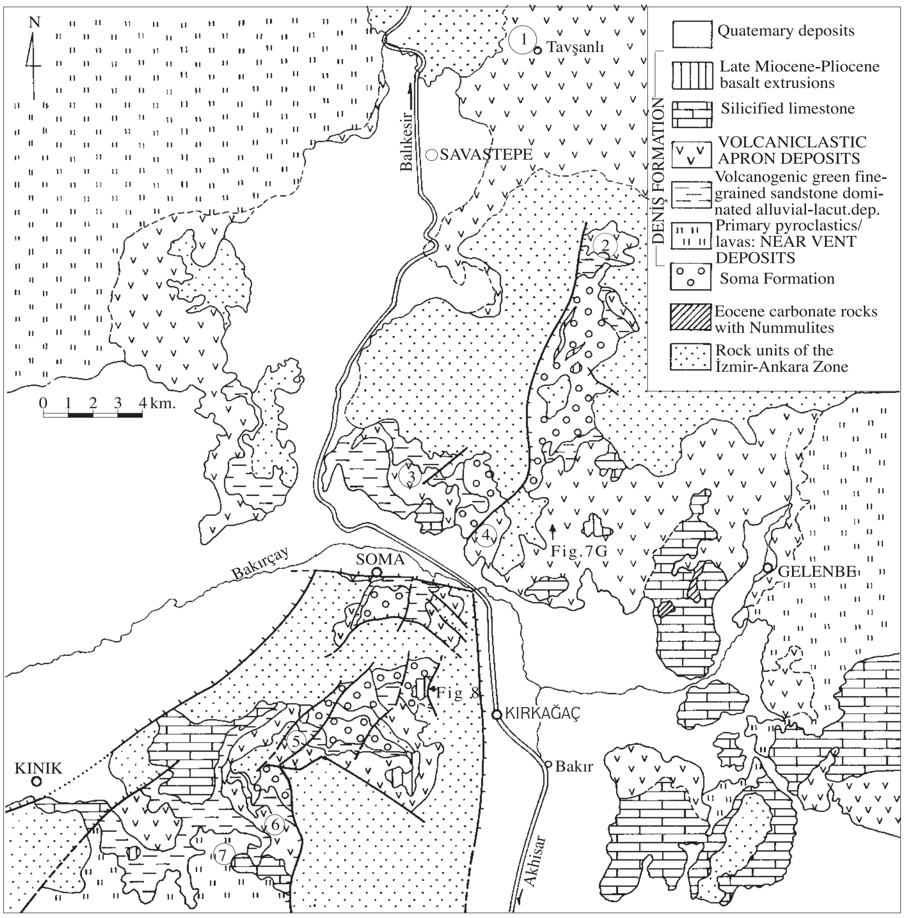


Figure 2. Geological map of the Soma basin. Circled numbers show the localities of the representive sections of the volcaniclastic apron and green fine-grained sandstone-dominated alluvial deposits (see Figures 4 and 5).

TRATIGRAPHIC SETTING OF THE VOLCANICLASTIC PRON DEPOSITS

In many cases, both the facies and the lateral variation n sedimentary features in volcaniclastic sequences adjaent to the volcanic source area or volcanoes suggest regular fan or fan-apron depositional setting dominated y volcanic debris flow and/or hyperconcentrated tream/flood deposits (e.g. Palmer and Walton, 1990; Waresback and Turbeville, 1990; Stollhofen and tanistreet, 1994).

Syndepositional calc-alkaline volcanism on the volcanic ource area of the northeastern part of the Soma basin rovided large amounts of coarse-to fine-grained volcanic ediments and lavas formed of volcaniclastic apron eposits. These deposits constitute the middle section of he Deniş Formation (Fig. 3).

The Soma basin fill indicates two depositonal cycles onsisiting of coarse-and fine-grained detrital rocks, marlstones and limestones. The first cycle or megaseuence was identified as the Soma Formation and the secnd megasequence as the Deniş Formation by Nebert 1978). According to this author, the Deniş Formation was assigned to the lower Pliocene and subdivided into our informal rock units (Fig. 3). However, the results of he palynological subdivisions and some radiometric age correlations from lignite-bearing Neogene sequences of northwestern and southwestern Turkey indicate an early to late Miocene age (e.g. Benda and Steffens, 1977; Takahashi and Jux, 1991; Seyitoğlu and Scott, 1991).

Two main depositional systems of the Deniş Formation are green coloured and fine-grained sandstone-dominated alluvial-lacustrine deposits (mainly intereruptive deposits which record without significant influence of volcanic activity or volcaniclastic deposits accumulated by normal sedimentary processes) sourced from the southwest and, tuffaceous volcaniclastic apron deposits (mainly syn-eruptive deposits related with volcanic eruptions and immediate syn-eruptive reworkings) derived from the northern calcalkaline volcanic terrane. Proximal coarse-grained volcaniclastics of the apron system mark the change from predominantly primary volcanic (nearvent volcanic rocks) to sedimentary processes and alternate with andesitic and basaltic lava flows aggradated vertically and cover unconformably the pre-Miocene basement rocks. In the medial/distal parts of the apron system, the volcaniclastic deposits are thinner, more finegrained than proximal areas and overlie the green sandstone-dominated alluvial deposits by an erosive contact and, the change laterally into the more distal apron (alluvial plain) deposits (Fig. 4)

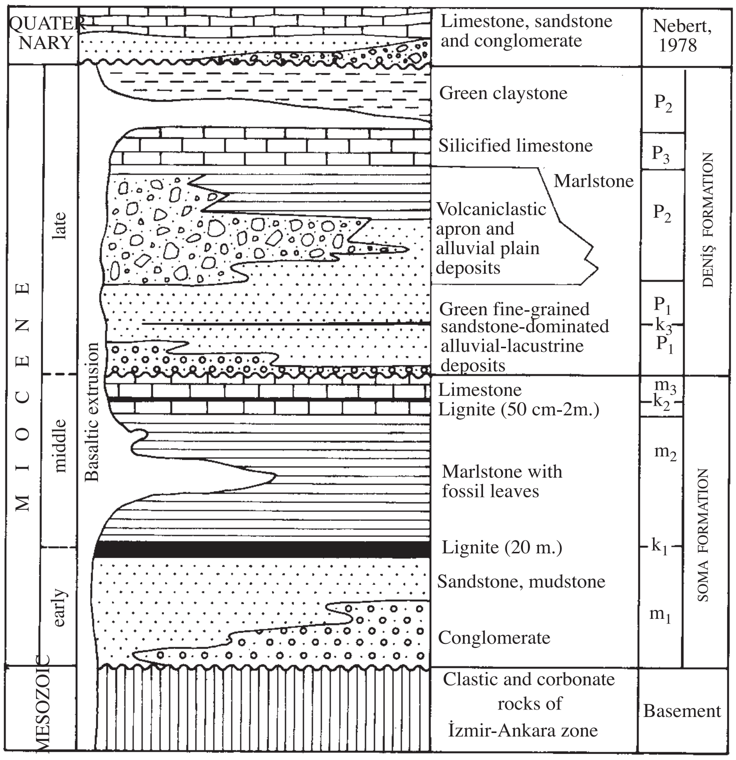
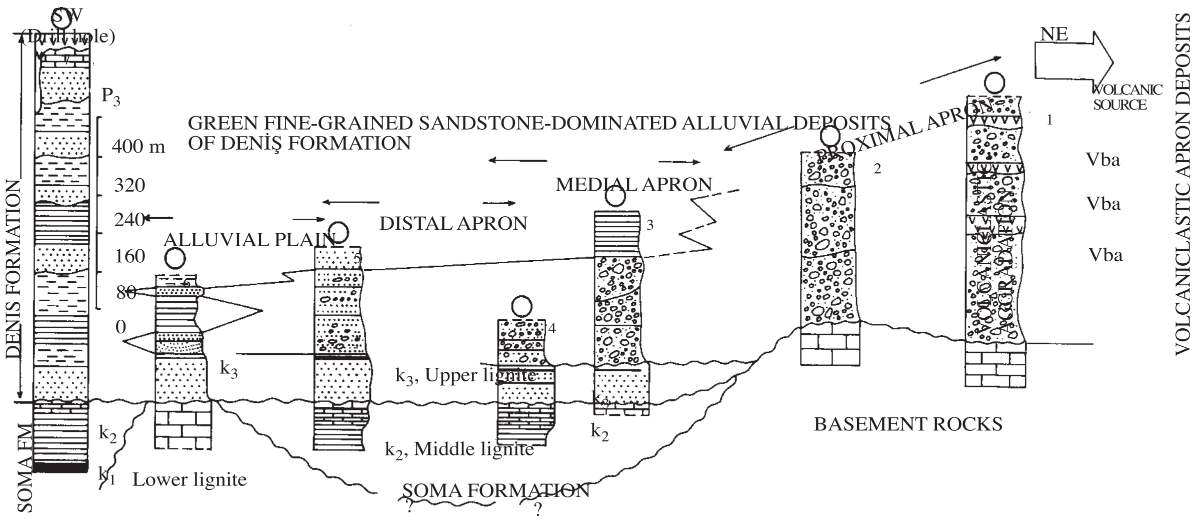


Figure 3. Generalized stratigraphic section of the Soma basin.



gure 4. Stratigraphic cross section showing relationship between the volcaniclastic apron deposits, green fine-grained sandstone-dominated alluvial deposits, Soma Formation and basement rocks. For location of section numbers, see Figure 2.

A complete section of the green sandstone-dominated luvial-lacustrine deposits is shown in a drill hole (Fig. 4, ection 7). This section of the inter-eruptive deposits is epresented by alternation of fine-grained sandstone, aystone and marlstones and, it is underlain or overlain y the volcaniclastic apron in the northern margin of the asin. The silicified limestone overlying these clastic rocks referred as p_3 informal rock unit in Nebert, 1978, see ection 7 in Figure 4) was eroded in measured section ocalities. The basalt lavas at the top of the drillhole secon are related with the latest subvolcanic emplacements r fissure basalt extrusions.

In summary, aggradationally accumulated proximal olcaniclastic apron deposits in the northeastern margin f the basin rest unconformably on the basement rock, nd the medial parts upperlie the green sandstone-domiated alluvial deposits with an erosional basal contact hanging into paraconcordance in distal parts. Toward asin, the depositional axis appeared as a river system depositing green fine-grained sandstone dominated alluval deposits or inter-eruptive deposits) flowed approximately parallel to the volcanic source area, the thickness f the volcaniclastic apron deposits decrease and they nterfinger laterally and vertically with the green sandtone-dominated alluvial-lacustrine deposits (Fig. 4). hus, both of these assemblages of Deniş Formation ccumulated synchronously throughout explosive volcanm. Similar depositional relationships and stratigraphic nterfingerings between green alluvial deposits and synolcanic units have also been observed in coal and tronaearing Miocene basins of northwestern central Anatolia e.g. İnci, et al., 1988; İnci, 1991).

Lithofacies, Lithofacies Assemblages and Characteristics of the Volcaniclastic Apron Deposits

The lithofacies classification used in this study is based on the system first inroduced by Miall (1977) and later modified for volcanism-related deposits (e.g. Mathisen and Vondra, 1983; Smith, 1986, 1987a and 1987b, 1988a and 1988b; Palmer and Walton, 1990; Waresback and Turbeville, 1990; Stollhofen an Stanistreet, 1994). Recognized lithofacies types (Table 1) including primary and reworked volcaniclastic deposits are grouped as volcanic flank or near-vent, proximal, medial and distal apron and alluvial plain deposits.

Near--vent assemblage

This assemblage, consisting predominantly of andesitic, dasitic, rhyolitic and basaltic lavas, pyroclastic breccias originated from these lavas, tuff and ash-fall deposits, is a volcanic complex located in the northern and northeastern part of te Soma basin. Despite the lack of studies on volcanic edifices of this volcanic complex, Ercan and Günay (1984), point out the presence of several andesitic-basaltic volcanoes and/or vents including intrusive bodies, basaltic and andesitic domes, rarely trachytic dykes, and pyroclastic surges and flows.

Within this volcanic complexity, volcanic and volcaniclastic rocks and related volcanic edifices of this assemblage may be incorporated with the near-vent facies assemblage as desiginated by Riggs and Busby-Spera (1990). Erosion and the nature of multi-vent explosive volcanism, and presence of a borate-bearing volcaniclastic-dominated sequence (Helvacı, 1995) within the northern part of the volcanic complex may indicate a low-relief, ut higher than the surrounding sedimentary basins, volanic field as expressed by White and Robinson (1992) nd Orton (1996). These deposits flowed or continued asinward onto the pre-Miocene basement rocks.

Volcaniclastic apron deposits, in this paper, are volaniclastic-dominated deposits which were depositied synhronously with explosive volcanism along the southern margin of the volcanic complex and fringed to the lignite epositing Soma sedimentary basin.

Clast-rich, matrix-supported conglomerates: proximal apron assemblage

Primary and prominent very coarse-grained volcaniclastic deposits interfingering with the flank or near vent assemblage have been desiginated as proximal apron deposits.

Volcanic clast-rich, matrix-supported conglomerates are dominant lithofacies types in this assemblage (Figs. 5 and 6 A, B and C). Basaltic/andesitc flows (Vba), clayey

able 1. Lithofacies nomenclature and coding of the volcaniclastic apron deposits of the Deniş Formation.

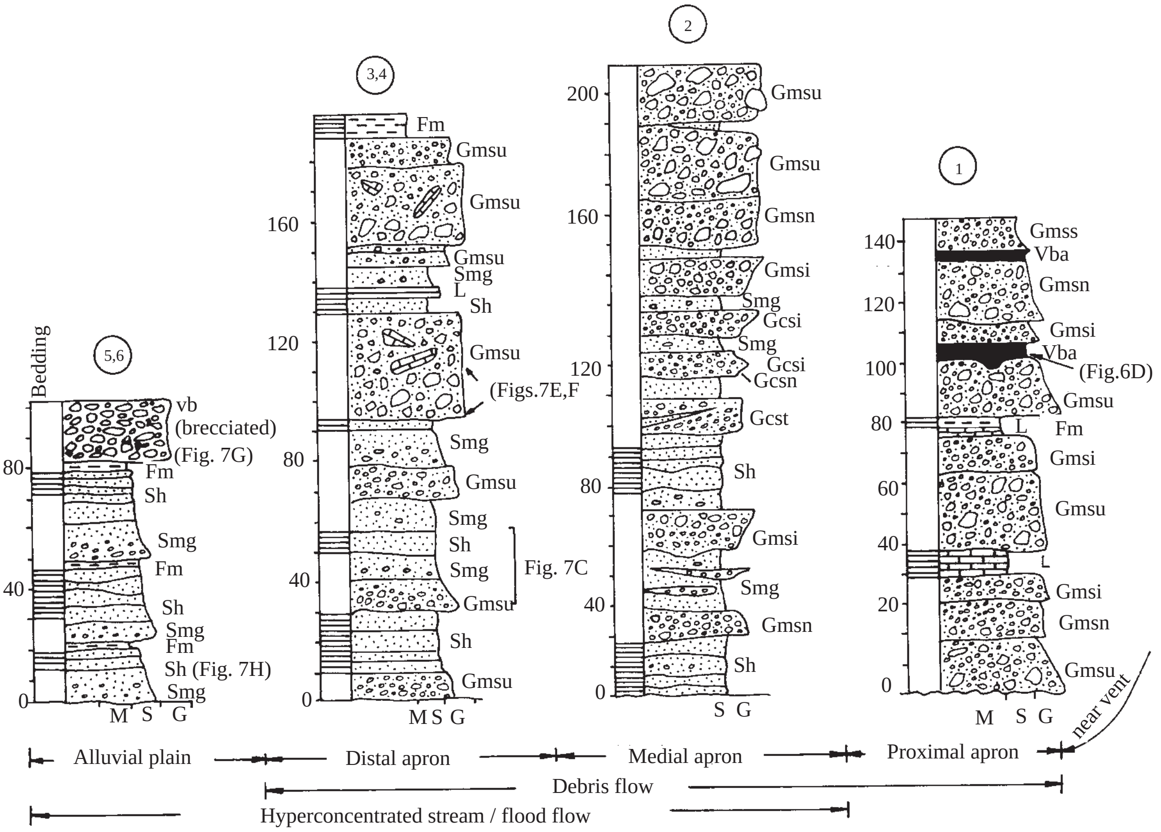
acies code	Lithofacies	Sedimentary structures	Interpretation
msu	Gravel, matrix-supported, massive, ungraded, includes cobbles/boulders	Non-erosive bases. rarely oriented clasts parallel to flow, laterally continuous, very thick (>10 m)	Debris flow, rockfall/avalanche deposits
msn	Gravel, matrix-supported evenly stratified, graded	Normal graded, planar basal contacts, erosional features, very thick (>5 m)	Debris flow/ mud flow
msi	Gravel, matrix- supported, massive, graded	Inverse grading, sharp basal contacts, erosional features, very thick (>5 m)	Mud flow and debris flow
mss	Gravel, matrix- supported, massive and crudely stratified	Normal/inverse grading, thick to very thick (0,5-3 m)	Mud flow and debris flow
csu	Gravel, clast-supported, massive, ungraded, includes tuffaceous sandstone lenses	Oriented clasts parallel to flow, erosional basal surfaces, thick (<4 m), laterally extensive	Clast-rich debris flow/ hyperconcentrated stream/flood flow
csn	Gravel, clast-supported, massive, graded, includes tuffaceous sandstone intercalations	Normal grading, erosional basal contacts, medium to thick (0,3-1,0 m)	Hyperconcentrated flood flow/fluidized debris flow
csi	Gravel, clast-supported, massive, graded, includes tuffaceous sandstone intercalations	Inserve grading, erosional basal surfaces, laterally extensive	Hyperconcentrated stream/flood flow, clast-rich debris flow
cst	Gravel, stratified	Trough cross-beds	Channelized deposits
h	Sand, fine to coarse-grained, stratified, pebbly	Horizontal bedding; laterally extensive, thick (0,5-5 m), non-erosive basal contacts	Sand-rich hyperconcentrated flood flow/sandy sheetflood
mg	Sand, fine to coarse-grained, massive, pebbly	Normal and inverse grading, laterally uncontinuous, medium to thick (0,2-0,8 m)	Rapid deposition by hyperconcentrated flood flow
m	Mudstone	Parallel lamination, thin beds	Lacustrine deposits
	Limestone	Sparse algal lamination, oolitic, thin beds	Lacustrine deposits
ba	Basaltic/andesitic lavas, brecciated	Thin and thick lava layers	Primary pyroclastic flows, block and grain flows

acies codes based on Miall (1977); Smith (1986); Waresback and Turbeville (1990) reshwater limestones (L) and mudstones (Fm) are accesory lithofacies tyes (Figs. 5 and 6 D). These volcanic-riginated conglomerates are subdivided into four differnt lithofacies according to their grain size, bed thickness, ounding surfaces and indication of deposits grading as ngraded, normal, inverse and crudely stratified (Gmsu, msi, Gmsn, Gmss, respectively) (Table 1). Thickness of onglomerate deposits range from 5 m to > 20 m and isplay planar (or slightly undulatory) and erosional lower oundaries. The clasts are made predominantly of angular nd subrounded porphyritic andesites and flow-banded hyolitic rocks. The largest clasts range in size from obbles to boulders > 1m in diameter. The matrix of the onglomerate facies consists of rhyolitic/andesitic ash xtrusions.

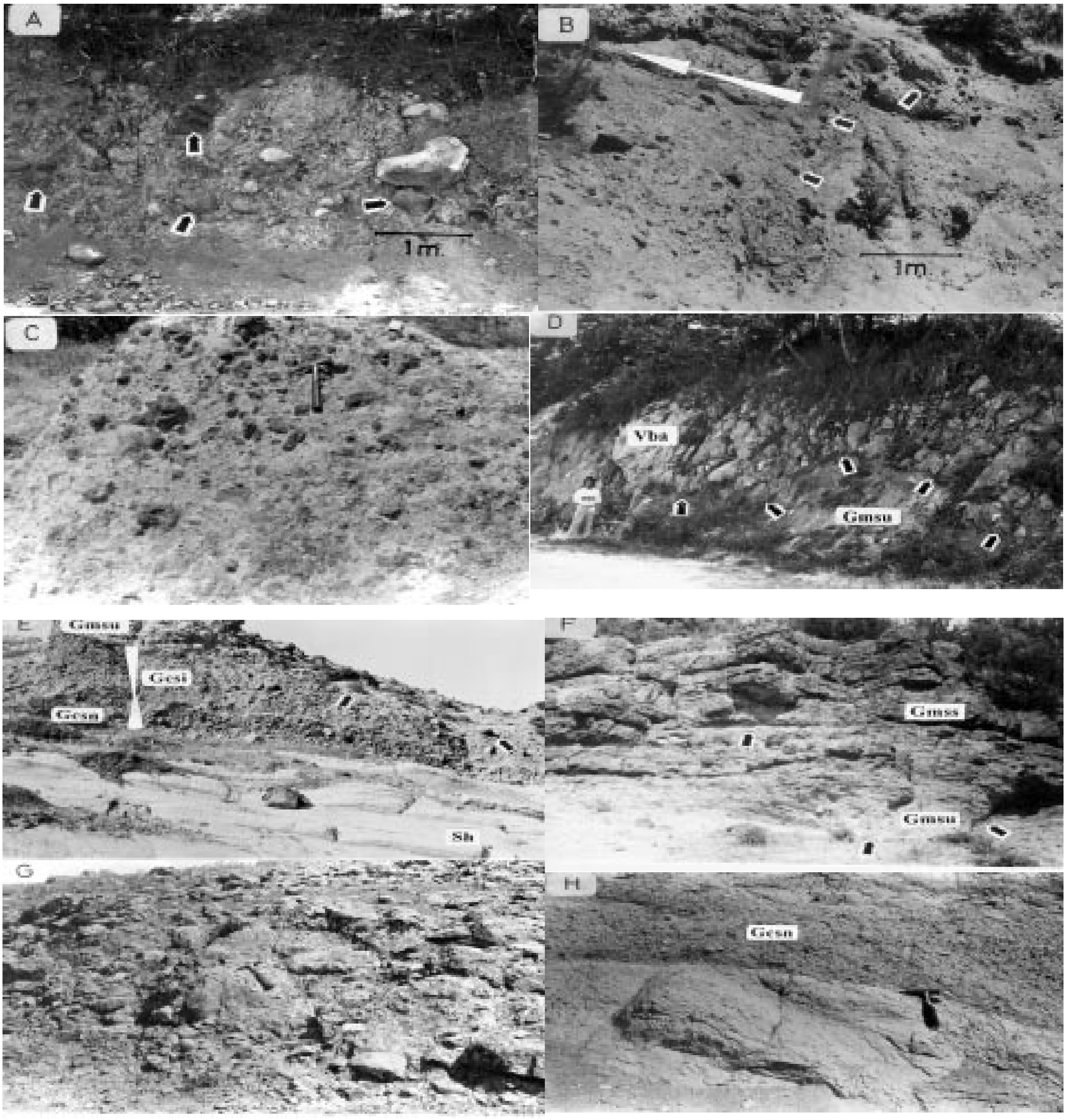
The basaltic/andesitic lava flows (lithofacies Vba) overe the clast-rich matrix supported conglomerates in areas ose to the volcanic source(s) and they infilled rills or valys (Fig. 6 D). Autobreccia-fracturing and postdepositional subaerial alteration is common in lower parts of the flows. The thicknesses of the lava flows range from 1 to 5 meters.

Conglomerate facies include clayey, oolitic and algal freshwater limestones and parallel laminated mudstones (lithofacies L and Fm, Fig. 5).

The peresence of angular cobbles and blocks between 50 cm and > 1 m in diameter may be interpreted as rocfall/debris avalanche deposits or deposits produced by sliding and shattering of the blocks. Spreading of these types of massive and unconfined debris avalanches at near-source areas of low-relief volcanic fields, is laterally and the matrix of grounded smaller clasts may be drained away (Orton, 1996). On the other hand, lava flows, ungraded/graded and disorganized nature, massive and sharp but erosional bases are suggestive of volcanic debris flow deposits (Cas and Wright, 1987; Mc Phie et al. 1993).



gure 5. Representive sections of the volcaniclastic apron deposits. Lithofacies codes and their interpreted mechanism of deposition refer to Table 1. See Figure 2 for section localities.



gure 6. Field photographs of the proximal-medial apron deposits. A. Unstratified matrix-supported conglomerate lithofacies (Gmsu). Arrows show the basalt clasts. Light coloured clasts are rhyolitic tuff. B. Normal-graded matrix-supported conglomerate lithofacies (Gmsn). Arrows indicate normal grading. Note the rounded clasts showing lineation (small arrows). C. Inversely graded, matrix-supported conglomerate lthofacies (Gmsi). Conglomerate is made of rhyolitic tuff clasts and ashy matrix. Hammer is 32 cm. D. Gmsu and andesitic lava flow (Vba). Arrows show the wavy contact between lava flow and conglomerate. The man is 1.65 m. Lava layer partially brecciated by volcanic cooling. E. Channelized clast-supported conglomerate showing normal and inversely grading. Note the sharp contact between the horizontal-bedded sandstone (Sh) and the conglomerate. Arrows show the well-rounded andesite clasts. F. Stratified matrix-supported conglomerate (Gmss) overlying the ungraded matrix-supported conglomerate (Gmsu). Gmss includes thin tuffaceous sandstone intercalates (arrow). Note the erosional basal of the Gmsu. G. Dominantly angular/subrounded andesite cobble-bearing Gmsu lithofacies. H. Normal-graded clast-supported conglomerate (Gcsn). Note the sharp eroisonal basal and transitional upper contacts with tuffaceous sandstones.

The clayey, oolitic and algal freshwater limestones and mudstone in conglomerate deposits were probably accumulated in a shallow lake or ephemeral pond environments. These kind of small and very shallow lakes, playa- kes or ponds may be developed in low-relief volcanic elds (Orton, 1996). For instance, in the northern part of he volcanic complex, the lowermost part of the Miocene orate and carbotate-bearing volcano-sedimentary equence (~750 m) alternates and interfingers with gglomerates, fine-to lapilli tuffs and basaltic, andesitic, rachy-andesitic, dasitic and rhyolitic lavas of the volcanic omplex (Helvacı, 1995). This stratigraphic setting may ndicate separated or interconnected small lakes in also igher parts of the apron and/or land low-relief volcanic omplex in the region.

last-rich, clast-supported conglomerates: medial pron assemblage

Representive deposits of this assemblage are clast- ch, clast-supported, channelized conglomerates and ravelly/pebbly tuffaceous sandstones (Fig. 5; section 2). his assemblage is subdivided into lithofacies types (Gcsu, csn, Gcsi, Sh, Gmsn, Gmsi) displaying differences in nternal and external sedimentary structures as grading, tratification, grain size, nature of lower bounding sur- ace and bed thickness (Table 1).

In medial apron exposures, clast-rich and clast-supported conglomerates exhibit channel-form geometry with slightly erosional basal contact with the underlying ebbly tuffaceous sandstones (Fig. 6 E, F). These chan- elized conglomerate sequences range from 2 m to > 10 m thick and, they exhibit coarse-grained, normal and nverse graded or ungraded, massive and crudely strati- ed internal texture. Massive channel-form conglomer- tes contain angular/subrounded andesitc and basaltic obbles (Fig. 6 G). Some channel-like, clast-supported onglomerates (lithotype Gcsn) exhibit slightly undulating asal surface, well-developed normal grading and grada- onal upper bounding with sandstones (Fig. 6 H). The hickness of these channel-like conglomerates range from 0 cm to 2 metres and, 30-50 m length.

Matrix-supported inversely-graded conglomerates Fig. 7 A) and clast-supproted trough cross-bedded con- lomerates are uncommon lithofacies types of the medial pron assemblage.

The clast-supproted framework, coarse grain size and lanar or slightly erosional basal surfaces of the channeled conglomerate may indicate reworking processes by hannel debris flows in proximal parts of the medial apron. Granule-size, inversely grading, crude stratification and angular andesitic/basaltic cobbles may indicate rapid deposition from high-sedimemt concentrated-proximal parts of the apron by dilution of debris deposits or hyperconcentrated flows.

Clast-poor, matrix-supported conglomerates and tuffaceous sandstones: distal apron assemblage

Clast-poor, tuff-matrix-supported conglomerates (Gmsu lithotype), massive and horizontally bedded pebbly tuffaceous sandstones (Smg, Sh) are predominant deposits of the distal assemblage (Fig. 5; section 3,4). The lowermost contact of this assemblage is slightly erosional on the older green alluvial deposits.

The clast-poor, ungraded, matrix-supported conglomerates (Gmsu) contain predominantly angular tuff clasts rangnig from 3 cm to 40 cm in size. Basal contact of this lithofacies is generally sharp, planar or silghtly erosive and displays a light reddish-yellowish oxidized zone interval 120 cm in thickness and 70-80 m in lateral extent (Fig. 7 B). The lithofacies contains large amounts of pumice clasts transported by airfall and debris flow processes. Gmsu lithofacies typically grade upward into pebbly and normal-graded tuffaceous sandstone lithofacies (Smg) ranging from 80 cm to 3 m in thicknesses. The lithofacies Smg also grades upward into horizontal bedded, (up to 30 cm thick) fine-grained and laminated sandstone lithofacies (Sh). From base to top, a succession of Gmsu, Smg and Sh respectively (Fig. 7 C), is characteristic in some exposed outcrops.

Sedimentological and stratigraphic features of these lithofacies resemble lithofacies types of Gms, Sm (g) , Sh (b)or Sh (1) described as debris flow and sand-dominated hyperconcentrated flood flow deposits by Rust (1978) and Smith (1986, 1987a and 1987b, 1988a and 1988b). Existing abundant pumice clasts and coarse tuff or tuffaceous sandstone (Fisher and Schmincke, 1984; Cas and Wright, 1987) may indicate syn-eruptive deposition and/or redeposition immediately after volcanic eruption. Cycles composing of Gmsu, Smg and Sh lithofacies may be considered as eruption units (Fisher and Schmincke, 1984; Orton, 1996). These cyclical sequences are repeated completely and incompletely, but thinner.

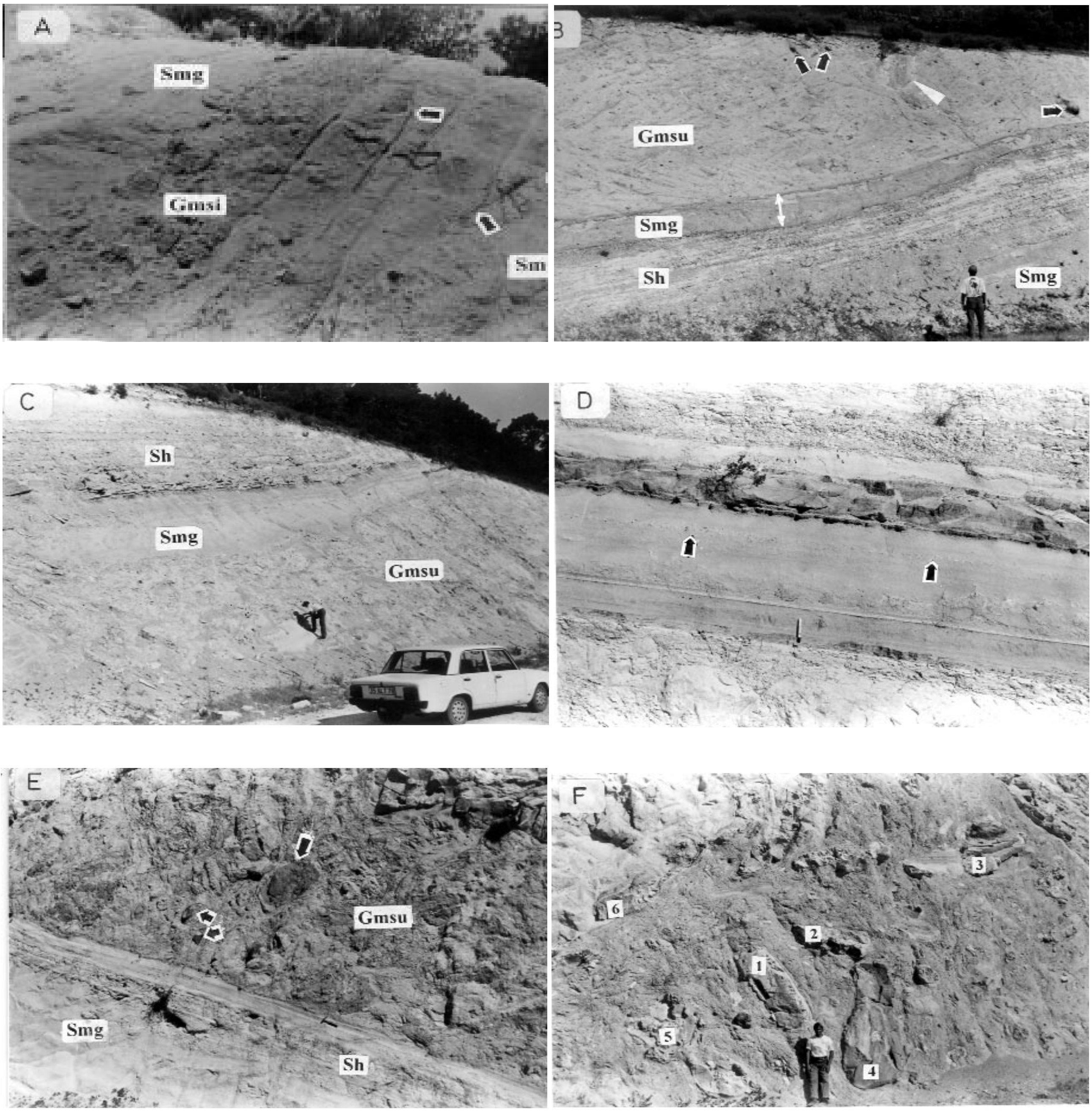
In some horizontal bedded sandstones present pumice clast that elongated parallel to the flow-direction and stratification surface (Fig. 7 D). These sandstone lithofacies may be sheetflood deposits generated from volcanism with sedimentation. These sheet-like sandstone beds containing pumice clasts are underlain sometimes by Gmsu lithofacies with flat-based contact (Fig. 7 E). Gmsu lithofacies overlying the sheet-like sandstone lithofacies ontains bed-form flat blocks eroded from older beds Fig. 7 F).

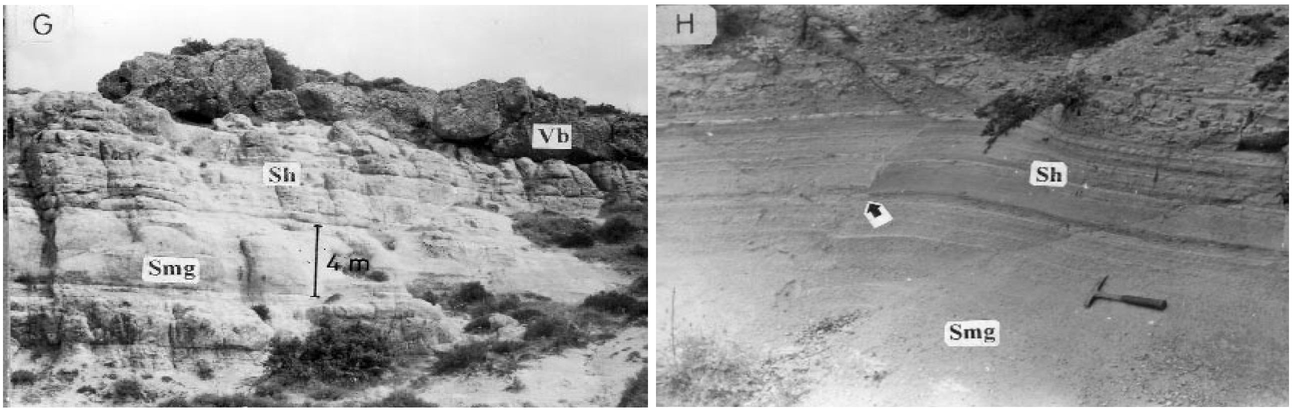
oarse-fine-grained tuffaceous sandstones: alluvial lain deposits

Coarse and fine-grained tuffaceous sandstones (Smg nd Sh lithofacies) are common lithologies of this assemlage. This deposit group is underlain in some localities by olcanic breccia consisting mainly of angular basalt clasts Fig. 7 G).

The sandstones of this assemblage are more thin-bedded than sandstones of other assemblages. Beds are usually 35-50 cm thick and resemble scour and fill structures. Normal bedding, thin horizontal stratification and lamination are the most common internal sedimentary structures (Fig. 7 H).

In contact between two fine-grained sandstone beds, thin mudstone layers were deposited. However, in some localities these thin mudstone layers were eroded by latter sand depositing flows and formed a flat sliding surface





gure 7. Field fhotographs of the distal volcaniclastic apron deposits. A. Laterally discontinous and inversely-graded matrix-supported conglomerate (Gmsi). Conglomerate grades rapidly into gravelly tuffaceous sandstone (Smg). Arrows show the scoured bases of the conglomerate and sandstone. B. A sequence displaying the Sh, Smg and Gmsu lithofacies. Dark grayish (light reddish in the field) Smg lithofacies (double arrows) and Gmsu represent an erosional deposition and channelized debris flow. The dominant clast in Gmsu is rhyolitic tuff. well-rounded basalt clasts (black arrows) and disorganized flat shape tuff blocks (white arrow) are rare. C. A typical sequence consisting of Gmsu. Smg and Sh lithofacies. Note abrupt contacts beween Gmsu and Smg. D. An outcrop of the horizontal bedded tuffaceous sandstone lithofacies including reworked pumice clasts (arrows) oriented parallely to the stratification surface. The pen is 13 cm. E. Flat-based contact between Sh and Gmsu lithofacies. Note subrounded basalt cobbles (arrows) in Gmsu. The hammer is 32 cm. Flat blocks in the Gmsu lithofacies indicating erosion and sliding during deposition of the Gmsu (1, 2, 3; silicified limestone. 4; andesite, 5, 6; tuff). G. Smg and Sh lithofacies in alluvial plain deposits. Brecciated basalt layer (Vb) flowed onto the volcaniclastic alluvial plain deposits. H. Typical transitional contact between Smg and Sh lithofacies. The hammer is 32 cm. Note the synsedimentary faulting (arrow) in the transition interval.

etween two sandstone beds. As a result of this sliding, urved joints that were later filled by ferriferous second- ry solutions formed perpendically to the sliding surface.

The laterally continuous beds, shallow scour and fill tructures, fine to coarse grain size, graded and horizon- al laminated stratification and sharp boundaries between eds may suggest deposition on a large plain by flashy ediment dischargings or shallow flows. The coloured pla- ar erosional surfaces may indicate the subaerial deposi- onal conditions in alluvial plain environment.

ccumulation of Volcaniclastic Apron Assemblages nd Interaction Between Volcanism and Alluvial edimentation

The assemblages described above are formed as an ntricate coalescing fan system or volcaniclastic apron with related calc-alkaline volcanism in the northeastern istrict of the Soma basin. Figures 4 and 5 show the lat- ral change of the primary volcanic rocks into volcaniclas- c lithofacies towards the basin.

Initally, primary volcaniclastic rocks and lavas extrud- d onto the basement rocks and they were reworked and ransported by debris flow processes. The proximal apron ssemblages were formed adjacent to the volcanic flank r nearly volcanic vents. Massive, clast-rich and matrix-supported debris flow conglomerates of proximal assemblage are the common lithofacies. Sedimentation is strongly aggradational because of volcanism or volcanic eruptions. The basaltic and andesitic flow layers in the conglomerates may indicate volcanic sources probably not far from the location of the proximal assemblage. Thin freshwater limestone and mudstone lithofacies may indicate short-lived ponds or transient shallow and small lakes. Existence of this kind of depositional system suggest a low-relief and/or slightly inclined paleotopographic morphology.

There is a lateral change from debris flow deposits into stream flow and hyperconcentrated flood flow deposits towards the basin and, the medial parts of the apron are represented by channelized debris flow and tuffaceous sandstone-dominated hyperconcentrated flood flow deposits. Absence of deep-incised valleys or valley-fills, existence of planar or slightly eroded basal contacts and massive or graded stratification may reflect the rapid and generally uninterrupted deposition in medial parts of the apron. The sedimentary features of these predominantly reworked sediments generated from proximal and/or near-vent assemblage may indicate low inclined paleodrainage areas. Proximal and distal apron assemblages form a zone ~6-8 km in width.

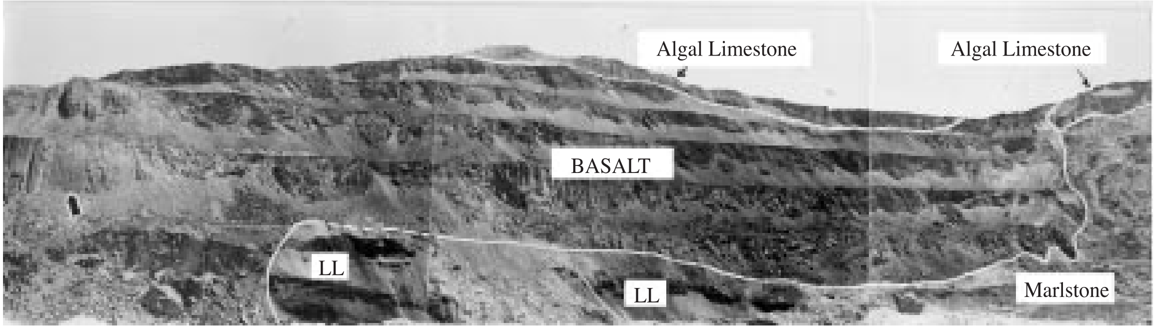
The basal section of the distal apron deposits accumuted by hyperconcentrated flood flows and debris flows n the green fine-grained sandsstone-dominated alluvial eposits of Deniş Formation. This apron assemblage eveloped on very low-slope depositional area and, eposit features represent deposition from large volcanic ebris fragments that were able to transport coarse sedments into distal areas.

Alluvial plain deposits, representing the most distal arts of the volcaniclastic apron, characterized by coarse o-fine-grained tuffaceous sandstones were formed by eworking and deposition from apron deposits. This ssemblage resembles model of sheetflood fluvial (alluval) plain of Miall (1985), indicating highly flashy disharge resulting in laterally continuous beds. Fine sandtone domination and sedimentary/stratigraphical feaures represent reworking and sedimentation from the pron assemblages by hyperconcentrated flood flow mechanism. All clasts of the apron deposits are volcanic, mainly made of andesite, rhyolite and minor amounts of asalt. The large input of volcanic detritus onto the basement rocks, resulted in natural dams. The freshwater mestone and mudstone lithofacies in proximal apron ssemblage may have been deposited in ephemeral lakes ocated back of these natural dams. However, these limetone beds may be also correlated with lacustrine deposits f the green alluvial system which were deposited on epositional centre of the basin and later prograded onto he higher parts, probably the proximal apron part covring the basement rocks, of the apron system (Fig. 4).

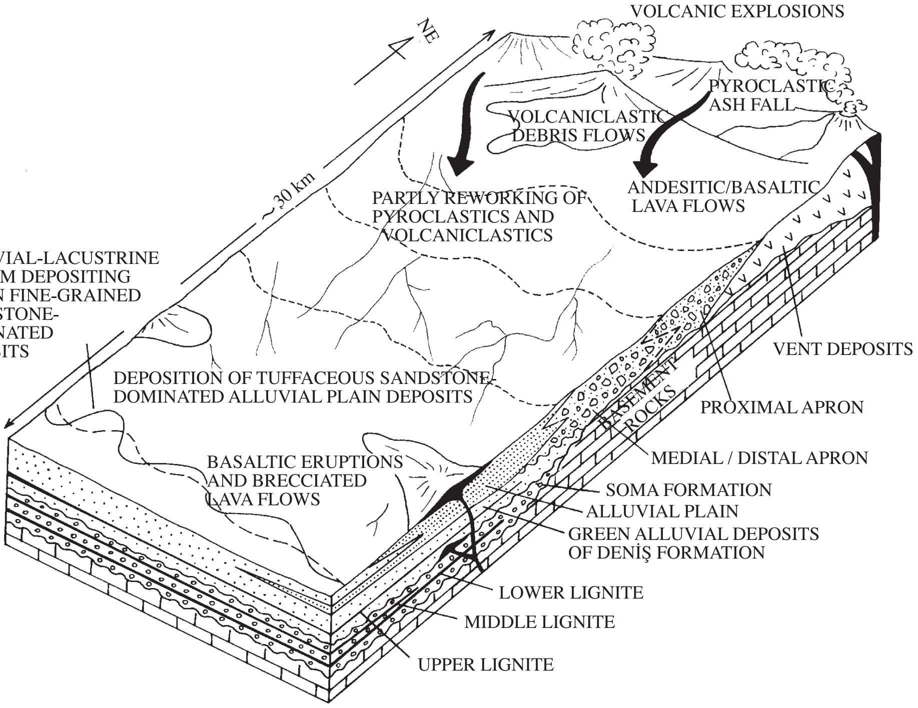
The matrix of the matrix-supported conglomerate thofacies is essentially rhyolitic tuff. Rhyolitic tuff mateal contributes into lithofacies texture ash-fall and/or eworked sediments. However, the most important evidence of the explosive volcanism is pumice fragments in apron deposits that were reworked and/or transported by fluidized sedimentary flow and hyperconcentrated stream/flood flows.

The Soma basin is located among two extensive volcanic fields (Fig. 1). The alluvial-lacustrine basin-fill sequence of this basin is intruded or cutted several sill, dyke or dome-shape olivine basalt extrusions (Fig. 2). Some of these basalt extrusions ordered along or parallel to the NE-SW and E-W trending high-angle faults were probably actived penecontemporaneously with explosive volcanism during late Miocene in the region. Areally restricted lava flows of these fault-controlled intrabasinal subvolcanic basalt emplacements flowed onto medial/distal parts of the apron even volcanic alluvial plain deposits (Vb lithofacies in Fig. 7 G). The vertical and lateral contact relationships with older strata (Soma Formation) of one of these basaltic extrusions are shown in Sarıkaya openpit coal mine area (Fig. 8). At this locality, the basaltic intrusion/extrusion has resulted in a local contact metamorphic influence at the lower lignite seam, marlstones and partially lignite-bearing algal limestone units of the Soma Formation. The maximum thermal effect of this basaltic intrusion on the lower lignite is less than 743 °C (Karayiğit and Whateley, 1997). Because of the nonflat paleotopographic surface, probably high viscosity of lavas or small volume of lava extrusions, these brecciated lava flows spread laterally for short distances.

The volcaniclastic apron deposits were deposited immediately adjacent to te multi-vent and probably lowrelief volcanic complex or volcanic terrane. This volcanic complex represented by near-vent assemblages includes several small and scattered volcanoes or volcanic intrusions in calcalkaline and/or intermediate character (Ercan



gure 8 . An olivine basalt extrusion/intrusion observed in a Sarıkaya opencast coal mine. Basalt was emplaced by crossing the lower lignite horizon (LL), marlstone and algal limestone (Soma Formation). Note columnar basalt joints (arrow). These basalt lavas were flowed onto volcaniclastic alluvial plain deposits (Figure 7 G). For locality of the basalt extrusion see, Figure 2.



gure 9 . Schematic block diagram illustrating volcanism and volcaniclastic alluvial sedimentation during the deposition period of the Deniş Formation in the Soma basin.

nd Günay,1984). The existence of the borate-bearing mall intra-volcanic lake (Helvacı, 1995) in the northern art of the complex, may indicate arid or semi-arid climate conditions during volcanic activity in the region.

onclusions

Figure 9 is a schematic diagram illustrating possible epositional environment of the tuffaceous volcaniclastic pron deposits and showing stratigraphic relationship of hese deposits with other rock assemblages of the Deniş ormation.

Faultings related to extensional tectonism created xtrusive volcanic activity during middle Miocene-early liocene period (Ercan and Günay, 1984). The predominance of primary volcanic rocks composed mainly of ndesitic, basaltic, rhyolitic lavas and pyroclastic rocks in ffusive character, may indicate that the rapid accumulaon of lava flows caused the modest or low topographicelief volcanic complex. The complexity and interstratifiation of these volcainc rocks that inferred as near-vent ssemblage may suggest the existence of multiple vents r sources in volcanism area.

During high rate explosive volcanism or syneruption, the volcaniclastic accumulations sourced from these volcanic centres built up gradually several volcaniclastic apron deposits located closely to the volcanic centres and they filled the low pre-existing topographic areas and depressions. Te medial/distal volcaniclastic apron deposits were prograded onto older sedimentary rock units and, they changed laterally into volcaniclastic alluvial plain deposits, which were fringed with green fine-grained sandstone-dominated alluvial-lacustrine deposits of the Deniş Formation. This prograding and lateral facies changes were created by debris avalanches, debris flows, hyperconcentrated flows and sheet and/or dilute flows from volcanic sources toward the basinal centre of the Soma region.

The subvolcanic emplacements, lava flowings and/or fissure/fault related basaltic intrusive extrusions on distal volcaniclastic apron deposits might indicate the violent volcanic activity or existence large intravolcanic lowlands. During volcanic quiescence, the younger deposits of the green alluvial system of Deniş Formation covered the volcaniclastic apron and other older deposits in the region.

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References

ahk, J.J. and Chough, S.K., 1996, An interplay of syn-and intereruption epositional processes: the lower part of the Jangki Group (Miocene), SE orea. Sedimentology, 43, 421-438.

enda, L. and Steffens, P., 1977, Litho-und biostratigraphische Deutung adiometrischer Alterbestimmungen aus dem Jungtertiar der Turkei. eol. Jb., B25, 139-167.

orsi, S. Ferrara, G., Innocenti, F. and Mazzuoli, R., 1972, eochronology and petrology of recent volcanics of Eastern Aegean Sea. ull. Volcan., 36/1, 473-496.

rinkmann, R., 1976, Geology of Turkey. Enke, Stuttgart, 158 pp.

andan, O., 1993, Petrography, petrology and metamorphism of the egion between Demirci and Borlu at the northern flank of the Menderes massif (in Turkish, with English abstract). Doğa-Turkish Jour. Earth Sci., , 69-87.

as, R. and Wright, J.V., 1987, Volcanic Successions, Modern and ncient. Allen and Unwin, London, 528 pp.

as, R., 1991, Nomenclature of Volcaniclastics. Newsletter Int. Ass.

olcanol. Chem. Earth's Interi. Communication Volcanogen. Sedim. 4.

ole, R.B. And Ridgway, K.D., 1993, The influence of volcanism on uvial depositional system in a Cenezoic strike-slip basin, Denial Fault ystem, Yukon Territory, Canada. Jour. Sedim. Petrol., 63, 152-166.

rcan, T. and Günay, E., 1984 The Oligo-Miocene volcanism in NW natolia, Thrace and the Aegean Islands: A review (in Turkish, with nglish abstract). Bull. Geol. Congr. Turkey, 5, 119-139.

rcan, T., Satır, M., Kreuzer, H., Türkecan, A., Günay, E., Çevikbaş, A., teş M. and Can, B., 1985, Interpretation of new chemical, isotopic and adiometric data on Cenosoic volcanics of Western Anatolia (in Turkish, with English abstract). Bull. Geol. Soc. Turkey, 28, 121-137.

sher, R.V. and Schmincke, H.U., 1984, Pyroclastic Rocks. Springer-erlag, Berlin, 472 pp.

ytikas, M., Innocenti, F., Manetti, P., Mazzuoli, R., Peccerillo, A. and illari, L., 1984, Tertiary to Quaternary evolution of volcanism in the egean Region. In: The Geological Evolution of the Eastern Mediterranean (Ed. By J.E. Dixon), 687-699.

enç, Ş.C. and Yılmaz, Y., 1997, An example of post-collisional magmatism in Northwestern Anatolia; the Kızılderbent Volcanics (Armutlu eninsula, Turkey). Tr. J. Earth Science, 6, 33-42.

üvenç, T. and konuk,T., 1981, Sedimentaiton and fracturation during riassic and Aegean-Anatolian Fracturation Zome (in Turkish, with nglish abstract). Yerbilimleri, Bull. Inst. Earth Sci. Hacettepe Univ., 7, 3-53.

Haughton, P.D.W., 1993, Simultaneous dispersal of volcaniclastic and non-volcaniclastic sediments in fluvial basins: examples from the Lower old Red Sandstone, east-central Scotland. In: Alluvial Sedimentation (Ed. By M. Marzo and C. Puigdefabregas) Spec. Publ. Int. Ass. Sedim., 17, 451-472.

Helvacı, C., 1995, Stratigraphy, mineralogy, and genesis of the Bigadiç borate deposits, western Turkey. Economic Geology, 90, 1237-1260.

Innocenti, F., Manetti, P., Mazzuoli, P., Peccerillo, A. and Poli, G., 1977, REE distribution in Tertiary and Quaternary volcanic rocks from central and western Anatolia. Proceedings of 6th Coll. Geology of the Aegean Region, p. 289-303.

İnci, U., Helvacı, C. and Yağmurlu, F., 1988, Stratigrphy of Beypazarı Neogene basin, Central Anatolia, Turkey. Newsl. Stratigr., 18(3), 165-182.

İnci, U., 1991, Miocene alluvial fan-alkaline playa lignite-trona bearing deposits from an inverted basin in Anatolia: sedimentology and tectonic controls on deposition. Sedimentary Geol., 71, 73-97.

İnci, U. (in prep). The depositional evolution of the Soma coal bearing Miocene basin of northwestern Turkey.

Karayiğit, A.I. and Whateley, M.K.G., 1997, Properties of a lacustrine subbituminous (k1) seam, with special reference to the contact metamorphism, Soma-Turkey. Int.Jour. Coal Geol, 34(1-2), 131-155.

Konak, N., Akdeniz, N. and Öztürk, E.M., 1987, Geology of south of Menderes massif: Guide Book for the Field Excursion Along Western Anatolia, Turkey. Pubb. General Directorate of Mineral Research and Exploration of Turkey, p. 42-53.

Krushensky, R.D., 1976, Neogene calc-alkaline extrusive and intrusive rocks of the Karalar-Yeşiller area, northwest Anatolia, Turkey. Bull. Volcanoloqiue, 17/4, 336-360.

Mathisen, M.E. and Vondra, C.F., 1983, The fluvial and pyroclastic depostis of the Cagayan basin, Northern Luzon, Philippines-An example of non-marine volcaniclastic sedimentation in an interarc basin. Sedimentology, 30, 369-392.

McPhie, S., Doyle, M. and Allen, R, 1993, Volcanic Textures. A guide to the interprtetation of textures in volcanic rocks. Spec. Publ. Univ. Tasmania, 190 pp.

Miall, A.D., 1977, a review of the braided river depositional environment. Earth Sci. Rev., 13, 1-62.

Miall, A.D., 1985, Architectural-element analysis: a new method of facies analysis applied to fluvial ldeposits. Earth Sci. Rev., 22, 261-308.

akayama, K. and Yoshikawa, S., 1997, Depositional processes of pri-ary to reworked volaniclastics on an alluvial plain; an example from the wer Pliocene Ohta tephra bed of the Tokai Group, central Japan. dimentary Geol., 107, 211-229.

ebert, K., 1978, Linyit içeren Soma-Neojen bölgesi, Batı Anadolu. MTA ergisi, 90, 20-69.

kay, A.I., 1989, Tectonic units and sutures in the Pontides, northern rkey. In: Tectonic Evolution of the Tethyan Region (Ed. By A.M.C. ngör), Kluwer, Dordrecht, 109-116.

rton, G.J., 1996, Volcanic environments. In: Sedimentary nvironments and Facies (Ed. By H. G. Reading), Blackwell Scientific ublications, pp.485-567, Oxford.

zgül, N., 1984, Alanya tectonic window and geology of its western part n Turkish with English abstract). Ketin Symposium, Turkish Geol. Soc., 7-121.

almer, B.A. and Walton, A.W., 1990, Accumulation of volcaniclastic rons in the Mount Dutton Formation (Oligocene-Miocene), Marysvale lcanic field, Utah. Geol. Soc. America Bull., 102, 734-748.

ggs, N.R. and Busby-Spera, C.J., 1990, Evolution of a multi-vent lcanic complex within a subsiding arc graben depression: Mount rightson Formation, Arizona. Geol. Soc. America Bull., 102, 1114-135.

ust, B.R., 1978, Depositional models for braided alluvium. In: Fluvial dimentology (Ed. by A.D. Miall), Canadian Soc. Petrol. Geologist emoir 5, 605-625.

arth, A., 1994, Volcanoes. Publ. Univ. Coll. London, 273 pp.

ngör, A.M.C., Satır, M. and Akkök, R., 1984, Timing of tectonic events the Menderes Massif, western Turkey: implication for tectonic olutions and evidence for Pan-African basement in Turkey. Tectonics, 693-707.

ngör, A.M.C., Görür, N. and Şaroğlu, F., 1985, Strike-slip faulting and lated basin formation in zones of tectonic escape: Turkey as a case udy. K.T. Biddle and N. Christier Blic (Editors), In: Strike-slip eformation Basin Formation and Sedimentation. Spec. Publ., Soc. econ. aleont. Miner., 37, 227-264.

yitoğlu, G. and Scott, B., 1991, Late Cenozoic crustal extension and sin formation in west Turkey. Geol. Magazine, 128, 155-166.

mith, G.A., 1986, Coarse-grained non-marine volcaniclastic sediments: rminology and depositional processes. Geol. Soc. America Bull., 97, 1-0.

Smith, G.A., 1987 a, Sedimentology of vocanism-induced aggradation in fluvial basins: examples from the Pacific northwest, USA. In: Recent Developments in Fluvial Sedimentology (Eds. by Ethridge, F.G., Flores R.M. and Harvey, M.D.), Spec. Publ., Soc.econ. Paleont. Miner., 39, 217-228.

Smith, G.A., 1987 b, The influence of explosive volcanism on fluvial sedimentation, The Deschutes Formation (Neogene) in central Oregon. Jour. Sedim. Petrol., 57, 613-629.

Smith, G.A., 1988 a, Sedimentology of proximal to distal volcaniclastics dispersed accross on active foldbelt: Ellensburg Formation (late Miocene), Central Washington. Sedimentology, 35- 953-977.

Smith, G.A., 1988 b, Neogene synvolcanic and syntectonic sedimentation in central Washington. Geol. Soc. America Bull., 100, 1479-1492.

Smith, G.A., 1991, Facies sequences and geometries in continental volcaniclastic sequences. In: Sedimenattion in Volcanic Settings (Ed. by R.V. Fisher and G.A. Smith), Spec. Publ. Soc. econ. Paleont. Miner., 45, 109-122.

Smith, G.A. and Lowe, D.R., Lahars; volcano-hydrologic events and deposition and the debris flow-hyperconcentrated flow continuum. In: Sedimentation in Volcanic Settings (Ed. by R.V. Fisher and G.A. Smith), Spec. Publ. Soc. econ. Paleont. Miner., 45, 59-70.

Stollhofen, H. and Stanistreet, I.G., 1994, Interaction between bimodal volcanism, fluvial sedimentation and basin development in the Permo-Carboniferous Saar-Nahe Basin (southwest Germany). Basin Research, 6, 245-267.

Takahashi, E. and Jux, U., 1991, Miocene palynomorphs from lignites of the Soma Basin. Bull. Faculty of Liberal Arts, Nagasaki Univ., Natural Science, 31(1), 7-165.

Vessel, R.K. And Davies, D.K., 1981, Non-marine sedimenatiton in an active fore-arc basin. In: Recent and Ancient Non-marine Depositional Environments (Ed. by F.G. Ethridge R.M. Flores) Spec. Publ., Soc. econ. paleont. Miner., 31, 31-45.

Waresback, D.B. and Turbeville, B.N., 1990, Evolution of a Plio-Pleistocene volcanogenic-alluvial fan: The Puye Formation, Jemez Mountains, New Mexico. Geol. Soc. America Bull., 102, 298-314.

White, J.D. L. and Robinson, P.T., 1992, Intra-arc sedimentation in a low-lying marginal arc, Eocene Clarno Formation, central Oregon. Sedimentary Geol., 80, 89-114.