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Timing of Cenozoic extensional tectonics in west Turkey

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Abstract: The timing of the transition from compressional to extensional tectonics in the late Cenozoic evolution of west Turkey has been constrained by K-Ar geochronology from acidic volcanic rocks and tourmaline leucogranite dykes in the central and east margin respectively of the Gördes basin.

Dacites and rhyolites in the centre of the Gördes Neogene sedimentary basin cut both the basement ophiolites of the Izmir–Ankara suture zone and the Neogene sediments. On the basin's eastern margin the leucogranites cut metamorphic basement along a major NE–SW-trending normal fault that controls the regional structure of the basin. Pebbles of these leucogranites occur in adjacent Neogene tuffites and conglomerates.

K–Ar dates on biotites from the central volcanic rocks vary from 18.4 ± 0.8 Ma to 16.3 ± 0.5 Ma (early Miocene) whilst muscovite from a leucogranite on the eastern margin of the basin provides ages of 24.2 ± 0.8 Ma and 21.1 ± 1.1 Ma (latest Oligocene to early Miocene).

Geochronological data and field relationships demonstrate that the earlier compressional regime had been replaced by extensional tectonics by latest Oligocene–early Miocene.

In north west Turkey, the Izmir–Ankara suture and ophiolite zone (Fig. 1) are considered to be lithospheric remnants related to a Jurassic (?Triassic) to Palaeocene ocean, the northern branch of Neo-Tethys (Şengör & Yılmaz 1981). This ocean, which separated the Anatolide platform from Eurasia (Pontides–Sakarya continent), commenced closure along a north-dipping subduction zone in the late Cretaceous, while initial collision, although poorly constrained, was probably in Palaeocene and continued to early Eocene (Şengör & Yılmaz 1981). Intracontinental convergence, north-south shortening and thrusting, however, continued after this collision with, among other events, the thrusting of the Lycian nappes composed of mainly Mesozoic aged platform carbonates, pelagic sediments, melanges and peridotite, to the south side of the Menderes massif (Şengör 1979; Şengör & Yılmaz 1981; Şengör *et al.* 1985).

The Menderes massif (Fig. 1), an integral part of the Anatolides which lies immediately to the south of Izmir–Ankara suture, underwent deformation and metamorphism during a middle Eocene to early Oligocene interval which is constrained biostratigraphically (Şengör *et al.* 1984). It has been suggested that the ophiolites of Lycian nappes root on the north side of the massif (Ricou *et al.* 1975) in the Izmir–Ankara suture zone and were thrust over the massif towards the southwest (Fig. 1). It is also suggested that the metamorphism of the massif is a consequence of its burial beneath the Lycian nappe pile (Şengör & Yılmaz 1981; Şengör *et al.* 1984). On the south side of the Menderes massif, the Lycian nappes at Isparta (Fig. 1) are transgressed by Burdigalian conglomerates (Guntic & Poisson 1970). Adjacent to Antalya, however, they rest on a Burdigalian conglomerate but are trangressed by Tortonian clastic sediments (de Graciansky *et al.* 1970) whilst on the island of Kos they are thrust onto a monzonite with a K-Ar date of 11.9 ± 0.4 Ma to 9.15 ± 0.2 Ma (Tortonian) Besang *et al.* (1970). These three, admittedly widespread, age data indicate a variation in nappe arrival from early Miocene in the north (at Isparta) to late Miocene to the south and west. This is consistent with a model that the nappes advanced from north to south but alternative interpretations are equally valid since the chronological constraints are sparse and the age variation may be related to different structural levels of exposure.

The area about the Menderes massif shows a widespread occurrence of Neogene and Quaternary basin development and related normal faulting with up to 1500 m of fluviatile and lacustrine sediments and volcanic activity (Price & Scott 1989; Seyitoğlu & Scott 1991). The origin of these late Cenozoic basins has been related to two separate causes. It is suggested that those pre-dating the Tortonian (i.e. early Miocene) belong to the Palaeogene north–south shortening described above. This shortening is believed (Şengör *et al.* 1985; Şengör 1987) to have generated a compressional regime in west Turkey with north trending Tibet-type graben (Tapponnier *et al.* 1981) in which early Miocene sediments may have been deposited. Tortonian and younger basins are thought to belong to a north–south extensional regime related to the tectonic escape of the Anatolian plate as it moved westwards via the North Anatolian fault (Dewey & Şengör 1979; Şengör & Yılmaz 1981; Şengör *et al.* 1985).

On the basis of published isotopic and isotopically supported palynological data, however, Seyitoğlu & Scott (1991) demonstrated that Tortonian does not mark the initiation of extension in west Turkey. It was also suggested that the continuing intracontinental convergence and north–south shortening of west Turkey which had commenced in the early Tertiary (see earlier) had ceased by the end of the Oligocene. This was replaced by north–south extension and related sedimentary basin development during the early Miocene (Seyitoğlu & Scott 1991), which continue to the present day (Price & Scott 1989).

Seyitoğlu & Scott (1991) proposed that north–south extensional tectonics in west Turkey is related to the spreading and thinning of a thickened crust which occurred immediately after the Palaeogene compression due to the high thermal profile of this crust.

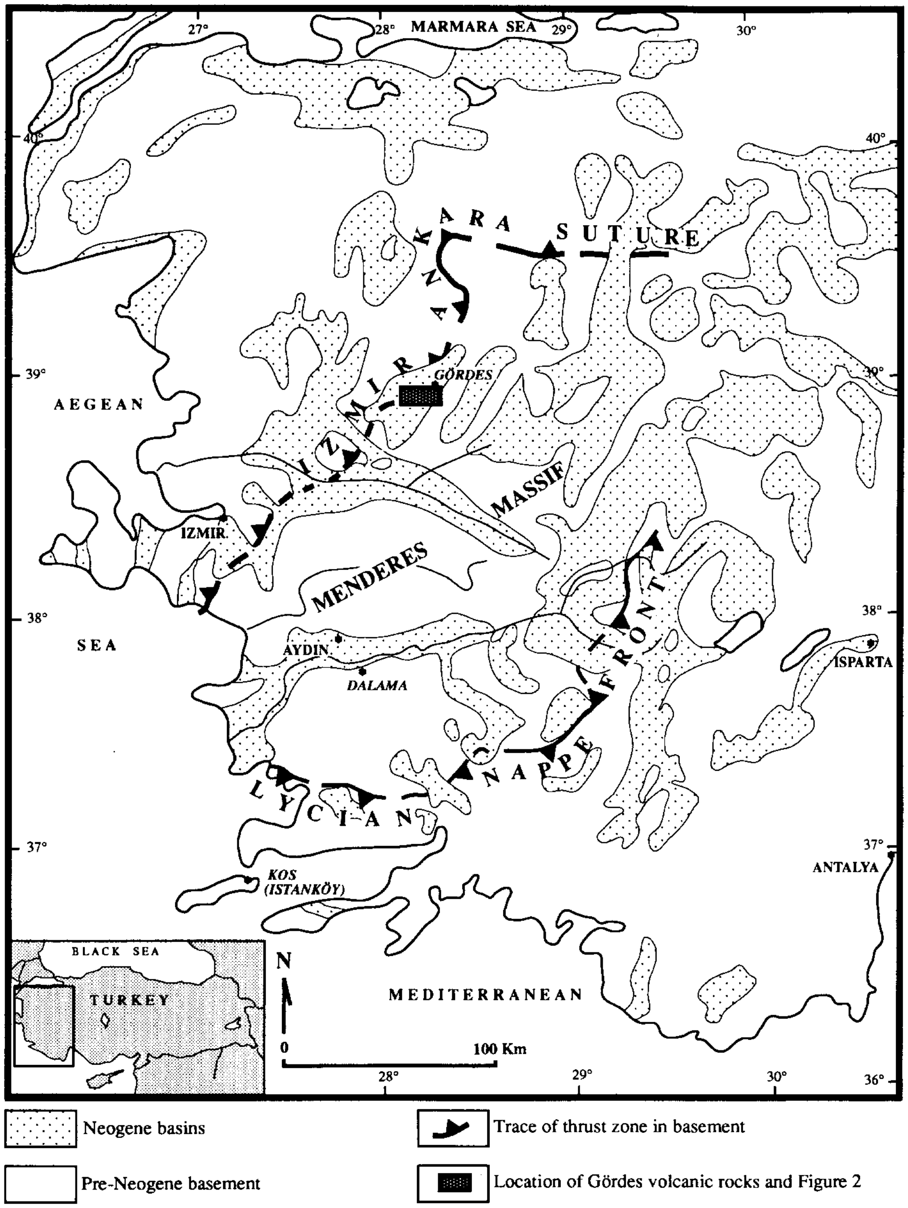

Fig. 1 Neogene basins and main basement structure in west Turkey. Modified from Ketin (1983) and Şengör *et al.* (1985). For location see inset.

Igneous geochemistry

The NE–SW-trending Gördes Neogene basin (Nebert 1961; Ercan 1983; Yağmurlu 1984) contains up to 1000 m of fluvio-lacustrine sediments, with associated volcanic rocks.

The volcanic rocks in the centre of the basin (Fig. 2) are dome shaped and form prominent hills above the general topography. They contain phenocrysts of quartz, feldspars (mainly zoned plagioclase) and biotite in a fine grained groundmass. The occurrence of the volcanic rocks in this location is of interest as field mapping by the authors (G.S. & B.C.S.) demonstrates that they cut both the ophiolite basement of the Izmir–Ankara suture, and the Neogene sedimentary succession. Around these volcanic domes the sedimentary rocks dip steeply outwards up to 87° (Fig. 2).

Chemical analyses on bulk samples have been undertaken at the Department of Geology in University of Leicester. Major elements were analysed on fused beads on ARL 8420 X-Ray Fluorescence Spectometer. Trace elements (Rb, Ba, Sr, Zr, La, Ce, Nd, Y, Th, Nb, Ni, Cr, Zn, V) were analysed on pressed powder disks on Philips PW 1400 X-Ray Spectometer. REE elements (Sm, Eu, Gd, Dy, Er, Yb, Lu) were analysed by using Philips PV 8060 simultaneous ICP Spectrometer.

According to major element analysis (Table 1) the volcanic rocks in the centre of Gördes basin are dacites and rhyolites (69–76 SiO_2 % wt) with calc-alkaline affinity (Fig. 3a & b). They display an enrichment of LIL (large ion lithophile) elements (Ba, Rb, Th, K) and relative depletion of HFS (high field strength) elements (Nb, P,Ti), somewhat similar to subduction-related Andean volcanics (see sample V–4 of Hickey-

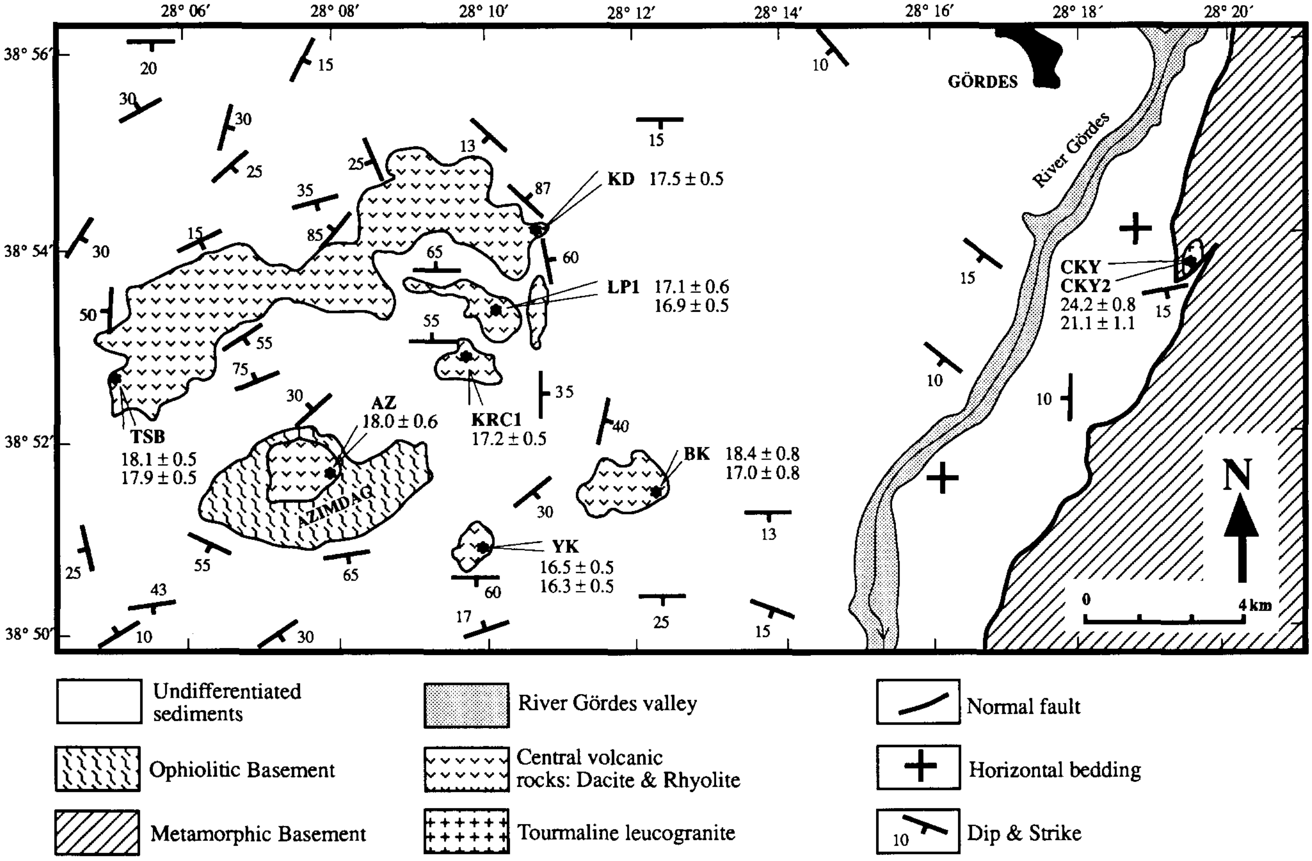

Fig. 2 Location map of central volcanic rocks and tourmaline leucogranite dyke of Gördes basin. For general location see Fig. 1. For details of chemical analysis and radiometric dating see Tables 1 & 2.

Vargas *et al.* 1989, Fig. 3c). The REE patterns of the Gördes volcanics (Fig. 3c) show an enrichment of LREE relative to HREE and the LREE/HREE ratios (La_N/Yb_N = 4 to 11) are consistent with melting involving residual garnet.

The Gördes volcanic rocks (Table 1) have similar trace element patterns to other early Miocene calc-alkaline intermediate–acid volcanism of west Turkey (Innocenti *et al.* 1979; Ercan *et al.* 1985, 1986). These trace element patterns are consistent with a subduction-related geochemical signature which is supported by the Th–Hf/3–Ta discrimination diagram of Wood *et al.* (1979) in which all such early Miocene data plot near to the field of 'magma series at destructive plate margins'. These early Miocene volcanic rocks, however, developed after the closure of the Izmir–Ankara suture (see above) and it is suggested by Güleç (1991) that they originated from subduction modified lithospheric or shallow asthenospheric mantle. They are contemporaneous with the development of extensional tectonics as demonstrated by their association with normal faulting and related development of Miocene sedimentary basins in west Turkey (Seyitoğlu & Scott 1991). We suggest that the subduction-related geochemical signature was inherited from earlier (i.e. pre-Miocene) compressional events analogous to the calc-alkaline volcanic rocks (early andesites, dacites and rhyolites) of the Basin and Range province western USA that were erupted during a period of extensional tectonics (Wernicke *et al.* 1987; Gans *et al.* 1989).

Geochronology

K-Ar analyses were undertaken at the NERC Isotope Geosciences Laboratories, Keyworth, Nottingham and only pure separated minerals were used for dating. Biotite and muscovite were separated using a 'Frantz' electromagnetic separator, followed by hand picking. Potassium was analysed in duplicate by conventional mixed-acid digestion followed by flame photometry using a lithium internal standard. The quoted errors are the difference between the mean and individual values expressed as a percentage. Argon was extracted by fusion under vacuum using external RF induction heating and analysed by the isotope dilution method in an MM1200 mass spectrometer. The quoted errors for the argon determinations (one sigma) are compounded from the errors on the isotope ratio measurements and 'spike' calibration and include any error magnification due to correction for contaminating atmospheric argon. Both the potassium and argon systems are calibrated regularly against international rock standards and so the results should be accurate within the precision limits. Ages were calculated using the decay and other constants recommended by Steiger & Jager (1977) and errors are quoted at the 95% confidence level.

K-Ar dating of seven samples of biotite from the volcanic domes in the central part of Gördes basin provides dates from 18.4 ± 0.8 Ma to 16.3 ± 0.5 Ma with the greatest number of

Table 1. *Major and trace element analyses of the volcanic rocks and tourmaline leucogranite from the centre and east margin respectively of Gördes basin*

	Volcanic rocks from the centre of Gördes basin							Tourmaline leucogranite	
	AZ	BK	TSB	KD	KRC1	LP1	YK	CKY	CKY2
SiO_2	76.28	73.17	74.49	67.79	70.33	69.13	70.49	75.51	76.38
TiO_2	0.23	0.43	0.26	0.56	0.38	0.49	0.40	0.02	0.02
Al_2O_3	12.96	12.65	13.10	14.43	13.94	15.09	13.86	14.89	13.70
Fe_2O_3*	1.30	2.92	1.98	3.95	2.77	3.70	3.04	0.46	0.48
MnO	0.03	0.04	0.03	0.05	0.06	0.08	0.03	0.01	0.01
MgO	0.59	1.08	0.83	2.20	1.35	2.26	1.23	0.18	0.15
CaO	1.72	2.23	1.53	3.80	2.51	3.44	2.72	0.77	0.85
Na_2O	3.10	2.61	2.48	2.98	2.57	2.99	3.15	5.03	4.27
K_2O	3.98	3.74	4.34	3.36	4.05	3.32	4.05	2.82	3.57
P_2O_5	0.05	0.07	0.06	0.11	0.08	0.10	0.09	0.08	0.04
Total	100.25	98.95	99.10	99.24	98.06	100.61	99.07	99.79	99.48
Rb	155	133	155	125	152	119	153	72	73
Ba	483	774	620	808	769	724	693	250	654
Sr	140	205	177	312	164	280	229	77	113
Zr	103	135	109	151	128	145	139	36	38
La	21.3	54.9	25.1	33.7	24.9	26.0	27.1	4.8	12.2
Ce	41.6	78.5	47.9	61.3	48.9	50.5	54.1	7.6	16.0
Nd	18.8	51.8	23.2	26.8	20.7	22.2	23.1	4.4	8.9
Y	40	44	37	27	30	27	32	24	30
Th	19	18	20	16	18	14	19	2	1
Nb	12	12	11	12	12	11	12	4	2
Ni	5	8	6	18	6	14	8	3	3
Cr	10	15	18	76	19	40	19	3	57
Zn	32	38	30	52	39	48	41	17	13
V	18	36	28	69	36	63	46	1	0
Sm	4.12	9.88	4.71	4.64	4.55	3.85	4.50	0.94	1.04
Eu	0.57	1.84	0.66	0.92	0.97	0.91	0.75	0.35	0.52
Gd	4.88	9.38	5.32	5.02	6.87	4.68	5.19	1.35	1.57
Dy	4.96	7.22	5.05	4.22	5.07	3.99	4.52	1.27	1.24
Er	3.02	3.91	3.05	2.31	4.10	2.29	2.61	0.55	0.43
Yb	3.05	3.19	3.03	2.09	2.39	2.10	2.39	0.49	0.48
Lu	0.45	0.46	0.46	0.31	0.36	0.31	0.35	0.06	0.07

AZ, Azimdağ; BK, NE of Baliklidağ; TSB, S of Tosbiyik tepe; KD, NE of Kedikayasi tepe; KRC1, Karaağaç köyü; LP1, N of Lalapeder tepe; YK, SE of Yakaköy; CKY & CKY2, W of Çerkezinyeri tepe. See Fig. 2.

*All Fe calculated as Fe_2O_3.

Table 2. *K-Ar dating of the volcanic rocks and tourmaline leucogranite from the centre and east margin respectively of Gördes basin*

Sample	%K	Atm. Ar nl; %	Rad. Ar nl/g ± %SD	Age ± 2SD Ma
Volcanic rocks from the centre of Gördes basin				
AZ (Bi)	6.750 ± 1	2.60; 41.90 ± 1.02	4.750 ± 1.24	18.0 ± 0.6
BK (Bi)	5.430 ± 2	1.32; 32.37 ± 1.06	3.8934 ± 1.12	18.4 ± 0.8
	5.430 ± 2	1.22; 31.92 ± 1.03	3.6045 ± 1.11	17.0 ± 0.8
TSB (Bi)	6.270 ± 1	0.87; 28.90 ± 1.04	4.4235 ± 1.09	18.1 ± 0.5
	6.270 ± 1	0.95; 30.99 ± 1.04	4.3837 ± 1.10	17.9 ± 0.5
KD (Bi)	3.730 ± 1	0.25; 8.97 ± 1.25	2.5456 ± 1.01	17.5 ± 0.5
KRC1 (Bi)	6.460 ± 1	1.57; 38.15 ± 1.03	4.3452 ± 1.18	17.2 ± 0.5
LP1 (Bi)	5.195 ± 1	1.99; 49.28 ± 1.01	3.4764 ± 1.40	17.1 ± 0.6
	5.195 ± 1	1.08; 38.06 ± 1.03	3.4243 ± 1.18	16.9 ± 0.5
YK (Bi)	4.460 ± 1	0.26; 11.40 ± 1.22	2.8701 ± 1.01	16.5 ± 0.5
	4.460 ± 1	0.90; 29.83 ± 1.03	2.8432 ± 1.09	16.3 ± 0.5
Tourmaline leucogranite from the east margin of the Gördes basin				
CKY (Mus)	7.250 ± 1	3.09; 49.27 ± 1.03	6.8562 ± 1.42	24.2 ± 0.8
CKY2 (Mus)	8.140 ± 2	3.61; 57.54 ± 1.01	6.7011 ± 1.70	21.1 ± 1.1

Bi = Biotite, Mus = Muscovite

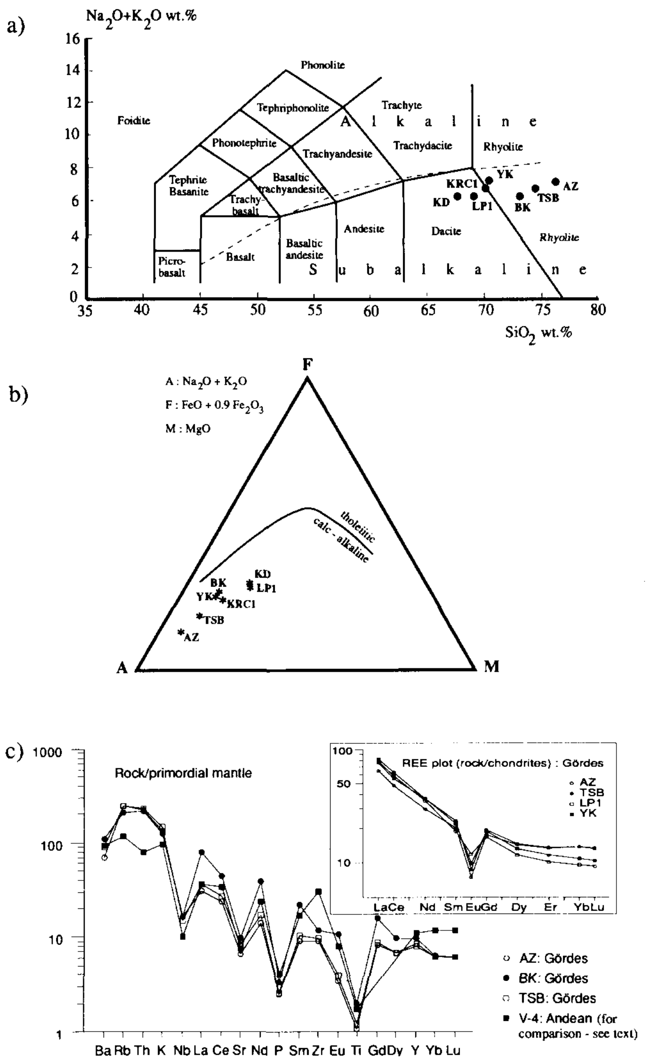

Fig. 3 Diagrams of volcanic rocks from the centre of Gördes basin. Abbreviations as in Table 1. (**a**) Total alkali–silica diagram (after Le Bas *et al.* 1986) with subalkaline–alkaline dividing line of Miyashiro (1978).

(**b**) AFM diagram with tholeiitic–calc-alkaline dividing line of Irvine & Baragar (1971).

(**c**) Multi-element variation diagram (rock/primordial mantle) and REE plot (inset).

determinations indicating eruption during the early Miocene (Table 2 & Fig. 2).

In the east margin of the basin, tourmaline leucogranites cut mica schists of the metamorphic basement as dykes (Fig. 2) and are composed of coarse grained quartz, feldspar, muscovite and tourmaline in a holocrystalline texture. Their major element analyses (Table 1) confirm their composition as granites. These dykes occur along major NE–SW-trending normal faults which control the Gördes basin structure (Fig. 2). Clasts from them occur in adjacent Neogene tuffites and conglomerates: such pebbles are easily distinguished by their leucocratic appearance in contrast to the other fill material which is derived from mica shists of the metamorphic basement.

K-Ar dating of muscovite from 2 samples of a leucogranite dyke from the eastern margin of Gördes basin provides dates of 24.2 ± 0.8 Ma and 21.1 ± 1.1 Ma (latest Oligocene–earliest Miocene) (Table 2 & Fig. 2).

Discussion

These new radiometric dates from the Gördes basin and recent field mapping demonstrate that the compressional movement on the Izmir–Ankara suture had ceased, at least, before the latest Oligocene. Additionally, they indicate that normal faulting and basin formation had commenced in north west Turkey by the earliest Miocene by which time an appreciable thickness of up to 1000 m of fluvio-lacustrine sediments had accumulated. These interpretations support the view of Seyitoğlu & Scott (1991) that extensional tectonics and related sedimentary basin formation in west Turkey commenced in the early Miocene, with the demise of compressional tectonics during the late Oligocene.

If the ophiolites of the Lycian nappes originated from the Izmir–Ankara suture zone, on the north side of the Menderes massif, then they were derived before early Miocene–late Oligocene (21–24 Ma). The occurrence of early Miocene volcaniclastic sediments dated by Becker-Platen *et al.* (1977) as early Miocene (21.0 ± 0.4 Ma) at Dalama (Aydın) (Fig. 1) in the centre of the Menderes massif demonstrates that by this time the massif had been uplifted and unroofed of any possible incumbent Lycian nappe pile. To the south of the massif, however, the three dated locations (see earlier) show that the Lycian nappes continued movement until at least the late Miocene (9.15–11.9 Ma). These later nappe movements might, however, result from gravity sliding rather than as a result of a north–south compression.

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