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The Geochemistry and Setting of the Demirci Paragneisses of the Sünnice Massif, NW Turkey

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Abstract: The Demirci migmatitic quartzofeldspathic gneisses of the Sünnice Massif, exposed in the İstanbul Zone north of Bolu, have compositions that show them to be paragneisses, associated with subordinate para-amphibolites. They consist principally of metamorphosed, rather calcareous greywackes, with sediment derived from a continental arc source. They occur in the para-autochthon below a nappe pile (Çele meta-ophiolite), deformed and subjected to amphibolite facies metamorphism before the emplacement of late Neoproterozoic metavolcanic rocks later subjected to greenschist-facies metamorphism (Yellice volcanics). As they are overlain in sequence by nappes comprising sections of the Çele meta-ophiolite with ocean floor basalt and island arc tholeiite compositions respectively, the Demirci paragneisses may represent a section of the ancient continental basement on to which the meta-ophiolite was obducted during the Proterozoic.

Key Words: geochemistry, nappes, Proterozoic paragneiss, Sünnice Massif, Turkey

Sünnice Masifi'nde Demirci Paragnayslarının Jeokimyası ve Tektonik Ortamı, KB Türkiye

Özet: Bolu kuzeyinde İstanbul Zonu içinde yüzeyleyen, Sünnice Masifi'ne ait Demirci migmatitik kuvars-feldispatik gnaysları paragnaysik bileşimde olup, az miktarda para-amfibolitlerle birlikte gelişmişlerdir. Birim, çoğunlukla kıtasal yaydan kaynaklanmış tortulları içeren biraz kalkerli metamorfik grovaklardan oluşmaktadır. Yeşilşist fasiyesinde metamorfizmaya uğramış Neoproterozoyik yaşlı metavolkaniklerin (Yellice volkanikleri) yerleşmesinden önce amfibolit fasiyesinde metamorfizmaya uğrayan birim, nap dilimlerinin (Çele metaofiyoliti) altında yarı-otokton konumludur. Sırasıyla okyanus tabanı bazaltları ve ada yayı toleyitlerinden teşekkül nap dilimlerinin oluşturduğu Çele metaofiyoliti tarafından yapısal bir dokunakla üzerlendikleri için Demirci gnayslarının Proterozoyik döneminde metaofiyolit naplarının üzerine bindirdiği eski bir kıtasal kabuğu temsil ettiği düşünülmektedir.

Anahtar Sözcükler: jeokimya, naplar, Proterozoyik paragnaysları, Sünnice Masifi, Türkiye

Introduction

The Sünnice Massif forms the largest exposure of basement to the İstanbul-Zonguldak Palaeozoic sequence of the İstanbul Zone in NW Turkey (e.g., Okay 1989; Figure 1, inset). The massif is an approximately east–west-trending structural culmination unconformably overlain by a 4-km-thick low-grade Palaeozoic (Lower Ordovician to Lower Carboniferous) metasedimentary sequence (Kurtköy formation and younger lithologies; e.g., Abdülselamoğlu 1959, 1977; Dean *et al.* 1993, 1997; Yılmaz *et al.* 1994, 1997).

The Sünnice Massif was subdivided into a lower migmatitic amphibolite facies complex, overlain by greenschist facies volcanic rocks, termed respectively the Sünnice Group and Çaşurtepe Formation by Ustaömer & Rogers (1999). At the same time, Yiğitbaş *et al.* (1999) followed an early nomenclature devised by Cerit (1990) and subdivided these rocks into several distinct lithologic associations. Both sets of names are currently in the literature, giving rise to some confusion. In this study we subdivide the Sünnice Group (Cerit 1990) into a structurally lower package of high-grade amphibolite-

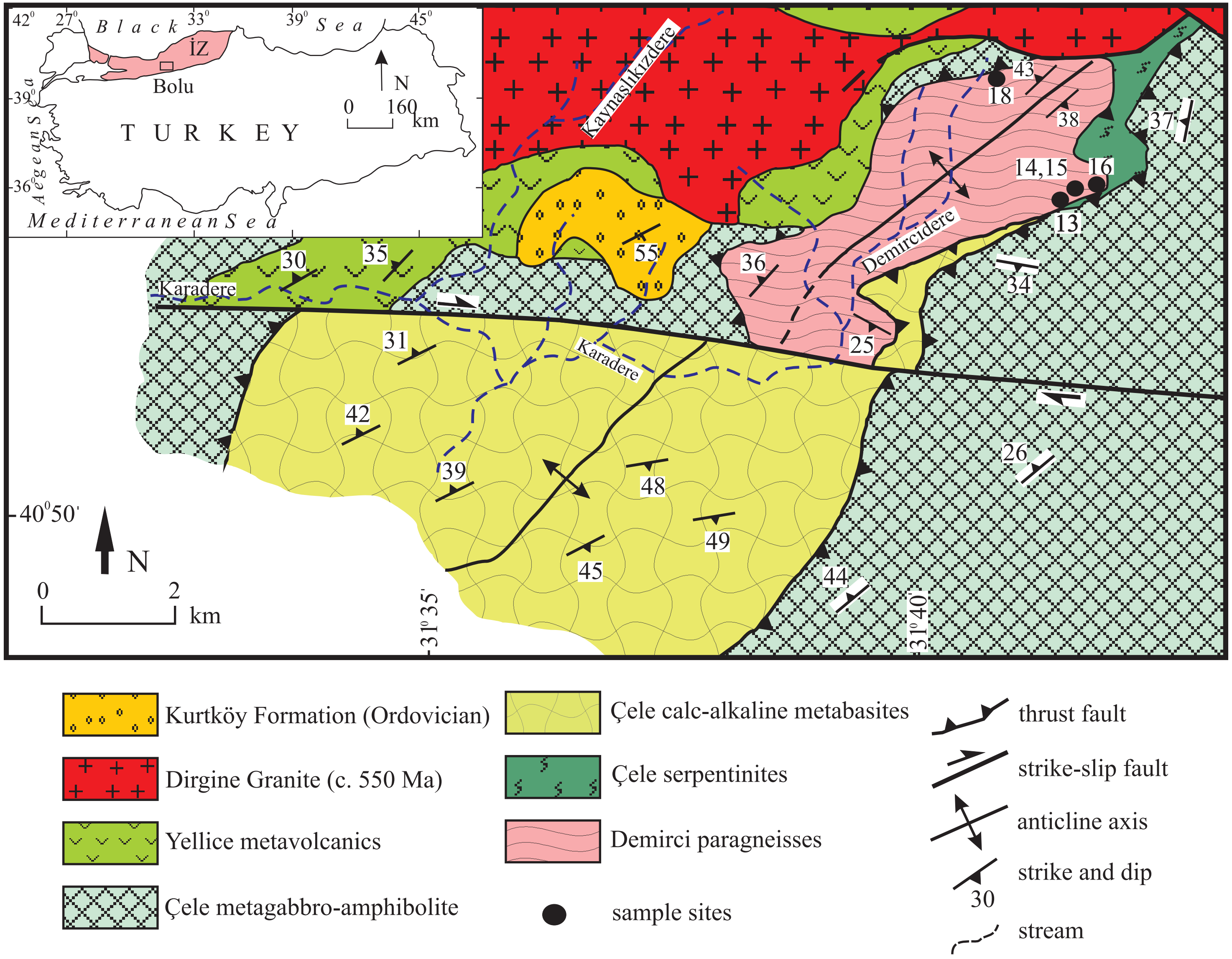

Figure 1. Map showing the setting and field relationships of the Demirci paragneisses, within the Bolu Massif. The inset shows the location within the İstanbul Zone (İZ) in northwest Turkey.

facies quartz-plagioclase-biotite-hornblende gneiss and amphibolites (termed the Demirci metamorphic association by Yiğitbaş *et al.* 1999), and a structurally higher assemblage of amphibolite-facies metaperidotite, serpentinized troctolite, metagabbroic amphibolite and (locally migmatitic) hornblende gneisses that constitute the lower parts of a dismembered ophiolite pseudostratigraphy (termed the Çele meta-ophiolite by Yiğitbaş *et al.* 1999). The overlying greenschist facies Yellice metavolcanic association by Yiğitbaş *et al.* (1999), which was also termed the Yellice formation (Cerit 1990) and Çaşurtepe Formation (Ustaömer & Rogers 1999), comprises greenschist facies metalavas (basalt, dacite and rhyolite) and metapyroclastic rocks. All these rocks are cut by intrusive granitoids (granodiorite, tonalite, quartz-rich granodiorite-tonalite and quartz monzonite) variously termed the Dirgine metagranite (e.g., Cerit 1990; Erendil *et al.* 1991; Elmas & Yiğitbaş 1998, 2001; Yiğitbaş *et al.* 2004) or the Tüllükiriş and Kapıkaya plutons (Ustaömer & Rogers 1999); they have yielded Ediacaran intrusive ages (Ustaömer & Rogers 1999; Ustaömer *et al.* 2005).

The Demirci metamorphic association (Yiğitbaş *et al.* 1999), as indicated by their geochemical compositions (detailed below) dominantly consists of gneissose metasedimentary rocks: they are therefore referred to in this study as the Demirci paragneisses, where their geochemistry is described. They only crop out on low ground at the mountain-fringed head of the Karadere valley, as a small inlier 5 km long, interpreted by Yiğitbaş *et al.* (2004) as occurring at the culmination of the axis of a NE–SW-trending antiform defined by foliation trends within the surrounding Çele Proterozoic meta-ophiolite (Figure 1). Although the Demirci metamorphic association has been subjected to multiple deformation and metamorphism (Elmas & Yiğitbaş 1998), and undisturbed contacts with adjacent amphibolites are nowhere exposed, their confinement to a topographically low area and their location at the crest of the broad antiformal structure revealed by foliation attitudes in the Çele meta-ophiolite lead us to believe that they structurally underlie amphibolites of the Çele meta-ophiolite (Yiğitbaş *et al.* 2004). Indeed, although the only recorded exposed contact is masked by late brittle faulting, which downthrows altered and reddened metalavas of the Yellice metavolcanic association into direct contact with the Demirci metamorphic association, the presence of broadly concordant ductile shear zones (strong shearing and mylonitic fabrics) in the adjacent Çele meta-ophiolite suggests that both internal contacts within the meta-ophiolite and the contact with the Demirci metamorphic association are likely to be ductile thrusts. So, while it is possible that the rocks of the Çele meta-ophiolite were thrust on top of younger rocks, the high amphibolite facies metamorphic grade of the Demirci metamorphic association, which is consistently as high as any other rocks in the area, and comparable only with the grade of the amphibolites of the Çele meta-ophiolite itself, suggests that the Demirci metamorphic association may be at least as old as, and possibly older than, the Çele meta-ophiolite. In the absence of evidence to the contrary, it is assumed that the Demirci metamorphic association were metamorphosed at the same time as the Çele meta-ophiolite, although we recognize that the metamorphism could have occurred at a completely different time.

The Demirci metamorphic association is therefore of interest as it contains the only non-ophiolitic rocks which may be associated with the Çele meta-ophiolite, and therefore the only rocks which may provide information about Proterozoic continental basement to the İstanbul Block. A few representative samples of the Demirci metamorphic association were therefore collected for petrographic study and geochemical analysis as part of a wider investigation into the Çele meta-ophiolite, and these preliminary results are described here.

Petrography

Individual outcrops are not sufficiently extensive to permit a subdivision of the Demirci metamorphic association, although some variation of rock-types has been noted (Yiğitbaş *et al.* 2004). Mostly they consist of grey, variably migmatitic quartzofeldspathic micaceous psammites and semipelites which otherwise provide little petrographic indication of their provenance. The migmatization has generally not generated a high proportion of neosome: there is thus little preserved evidence of wholesale compositional change in the rock: more a redistribution into biotite and hornblende-rich and quartzofeldspathic segregations. Some gneisses contain a higher proportion of biotite, while others may contain large porphyroblasts of andesine, around which the foliation, defined dominantly by biotite and amphibole alignment, appears to flow. Amphibole, usually a rather pale green hornblende, is also a common phase and, with an increase in its abundance biotite gneisses may grade into biotite-rich para-amphibolites in thin interlayers. Apatite is a common accessory phase. Garnet, pyroxene and magnetite were not observed, but their absence may largely be controlled by original rock composition, rather than be purely a reflection of metamorphic grade. Localised replacement of biotite by chlorite suggests that a later greenschist facies metamorphic event may have affected these rocks. Similar indications of a late greenschist facies metamorphic overprint have also been observed in the Çele meta-ophiolite: this and the absence of evidence of a sheared contact with the overlying greenschist-facies Yellice metavolcanic association suggest that these rocks all experienced the same greenschist facies metamorphism, and hence that the Yellice metavolcanic association is most likely to overlie all the Sünnice Group rocks unconformably.

In many places the Demirci metamorphic association is intruded by mostly concordant granitoid bodies and plagioclase-phyric basalts which are either unmetamorphosed or display only slight metamorphism. They may respectively be linked with either the Ediacaran granitoids (Ustaomer & Rogers 1999; Chen *et al.* 2002) and basaltic Yellice metavolcanic association, or the much later Phanerozoic intrusive events, which are also recorded in the İstanbul Zone. But intrusion of all these rocks by granitoid plutons yielding Ediacaran emplacement dates provides the field evidence that all these rocks are Ediacaran or older.

Geochemistry

Representative major and trace element analyses of gneisses from the Demirci metamorphic association are shown on Table 1. Only the fresher samples were selected and they were also chosen as typical of the common lithologies present. Care was taken to sample only specimens devoid of granitoid veining. The samples were crushed at the Middle East Technical University, Ankara and analysed at Keele University, England, using an ARL 8420 X-ray fluorescence spectrometer, calibrated against both international and internal Keele standards of suitable composition (Floyd & Castillo 1992). Analytical methods and precision are detailed in Winchester *et al.* (1992). Selected samples were also analysed for rare earth

Table 1. Whole-rock analyses of Demirci paragneisses. Abbreviations: nd– not determined; amph– amphibolite; m'gw– metagreywacke.

Sample	03\13	03\14	03\15	03\16	03\18
Lithology	amph	m'gw	m'gw	m'gw	m'gw
wt%					
SiO_2	56.15	63.65	61.83	62.21	57.08
TiO_2	0.65	0.75	0.81	0.73	1.37
Al_2O_3	14.91	13.59	13.74	13.81	16.16
$Fe_2O_3^T$	8.99	6.84	7.66	7.40	7.06
MnO	0.11	0.08	0.10	0.10	0.10
MgO	4.94	3.90	3.82	3.75	4.28
CaO	8.01	4.65	5.14	4.72	5.77
Na_2O	3.69	3.38	3.67	3.95	5.69
K_2O	0.89	1.43	1.55	1.46	1.01
P_2O_5	0.38	0.17	0.18	0.15	0.37
LOI	0.80	1.23	0.90	1.33	1.16
S	0.17	0.02	0.02	0.02	0.01
Total	99.71	99.69	99.42	99.62	100.07
ppm					
Ba	338	736	809	816	363
Cl	163	97	108	71	195
Co	30	19	nd	19	24
Cs	0.03	0.82	nd	1.22	0.93
Cr	225	229	258	247	156
Cu	208	30	39	37	42
Ga	21	17	17	17	18
Hf	0.59	0.76	nd	0.46	0.95
Nb	6.7	12.4	10.0	10.0	17.2
Ni	58	76	74	72	56
Pb	14	8	10	6	2
Rb	13	31	31	30	22
Sc	16	13	nd	11	14
Sr	306	349	330	394	475
Ta	0.44	0.70	nd	0.54	1.09
Th	3.5	9.6	9.0	29.6	7.5
U	0.84	0.82	nd	0.74	1.28
V	120	120	119	113	125
Y	24	26	28	23	27
Zn	83	71	73	72	55
Zr	137	167	154	134	194
La	31.1	42.8	32.0	55.0	28.2
Ce	65.7	78.1	62.0	106.9	58.1
Pr	8.44	9.50	nd	12.97	7.42
Nd	33.0	35.2	35.0	44.8	27.7
Sm	6.17	6.25	nd	7.13	5.39
Eu	1.32	1.58	nd	1.45	1.40
Gd	5.36	5.74	nd	5.47	5.25
Tb	0.76	0.85	nd	0.76	0.84
Dy	4.17	4.78	nd	4.21	4.98
Ho	0.82	0.97	nd	0.82	1.04
Er	2.07	2.57	nd	2.16	2.78
Tm	0.31	0.40	nd	0.33	0.43
Yb	1.83	2.40	nd	2.01	2.70
Lu	0.29	0.39	nd	0.32	0.42
(La/Yb)CN	11.48	12.05		18.51	7.05
Eu/Eu*	0.69	0.79		0.68	0.79

elements together with Cs, Hf, Sc, Ta and U, using a PE Sciex Elan 6000 inductively-coupled plasma mass spectrometer (ICP-MS) at Durham University. More precise determinations for Nb and Th in these samples were also obtained by this method.

Because these rocks have been subjected to amphibolite-facies metamorphism, it is possible that there has also been some compositional change. However, if wholesale chemical change did occur, a considerable scattering of results might be expected, influenced by differing amounts of fluid flow. Instead, the samples display a rather restricted compositional range, notably in SiO_2 (56.2–63.7%), Al_2O_3 (13.6–16.2%), Fe_2O_3 total (6.8–9.0%) and MgO (3.7–4.9%). All are relatively calcic, and Na_2O always greatly exceeds K_2O. All show enhanced P_2O_5, reflecting the ubiquitous presence of apatite as an accessory phase. While some of the diagrams that follow use elements such as Na, K and Rb, which are known to be mobile during metamorphism, others use the high field strength elements (HFSE) which tend to be relatively immobile (Winchester & Floyd 1977), except within major shear zones (e.g., Winchester & Max 1984) in which the HFSE and almost every element may be mobilised. However, the consistency of the results suggests that even mobility of the volatile elements may have been restricted in the Demirci metamorphic association, with K fixed in stable biotite and Na fixed in plagioclase during much of the metamorphism.

Because earlier metamorphic segregations may deceptively present the appearance of earlier bedding, or because the compositional variation falls within the range to be expected in a series of metamorphosed sediments, clarification of the origin of these rocks was sought from their compositions, using less mobile elements. Relatively high concentrations of Cr and Ni compared to igneous rocks of intermediate silica content suggests that the Demirci metamorphic association originated as sedimentary rocks and therefore comprises paragneisses. This is illustrated by a Zr/TiO_2-Ni binary plot (Winchester & Max 1982), which, because the samples mostly tend to cluster above the discriminant line separating igneous from sedimentary rocks, establishes that they were of sedimentary origin (Figure 2a). However, on this diagram it must be remembered that the discriminant line is interpreted as a maximum value for igneous rocks: sedimentary rocks directly derived with little weathering from an igneous protolith can also plot below the line in the igneous field. On this basis therefore the Demirci metamorphic association should be regarded as paragneisses, although the source for the original sedimentary rocks could well have been igneous.

SiO_2 contents ranging between 56–64% are relatively low for micaceous psammites and more typical of pelitic and semipelitic rocks. Despite the migmatization, however, there is little evidence of significant SiO_2 depletion as its concentration is consistent with those of the relatively immobile HFSE in comparable unmetamorphosed rocks. However, both Al_2O_3 and K_2O compositions are low for pelitic rocks, and the Demirci paragneisses, which are relatively sodic, plot on a Na_2O/K_2O–SiO_2/Al_2O_3 sandstone type discrimination plot (Pettijohn *et al.* 1972) as metagreywackes (Figure 2b). The low silica values may therefore reflect that the sedimentary protolith of these rocks was very poorly sorted, and thus retained a high proportion of non-silica grains. No evidence of former grain size remains, but with the significant clay fraction indicated by the current composition, it is likely that these rocks were formerly distal turbidites. The use of volatile elements, such as Na and K on this diagram may be questioned, but the high Na/K ratio is entirely consistent with that seen in unmetamorphosed greywackes and there is little evidence that the proportion has been significantly altered.

This conclusion is also backed by their very high Sr/Rb ratios (Figure 2c), which indicate that Sr-rich feldspars in the original sediment had undergone relatively little degradation into (normally Rb-rich) clay minerals, a feature of immature and ill-sorted sediments. Hence, if these rocks were highly immature sediments, they must retain a record of the chemistry of the source rocks from which the sediments were derived. In this respect, the low SiO_2 and Al_2O_3 contents, coupled with the high Fe_2O_3 (total), MgO and CaO concentrations compared to average greywacke figures and high Na/K ratios typical of these gneisses suggests a significant mafic igneous source (Figure 2d). One sample contains particularly high concentrations and is representative of associated para-amphibolites: together the enhanced values of these elements also suggest that a significant proportion of the sediment source may have been of basic igneous composition.

Other indications of the provenance of the original Demirci sediments may be obtained from a

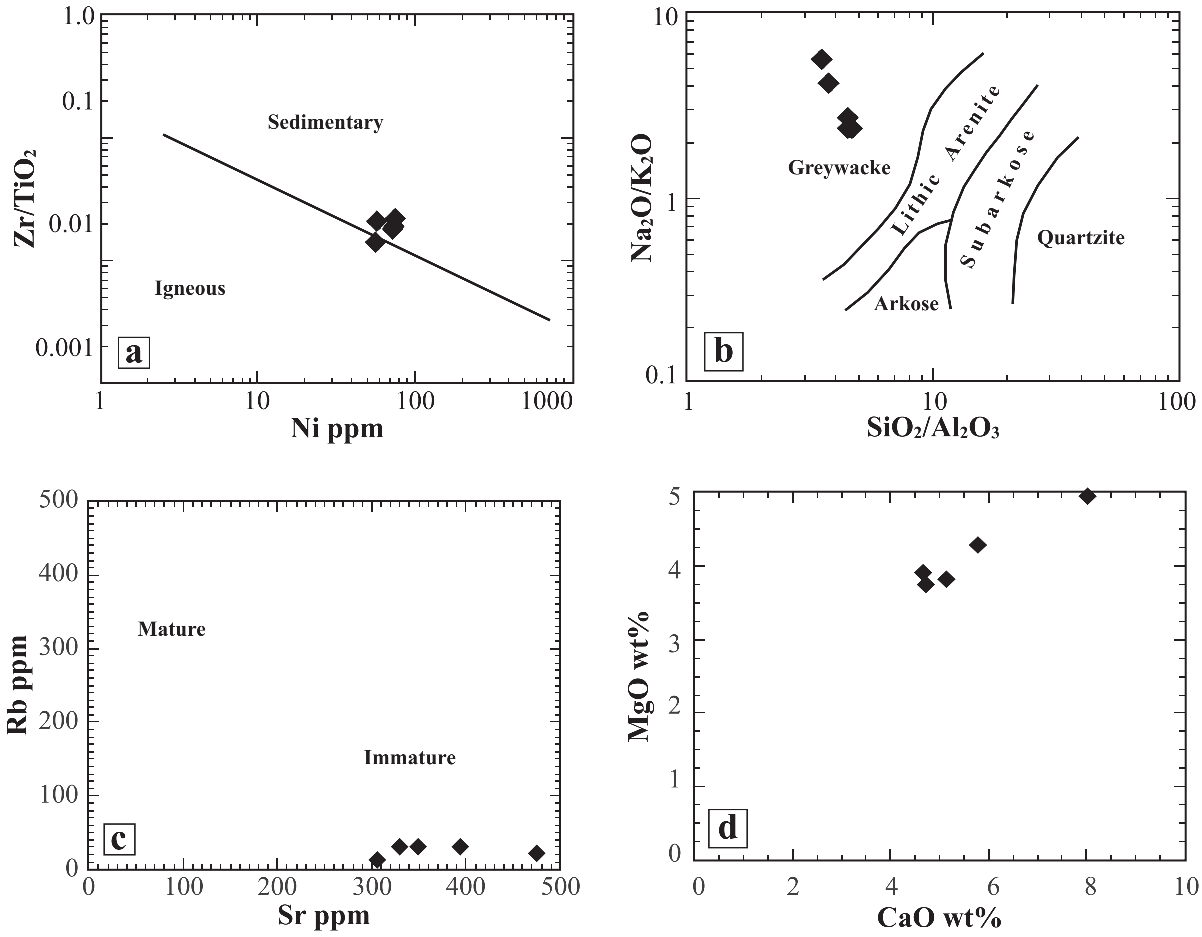

Figure 2. Discrimination diagrams showing the chemistry of the sedimentary rocks from which the Demirci paragneisses are derived: (a) Zr/TiO_2-Ni plot after Winchester & Max (1982) distinguishing igneous from sedimentary fields; (b) Na_2O/K_2O-SiO_2/Al_2O_3 sandstone type discrimination plot, after Pettijohn *et al.* (1972); (c) Rb-Sr diagram illustrating the immaturity of the metagreywackes; (d) MgO-CaO plot indicating the high concentrations of these elements in these rocks.

K_2O/Na_2O–SiO_2 plot (Roser & Korsch 1986), on which they plot within the island arc field (Figure 3a). However, owing to the high CaO content of the Demirci paragneisses, and the well-documented mobility of Na and K during metamorphism, this discriminant plot may not always produce a reliable result. On a TiO_2–Fe_2O_3(total)+MgO plot (Bhatia 1983), employing somewhat less mobile major elements, the Demirci gneisses plot outside all the defined fields, although, with allowance for their high MgO values, they may relate best to the continental arc field (Figure 3b). A La-Th variation diagram (Bhatia & Crook 1986) shows most rocks plotting in the continental island arc field (Figure 3c), while on a Nb-Y diagram albeit one designed to discriminate the tectonic settings of granites (Pearce *et al.* 1984), all the Demirci paragneisses cluster within the volcanic arc field, and away from either the within-plate or ocean ridge fields (Figure 3d). These latter diagrams, using trace elements usually regarded as immobile during metamorphism, are consistent in providing clear confirmation of a continental arc derivation for the source rocks of the Demirci paragneisses, and other discriminant diagrams (not shown here) using Sc, Ta and other relatively immobile trace elements tend to produce similar results.

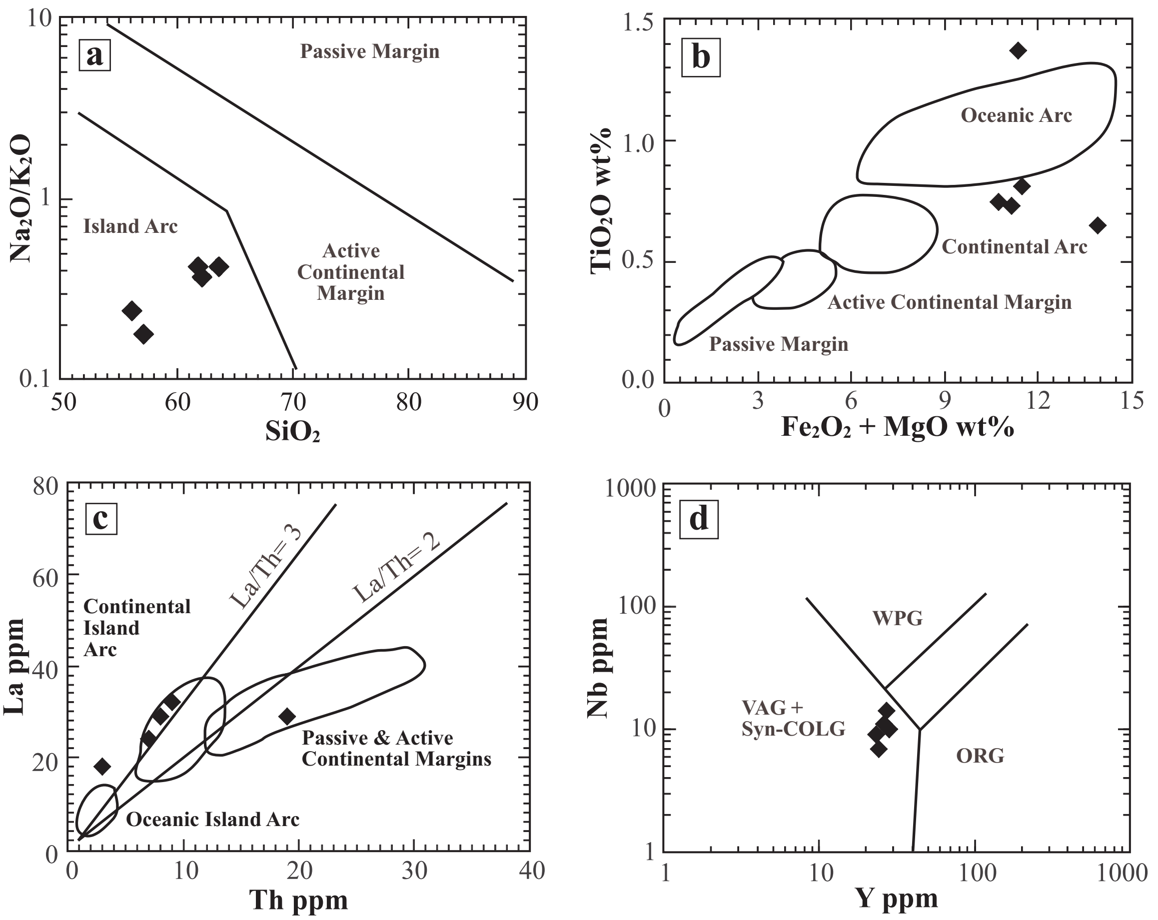

Figure 3. Diagrams to illustrate the likely tectonic setting of deposition of the Demirci metagreywackes. (a) K_2O/Na_2O-SiO_2 diagram, after Roser & Korsch (1986); (b) A TiO_2-Fe_2O_3(total)+MgO diagram, after Bhatia (1983); (c) A La-Th diagram, after Bhatia & Crook (1986); (d) A granite tectonic setting Nb-Y discriminant diagram, after Pearce *et al.* (1984).

Chondrite and NASC-normalised REE profiles for representative Demirci paragneisses are shown in Figure 4a, b. A chondrite-normalised profile is typically sloping, with $(La/Yb)_{CN}$ averaging 12.3 (Figure 4a). A small negative Eu anomaly is also typical, with Eu/Eu* averaging 0.74, but, normalised against the North American Shale Composite (NASC, Gromet *et al.* 1984) the profile is broadly level, with light REE comparable to NASC, and a slight depletion in the HREE (Figure 4b). A similar result emerges from a multi-element spider diagram (Figure 4c), on which the Demirci gneisses, normalised against NASC, tend to be depleted in light ion lithophile elements (LILE). It displays a broadly rising profile, with characteristic Sr and Y peaks, both typical of a continental island arc provenance and reflecting, together with the Rb trough, the immaturity of the sediments already discussed (Winchester & Max 1989).

Tectonic Setting and Discussion

The geochemistry of the Demirci paragneisses therefore consistently provides evidence of sedimentation in a continental arc setting, albeit with a proportion of mafic source material too. However, existing discrimination diagrams do not distinguish whether the oceanic rocks of the suprasubductional Çele meta-ophiolite could have formed in a back-arc basin developed behind and associated with the continental island arc which was also a source for the original Demirci sediments, or whether those rocks were derived from much older arc material

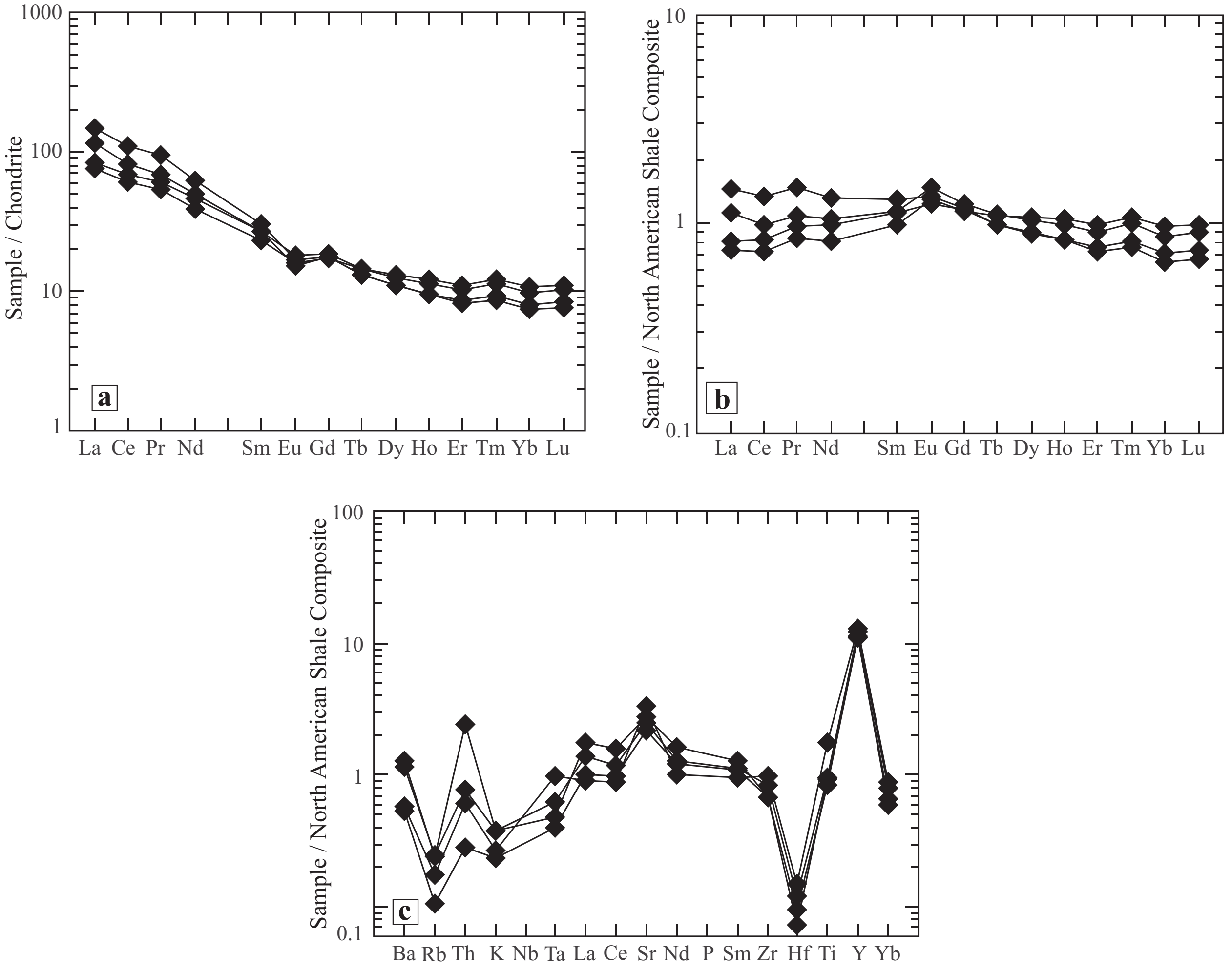

Figure 4. Multi-element diagrams. (a) Chondrite-normalised REE pattern; (b) REE pattern normalised against the (c) A multi-element spider diagram, normalized against North American Shale Composite North American Shale Composite with the same source of normalization factors.

on a former continent passive margin. Only dating of zircon cores separated from and predating overgrowths developed during the amphibolite facies metamorphism might resolve this question decisively.

How this early geology is interpreted depends on the field relationships between the main geological components of the area, and these are notoriously difficult to see because of limited outcrop and extensive vegetation. However, both in the Çele meta-ophiolite and in the related Almacık meta-ophiolite parallel studies have shown structural evidence that the ophiolitic rocks are now disposed in a series of thrust slices, separated by ductile shear zones. Mafic rocks of the Çele meta-ophiolite are geochemically divisible into two distinct units: a lower set of calc-alkaline metabasites cropping out in the core of a NE-trending antiform, overlain by geochemically distinguishable metabasites with the composition of island arc tholeiites, which crop out on both limbs of the antiform (Figure 1). On the western side of the antiform the contact zone between these two metabasites is exposed on the south side of the Karadere valley. These rocks are highly strained, with a mylonitic fabric concordant with the gently west-dipping foliation, and the underlying rocks are also pervasively invaded by granitoid veins. We therefore interpret the two sets of metabasite separated by a high strain zone as two nappes separated by a ductile thrust, and infer that a second ductile thrust separates the base of the Çele meta-ophiolite from the underlying Demirci paragneisses (Figure 1). In this model the serpentinized ultramafic rocks east of the Demirci paragneisses occur at the base of the upper Çele meta-ophiolite nappe, while the lower Çele meta-ophiolite nappe wedges out towards the northeast.

The geometry of the overthrusting indicated by the relative distribution of the thrust slices may clarify their original relationships. If the Demirci paragneisses indeed underlie the entire Çele meta-ophiolite, this can suggest a former spatial relationship before compression. The abundance of the IAT amphibolites argues that the Çele meta-ophiolite formed in a supra-subductional setting, and is therefore likely to be derived from an oceanic back-arc basin. However, because the CAB nappe is now situated between the Demirci paragneisses and the IAT nappe, this suggests that nappe development did not occur as a simple overriding of slices progressively more proximal to a former arc (Figure 5). In a normal oceanic back-arc development, the basalts showing IAT chemistry

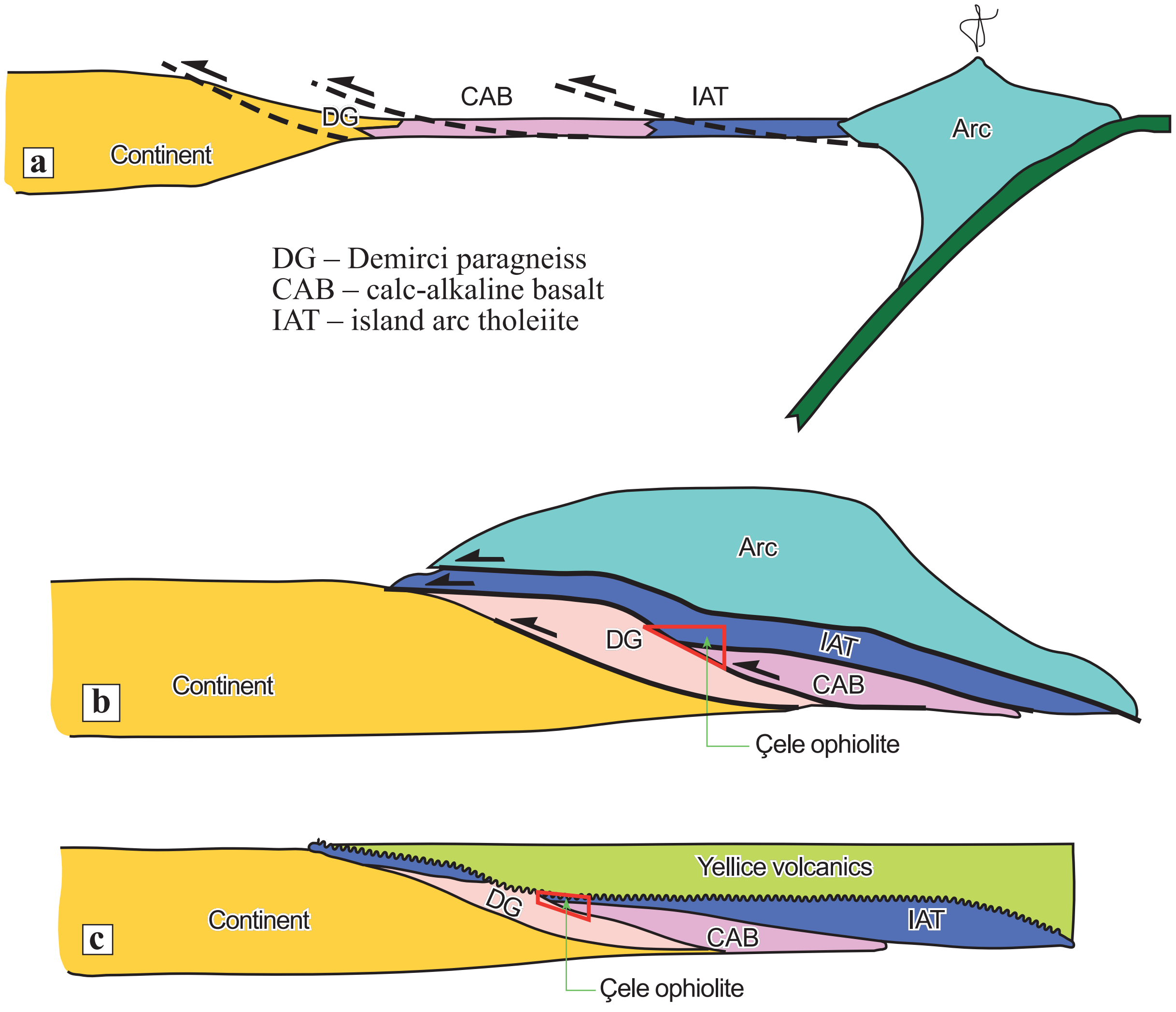

Figure 5. Schematic sections illustrating how the present nappe complex may have formed. (a) The Çele back-arc basin and its pre-thrusting configuration; (b) Nappe structure after thrusting: note that the former arc provides the depth of burial to produce the amphibolite facies metamorphism, and that the ocean floor basalt nappe does not completely separate the Demirci nappe from the island arc tholeiite nappe; (c) Late Neoproterozoic configuration, following erosion of the nappe stack and the deposition of the Yellice metavolcanic association unconformably above the Çele ophiolite. Compass orientations at the time are uncertain and so are not shown.

are likely to have been erupted closer to the arc, where the composition of subducted material is most likely to contribute to their chemical signature. Basalts with CAB chemistry are only likely to develop in back-arc basins which are large enough for them to be little affected by slab chemistry. They should therefore have been produced further from the arc than the IAT basalts. However, in the Çele meta-ophiolite, the metamorphosed CAB are in a structurally lower position, partly adjacent to the Demirci paragneisses, suggesting that the original position of the latter was on the opposite side of the back-arc basin from the related arc. But, since the Demirci paragneiss chemistry suggests derivation from a continental arc provenance, it is possible that the gneisses are derived either from an earlier-formed arc, or from an early stage of development of an arc which subsequently rifted axially to give rise to the Çele back-arc basin. Only an indication of relative provenance ages will resolve which of these possible scenarios is correct.

The absence of any other arc related to the back-arc basin is easily explained. Crustal thickening associated with the formation of the Demirci and Çele meta-ophiolite nappes seems to have developed with the rocks most distant from the former continent forming the highest nappes (Figure 5b). In this construction the former arc would have formed the highest nappes, and would have buried the underlying nappes sufficiently deeply to cause the amphibolite facies metamorphism to which they were subjected. At the base, the Demirci para-autochthon contains migmatitic gneisses metamorphosed under upper amphibolite facies conditions. However, uplift, followed by erosion, then removed the uppermost nappes entirely, and briefly exposed the lower nappes before renewed magmatism associated with the Yellice volcanics buried them once again (Figure 5c). In this model, therefore, the Yellice volcanics, which have generally only been subjected to greenschist facies metamorphism, sit unconformably above the amphibolite-facies rocks of the Çele meta-ophiolite and, as they were erupted after the amphibolite-facies event had ceased, they do not exhibit amphibolite-facies assemblages. They also confirm that the amphibolite-facies metamorphism must predate their Ediacaran time of extrusion.

Conclusions

The amphibolite facies Demirci paragneisses are dominantly metagreywackes, deposited as distal turbidites, in which the original sediment was derived mainly from source rocks with a continental island arc chemical signature, and a subordinate contribution from a mafic source. Their situation, as a para-authochthon at the base of a series of nappes, and overlain in sequence by calc-alkaline basalts and island arc tholeiites of the Çele meta-ophiolite, suggests that they may have formed the continental margin on to which the Çele meta-ophiolite was obducted. Their source rocks may therefore have been part of an older arc system than the one related to the Çele meta-ophiolite, and dating is needed to establish both the age of the source material for the Demirci paragneisses and the timing of their amphibolite-facies metamorphism.

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