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Halitpaşa Transpressive Zone: Implications for an Early Pliocene Compressional Phase in Central Western Anatolia, Turkey

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Abstract: The Late Cenozoic evolution of the eastern Aegean is dominated by widespread continental extension. The most prominent structures are E–W- and NE–SW-trending grabens and intervening horsts, while NW–SE- and N–S-trending faults form the other less important structures. This paper documents the results of recent geological mapping and structural and stratigraphical analysis from the Halitpaşa half graben, which forms the northwestern continuation of the Gediz Graben. Field evidence for a new NW–SE-trending dextral wrench-dominated fault zone (here named the Halitpaşa transpression zone), which involved the thrusting of pre-Palaeogene basement onto Upper Miocene–Lower Pliocene sediments, is presented. The fault zone is correlated with the timing of a major unconformity that separates Upper Miocene–Lower Pliocene lacustrine sediments (Develi and Halitpaşa formations) from overlying late Early Pliocene, distal alluvial-fan sediments (Kızıldağ Formation). The field relations and mammalian data suggest an early Early Pliocene age for this unconformity. The manuscript therefore documents structural evidence for a compressive phase during the evolution of active continental extension in western Turkey. The deformation is attributed to the known Early Pliocene compressive pulse of the Aegean Arc.

Key Words: western Turkey, Aegean, Late Cenozoic, transpression, extension

Halitpaşa Transpresif Kuşağı ve Orta Batı Anadolu'da (Türkiye) Erken Pliyosen Yaşlı Sıkışma Fazı İçin Önemi

Özet: Doğu Ege'nin Geç Senozoyik evrimi yaygın bir karasal genleşme ile temsil edilir. D–B ve KD–GB uzanımlı graben ve aralarındaki horstlar bölgedeki en önemli yapıları oluştururken KB–GD ve K–G uzanımlı faylar ise diğer yapılardır. Bu makalede Gediz grabeni'nin kuzeybatı uzantısını oluşturan Halitpaşa yarı grabeni ve yakın civarında yapılan güncel jeolojik harita alımı ile yapısal ve stratigrafik analizlerin sonuçları sunulacaktır. Makale ayrıca, Paleojen öncesi döneme ait temel kayaçlarının Geç Miyosen–Erken Pliyosen yaşlı sedimanların üzerine bindirdiği ve bu çalışmada ilk kez tanımlanan KB–GD uzanımlı sağ yanal doğrultu-atımlı fay kuşağının (Halitpaşa transpresif kuşağı) saha verilerini de ortaya koymaktadır. Fay kuşağı Geç Miyosen–Erken Pliyosen yaşlı gölsel sedimanları (Develi ve Halitpaşa formasyonları) ile geç Erken Miyosen yaşlı alüvyon konisi sedimanları (Kızıldağ Formasyonu) arasında yer alan önemli bir diskordans dönemi ile ilişkilendirilmiştir. Saha ilişkileri ile memeli fosil verileri bu diskordansın yaşını en Erken Pliyosen olarak önermektedir. Makale sonuç olarak batı Turkiye'de etkin olan kıtasal gerilme dönemi içinde gelişen bir sıkışma fazının varlığını ve ilgili yapısal verilerini ilk kez ortaya koymaktadır. Bu deformasyon Ege Yayında varlığı bilinen Erken Pliyosen yaşlı sıkışma rejimine atfedilmiştir.

Anahtar Sözcükler: batı Türkiye, Ege, Geç Senozoyik, transpresyon, gerilme

Introduction

The Late Cenozoic fracture system in the eastern Aegean is characterised by NE–SW- and approximately E–W-trending graben/horst-bounding normal faults, and less prominent NW–SE- and N–S-trending faults (Figure 1). Structural models pertinent to the evolution of Late Cenozoic tectonics in the region can be grouped into two generalised classes: (i) a continuum of extensional

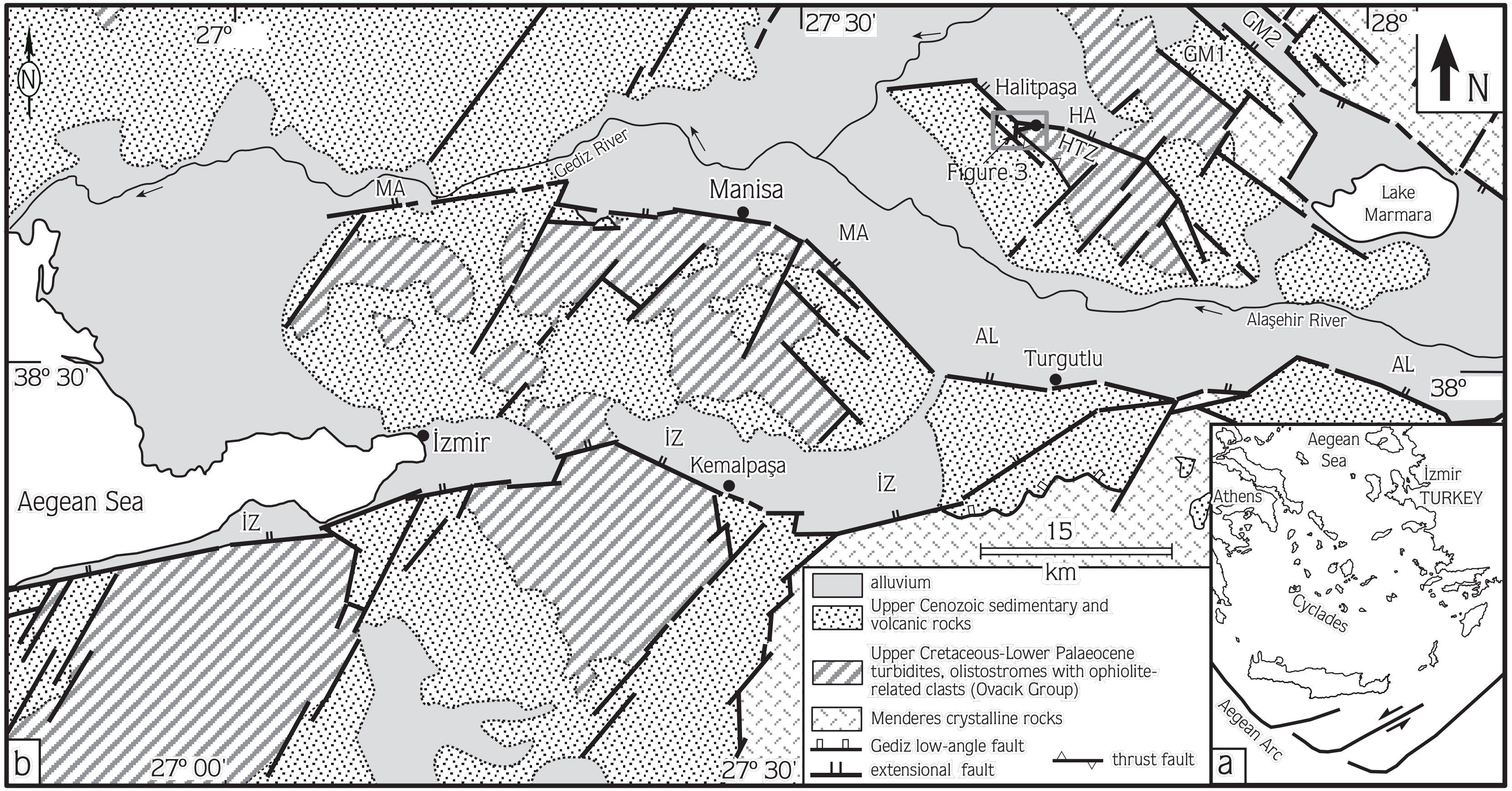

Figure 1. Late Cenozoic faults defining the distribution of the Upper Miocene to Pleistocene rock units in central western Anatolia. AL– Alaşehir half graben; GM1, GM2– Göl Marmara half grabens; HA– Halitpaşa half graben; İZ– İzmir half graben; MA– Manisa half graben; GE– Gediz half graben system comprises İZ, AL, MA, HA, GM1 and GM2; HTZ– early Early Pliocene Halitpaşa transpression zone (this study); CTF– post-late Early Miocene "Cumalı Thrust Fault" (Eşder & Şimşek 1975).

tectonics expressed by an almost uniform stress system (e.g., Dewey & Şengör 1979; Seyitoğlu *et al.* 1992; Armijo *et al.* 1996), or successively alternating stress systems (e.g., Kaya 1982; Şengör 1982, 1987; Şengör *et al.* 1985; Bozkurt 2000; Yılmaz *et al.* 2000), and (ii) an "Late Miocene–Early Pliocene or most likely Early Pliocene" compressive phase within a multiple-stage extension (e.g., Mercier 1981), or a late Serravalian–late early Pliocene compressive phase separating an episodic two-stage extension (Koçyiğit *et al.* 1999a, 1999b, 2000; Bozkurt 2000).

In terms of a general consensus, the Late Cenozoic sediments in central western Anatolia can be grouped in three main assemblages separated by major unconformities (Figure 1): a lower lacustrine assemblage, a middle alluvial-fan to muddy fluvial assemblage, and an upper lateral alluvial-fan assemblage. The lower and middle assemblages have been generally considered as Miocene and Pliocene in age and the upper assemblage as Plio-Quaternary (e.g., Koçyiğit *et al.* 1999a, 1999b). An alternative model involves lateral correlation between the units of the lower and middle assemblages (Seyitoğlu & Scott 1991, 1996; Seyitoğlu 1997; Seyitoğlu *et al.* 2000, 2002). Although Late Miocene (e.g., Yılmaz & Karacık 2001; Yılmaz *et al.* 2000) or Early Pliocene (Emre 1996; Yusufoğlu 1996; Koçyiğit *et al.* 1999a, 1999b; Sarıca 2000; Bozkurt 2000, 2002; Sözbilir 2001, 2002) ages are proposed for the major unconformity between the lower and middle assemblages, the detailed dating of the unconformity surface using biostratigraphic data is lacking.

The present paper therefore examines the Halitpaşa half graben – the northwestern continuation of the Gediz graben approximately 20 km east of Manisa – and reports the results of recent field geological mapping and structural and stratigraphical analysis, which bears upon the evolution of extensional tectonics in western Turkey (Figures 1 & 2). We introduce field constraints on and biostratigraphic data for an early Early Pliocene age for the major unconformity between the lower and middle sedimentary assemblages. The manuscript also documents structural evidence for a compressive phase delineated by a recently recognized transpressive structure along the eastern margin of the Halitpaşa half graben.

Stratigraphy

The rocks exposed in the study area are grouped into two major units: basement (Ovacık group) and unconformably overlying Neogene sediments (Figure 3). The basement is composed of ophiolitic rocks (serpentinitic ultramafic tectonites, mafic volcanic rocks and red-green radiolarite) and grey-red recrystallised limestones. The detailed description of basement lithologies lies outside the scope of the present manuscript, but special attention is given to the Neogene units as they carry important implications for our understanding of tectonic processes prevailing in the region since the latest Miocene time.

Neogene sediments in the Halitpaşa area can be grouped into three contrasting lithological associations: the Develi, Halitpaşa and Kızıldağ formations; these units are separated by angular unconformities (Figure 3). Details of the stratigraphy and palaeontological data for dating the various lithological associations are given below.

The Develi Formation is the lowermost unit of the Neogene sediments and unconformably overlies the pre-Palaeocene basement rocks; it is divided into four informal members: fanglomerate, conglomerate-limestone, sandstone-mudrock and limey mudrock members (Figure 3). The fanglomerate member (df) is composed primarily of red radiolarite-fanglomerate, and subordinate amounts of recrystallised limestone-fanglomerate, both being derived from the immediate basement rocks. The conglomerate-limestone member consists primarily of texturally sub-mature, light green-grey polymictic conglomerates with clasts derived mainly from the underlying ophiolitic rocks; the clast size is variable (up to small blocks). The conglomerates show rapid lateral and vertical facies variations into pebbly and sandy white limestones. An approximately 7-m-thick felsic tuff occurs locally in the lower part of the member. Where exposed, the unit laps onto the basement, and involves an early coarsening-upward and then a late fining-upward sequential development. The sandstone-mudrock member comprises light to medium brown-grey, weakly indurated, thick-bedded, texturally mature sandstone and mudrock. The limestone-limey mudrock member is characterised by interfingering white limestones and limey mudrocks of freshwater lacustrine origin. The measured thickness of the Develi Formation is about 175 m.

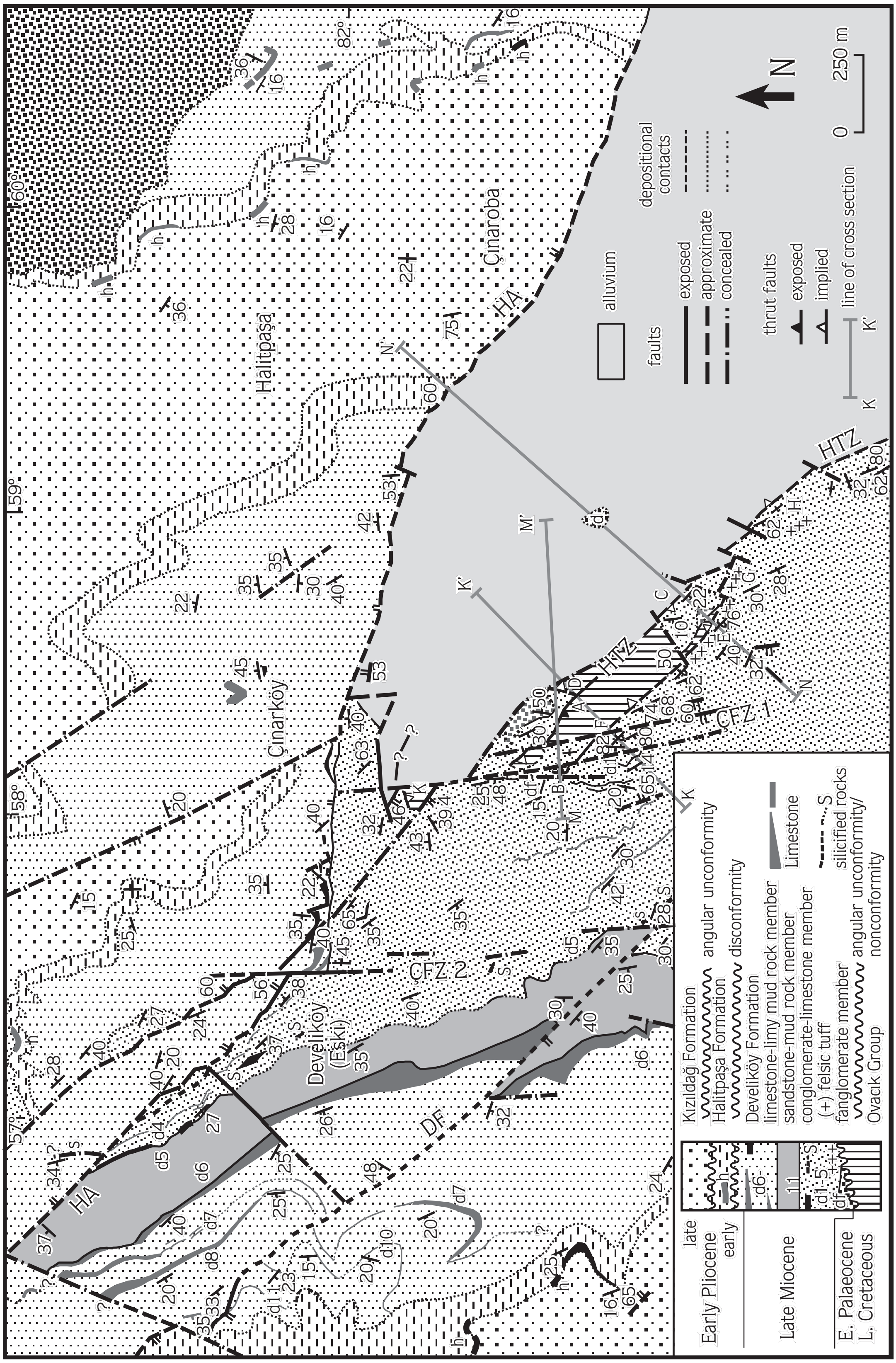

Figure 2. Geological map of the Halitpaşa area. HTZ– Halitpaşa transpression zone; DF– Develi fault; ÇFZ– Çinarköy fault zone; HA– boundary fault of the Halitpaşa half graben.

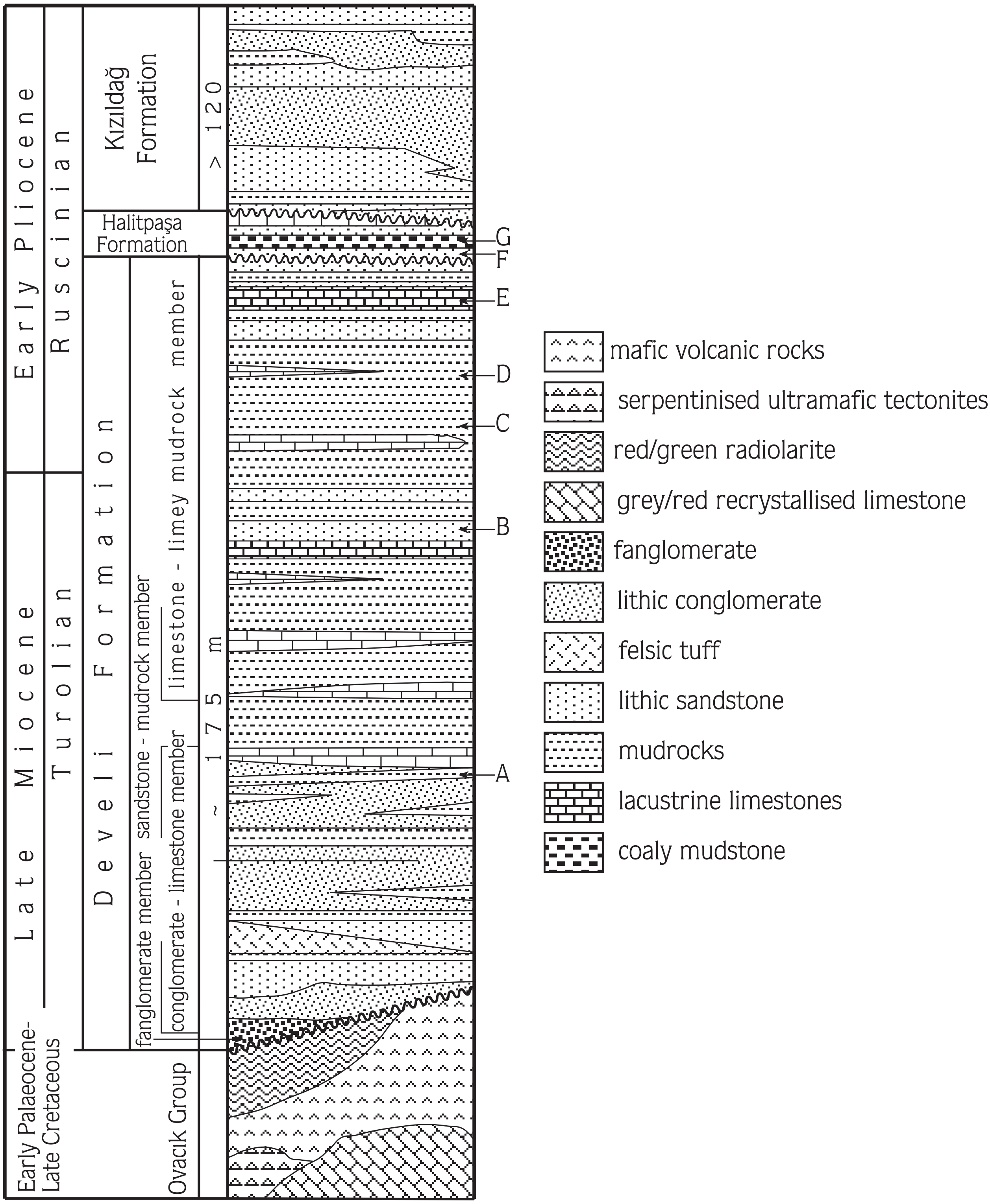

Figure 3. Generalised rock succession of the Halitpaşa area. A–G, Age-diagnostic fossil horizons (see text).

There are six horizons of age-diagnostic fossils identified in the Develi Formation (Figure 3): (1) Horizon A – *Hipparion matthewi*, Turolian (Kaya *et al.* 1998); (2) Horizon B – *Dipoides anatolicus*, *Gazella gaudryi, Hipparion matthewi*, late Late Miocene, (Ozansoy 1960); (3) Horizon C – *Prolagus michauxi, Apodemus* sp., *Pseudomeriones* sp., Spermophilinus sp., Early Pliocene (Şen *et al.* 1989); (4) Horizon D – *Gyraulus* aff. *crista*, Early Pliocene (Ozansoy 1960); (5) Horizon E – *Nitellopsis (Tectochara) meriana*, Pliocene (Ozansoy 1960); (6) Horizon F – *Apodemus* cf. *dominans*, about 1 m beneath the unconformity, Pliocene. On the basis of this mammalian fauna, a late Late Miocene–Early Pliocene age is assigned to the Develi Formation.

The Halitpaşa Formation unconformably overlies different horizons of the Develi Formation (Figure 2); it consists primarily of red-brown lithic sandstone, lithic conglomerate and mudrock with subordinate pink to green-grey mudrock and white to light brown-grey limestone. At several localities the formation commences with coaly mudstone, and a layer of reddish-grey, well-sorted, loose sand (up to 30 cm thick). The limestone is up to 4 m thick and is characterised by microcrystalline (microcrystalline calcite), and is partly clayey and apparently free of skeletal fragments. The limestone is not laterally continuous but has been removed by an erosional truncation defining the base of the overlying Kızıldağ Formation. The sandstones and conglomerates are interpreted as distal parts of an alluvial fan. The formation rests unconformably on various horizons of the Develi Formation (Figure 2). The basal coaly mudstone (Horizon G in Figure 3) contains small mammalian fauna of *Promimomys cor, Apodemus* sp., *Myomimus* sp., *Occitanomys* sp., *Ochotona* sp., *Prolagus* sp., *Orientalomys* sp., *Prolagus* sp., Erinaceidae, Gerbillidae (Pseudomeriones?), Leporidae, Ochotonidae, Sciuridae, Soricidae, Spalacidae, Talpidae and Insectivora, which as a whole, indicate a mid-Ruscinian (late MN 14) age, Early Pliocene.

The Kızıldağ Formation is the youngest unit in the Halitpaşa area and unconformably overlies the Halitpaşa Formation. It consists primarily of a red-bed succession of conglomerates, sandstones and mudrocks that represents a distal alluvial-fan facies; these lithologies show rapid lateral and vertical facies variations. Locally, the colour, is brownish grey. The basal part of the formation is defined by conglomerates containing, in places, large amounts of Upper Miocene to Lower Pliocene limestone detritus. The unit is thought to be the time equivalent of red beds in the proximal facies widely exposed in the footwall block of the present-day Alaşehir half graben. The formation is apparently free of evidence useful for age-dating.

If the Early Pliocene termination of the Develi Formation (Figure 3) is considered, the major unconformity separating the Develi Formation above from the Halitpaşa and Kızıldağ formations below (lower and middle sedimentary assemblages, respectively; see Introduction) can be described as an early Early Pliocene to late Early Pliocene erosional event, delineated by two pulses. The parallel unconformity between the Halitpaşa Formation and the Kızıldağ Formation seems to reflect a late, eventual pulse of compressive force.

Structure

Structures in the study area are grouped into two categories: (1) the ~E–W- and NE–SW-trending high-angle normal faults of diverse size, and (2) ~ E–W-trending, south-dipping thrust faults. Normal faults constitute the margin-bounding faults of the Halitpaşa half graben (HA) – a graben that is considered to be a linked strand of the Alaşehir half graben (Figure 1). The boundary faults consist of WNW–ENE-, NW–SE- and E–W-trending segments (Figure 2). The offset on the steeply N-dipping boundary fault amounts to more than 1000 m. The plane of the Late Miocene unconformity may indicate about 15º S-tilting of the footwall (Figure 4). Because the same lithological association of the Halitpaşa Formation occurs on either side of the Halitpaşa graben (Figure 2), the age of the normal faulting is likely post-Early Pliocene. The detailed description of the normal faults lies outside the scope of this paper, but a special emphasis is given to the thrust fault zone, herein named the Halitpaşa transpression zone (HTZ). Analysis of this structure was carried out at various locations in the present area and the observations are summarised below.

At *Location A* (58.38:81.28), the HTZ is marked by occurrence of the basement rocks directly above the basal strata of the Upper Miocene Develi Formation (Figures 2, 4 & 5a). There, the rock succession is overturned northward (Figure 2); the thrust surface is undulating

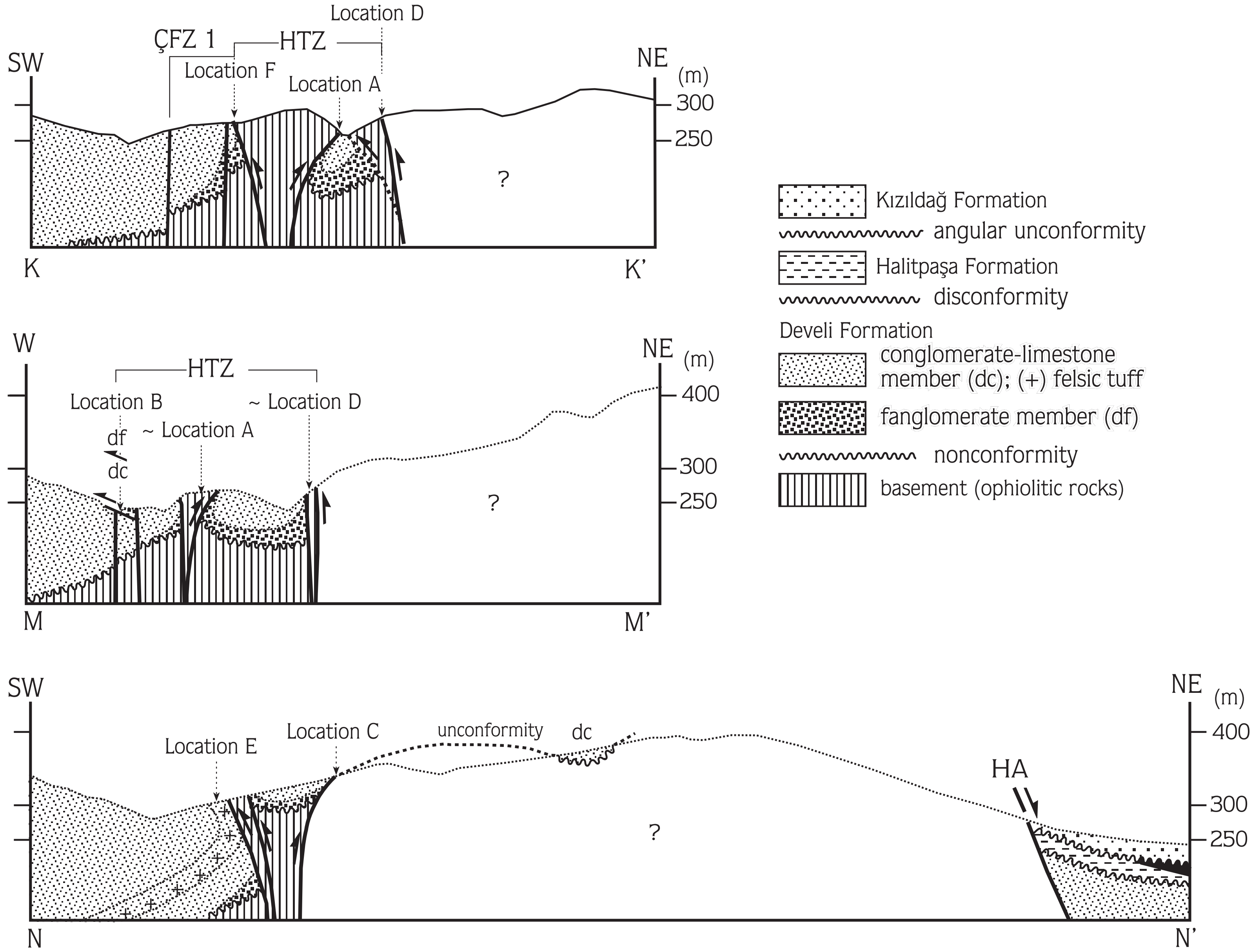

Figure 4. Interpretative cross-sections across the Halitpaşa transpression zone. Geometry of the deep structures not to scale. See Figure 2 for location and abbreviations.

and strikes between N82ºE and N75ºW and dips 28ºSE to 43ºSW. The shear planes (Figure 6a) in the basement rocks and the strongly deformed Develi Formation are oriented parallel to the general trend of the thrust plane. An ~20-cm-thick cleavage slice in the Develi Formation (Figure 5a), with planes having an average attitude of N65ºE, 48ºSE, discloses a dextral shear component. The HTZ is also locally defined by the occurrence of the fanglomerate member resting on the younger conglomerate-limestone member.

At *Location B* (58.15:81.30) (Figure 5b), the thrust fault has an average attitude of N18ºE, 32ºSE, and is accompanied by parallel shear planes (Figure 6b). An outcrop-scale overturned fold in the fanglomerate member of the Develi Formation (Figure 5b), drag folds and axes of minor asymmetric folds (Figure 6b) indicate WNW-directed thrusting.

At *Location C* (58.66:80.94), the near-horizontal, openly folded shear zone in the basement rocks occurs adjacent to the basal strata of the conglomerate-

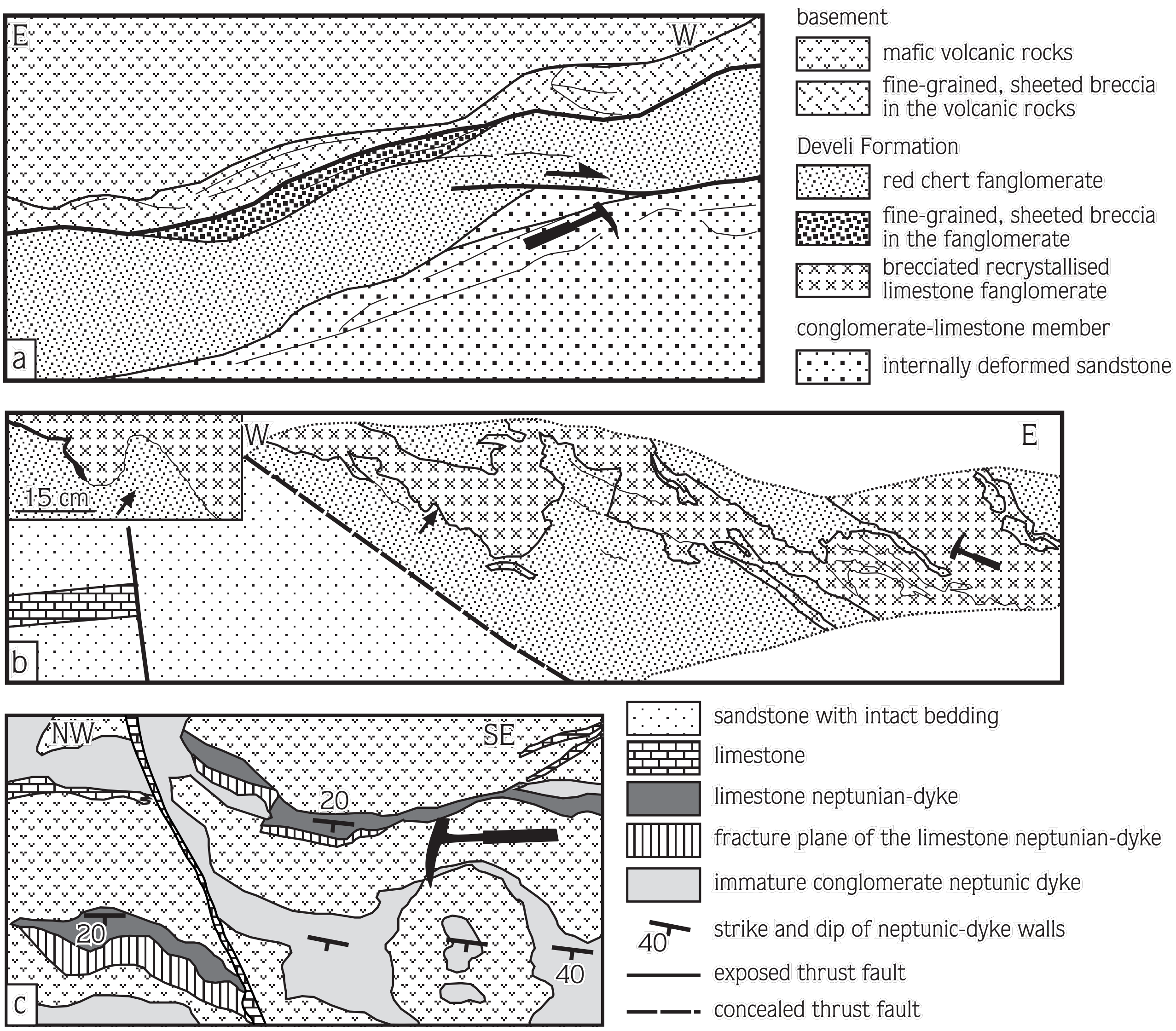

Figure 5. Sketches from field photographs of thrust faults at locations A and B, and overturned basement segment at location C. See text for locations.

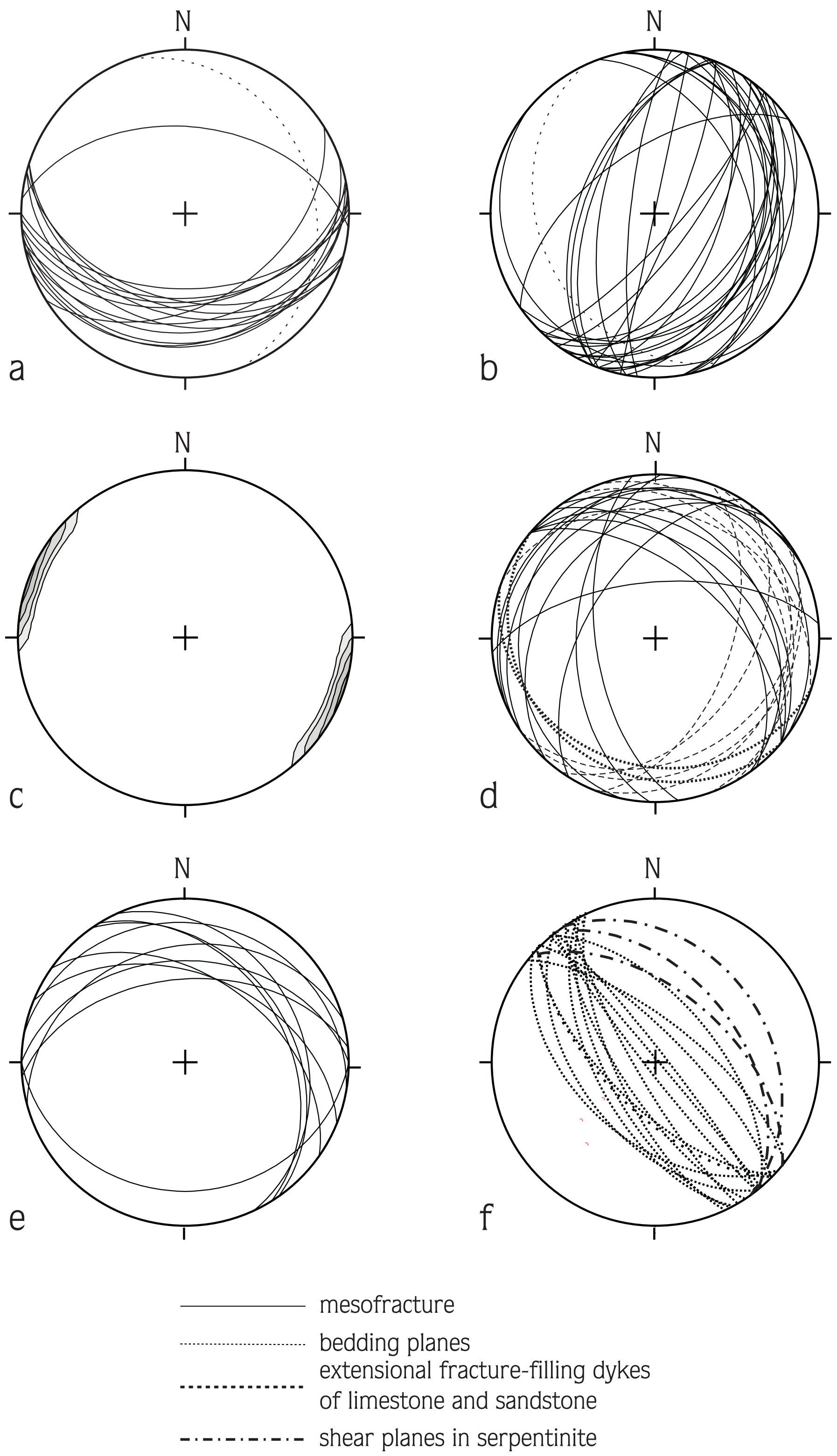

Figure 6. Lower-hemisphere Schmidt steroplots of mesofractures at locations A to E, and bedding planes between locations E and F (see Figure 3 for locations).

limestone member of the Develi Formation (Figures 5c & 6c). The member overlaps the basement rocks where the latter is dissected by extensional fractures filled with up to 25 cm of sandy to fine pebbly limestone, and relatively thicker poorly sorted, fine-grained conglomerate and pebbly sandstones. It is suggested that the fractures are similar to neptunian dykes, and the fill material is derived from overlapping sediments of conglomerate-limestone member. The present-day near-horizontal setting of the neptunian dykes indicates northward overturning on a NW–SE axis.

At *Location D* (58.40:81.30), the thrust contact is not exposed. However, shear planes in the cataclastic basement rocks have a general NNE dip (Figure 6d), opposite to that at Location A, lying immediately to the south.

At *Location E* (58.62:80.82), a felsic tuff horizon of the Develi Formation is overturned, possibly due to the activity of an adjacent thrust fault slice made up of basement rocks and the fanglomerate member to the north (Figures 2 & 4). Between locations E and F, the Develi strata adjacent to the basement rocks are unusually steepened southeastward and overturned.

At *Location F* (58.40:80.97), strongly sheared serpentinite in contact with the conglomerate-limestone member supports SW-directed compression (Figure 6e). At locations A–E, the variable attitude of the shear planes in the thrust fault zone is geometrically consistent with a helicoidal flower structure. Wrench-dominated transpression with a convergence angle <20º is evident from symmetric flower structure, its localisation and the apparent dominance of steeply dipping Y-faults to the SE and NW (Casas *et al.* 2001).

Striations on fault planes are not recognisable because of the weak state of induration of the Develi Formation at the time of deformation, and reactivation and late precipitation of carbonates along the fault planes during a subsequent extensional episode. The data from fault zones F–H are not conclusive due to poor outcrop conditions.

Further support for a dextral sense of displacement along the HTZ, in addition to the cleavage slice at Location A, comes from (i) sinistral motion along a basement fault with an attitude of N85ºE, 52ºNW where the rake of slickenlines is 10ºE. This structure is interpreted as an antithetic X-shear in a transpressional field (Bartlett *et al.* 1981) (Location 58.07:81.79), (ii) NNE–SSW- and N–S- trending fault patterns in map view, which are comparable to antithetic Riedel and extensional fracture-type patterns in a wrench system, respectively, and (iii) dextral lateral offset of limestone horizons across the Develi fault (DF) that parallels the trend of the HTZ (Figure 2). Because a marker horizon is absent on either side of the transpression zone, the amount of the lateral offset along the HTZ is not evident.

An interpretation of temporal correspondence between the transpressional deformation and the early Early Pliocene unconformity is supported by the following arguments. The transpressional deformation has affected the Late Miocene (Turolian) strata, and is older than the late Early Pliocene onset of a regional, easterly-trending extensional basin that entrapped the Halitpaşa Formation. It is older than the post-late Early Pliocene development of the Halitpaşa half graben. The early Early Pliocene angular unconformity is associated with widespread subaerial erosion, as revealed by an excess supply of Late Miocene to Early Pliocene limestone detritus which contributed to deposition in the distal alluvial-fan environment of the Halitpaşa Formation.

Discussion and Conclusion

The Late Cenozoic events in the Halitpaşa area, that precede the development of the Halitpaşa half graben, can be summarised, in broad terms, as (1) Late Miocene to early Early Pliocene lacustrine deposition (*extension*), (2) early Early Pliocene major unconformity consequent to the Halitpaşa transpression (*compression*), (3) late Early Pliocene restricted lacustrine deposition (*extension*), (4) late Early Pliocene truncational erosion of the late lacustrine deposits (*extensional tilting?*) and (5) late Early Pliocene to Late Pliocene continuum of distal alluvial-fan deposition (*extension*). Although slight chronological differences exist, the succession of these events is consistent with the post Mid-Miocene tectonic evolution of the Aegean where “Late Miocene extension, latest Miocene/Early Pliocene (most likely Early Pliocene) compression and Early to Late Pliocene extension” is documented (e.g., Mercier 1981).

Neotectonic deformation in the Aegean has been generally assumed to be controlled by the westward motion of the Anatolian block along the North Anatolian Fault System (NAFS) since the Late Miocene, in relation to indentation of the Arabian promontory (e.g., Dewey & Şengör 1979). However, recent approaches are in favour of a younger age for the westward motion concentrated on the NAFS (e.g., Armijo *et al.* 1999; Bozkurt 2001 and references therein). In the southern Aegean, the Early Pliocene compressive stress distribution related to the Aegean Arc (e.g., Mercier 1981) and the HTZ represent parts of interacting fault systems with NE–SW and NW–SE trends, which geometrically resembles a simple conjugate shear pattern (Kaya & Foulger 2000) (Figure 7). The Early Pliocene, wrench-dominated HTZ, seems to be compatible with a cyclic compression caused by the Aegean Arc.

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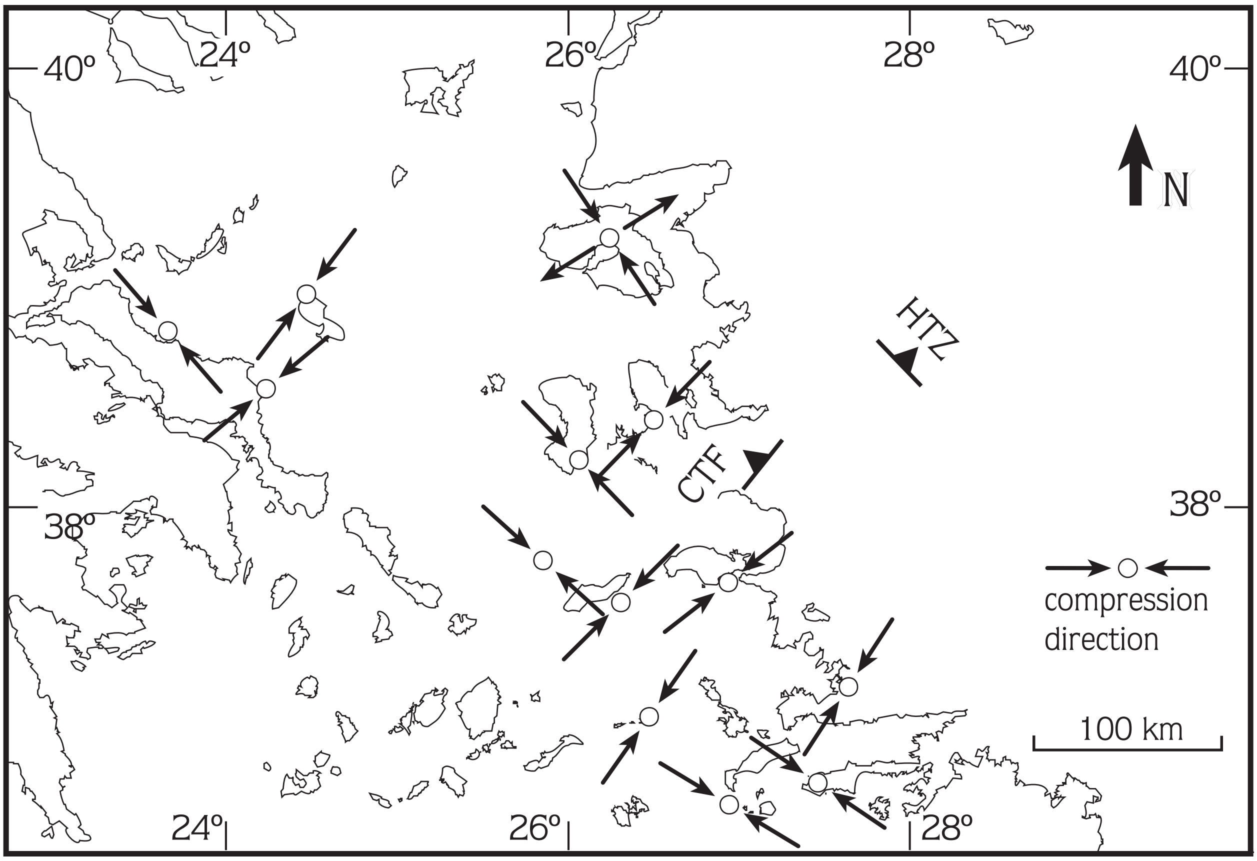

Figure 7. Early Early Pliocene compressive stress pattern of the Aegean. c.d., compressional directions (e.g., Mercier 1981). HTZ, early Early Pliocene Halitpaşa transpression zone; CTF, post-late Early Miocene “Cumalı thrust fault” (Eşder & Şimşek 1975).

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