

Geochemistry and tectonic environment of the Şarkışla area volcanic rocks in central Anatolia, Turkey

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Abstract

The volcanic rocks of the Şarkışla area in northeastern central Anatolia are associated with volcanoclastics, turbiditic limestones and pelagic-hemipelagic shales of Upper Cretaceous-Palaeocene age. A preliminary geochemical study was undertaken to constrain local tectonic models, and due to the variable altered nature of the volcanics, determine the lithological composition and magma type. Chemically the volcanics are an andesite-dominated suite of calc-alkali lavas, probably developed adjacent to an active continental margin in a local (ensialic back-arc?) basinal area. The volcanic activity was probably related to a postulated magmatic arc just south of the area during the early Tertiary.

KEYWORDS: volcanic rocks, geochemistry, tectonics, Anatolia, Turkey.

Introduction

SUBMARINE volcanic extrusive rocks occur at different stratigraphic levels within an Upper Cretaceous to Palaeocene flysch sequence in the Şarkışla province of central Anatolia, Turkey (Fig. 1). The extrusive lavas are frequently associated with volcanoclastics and alternate with thick sequences of turbiditic limestones and pelagic to hemipelagic shales. The sequence has been folded by Tertiary orogenic events and exhibits local erosion levels from the Miocene to the present. Details of the stratigraphic relationships and the tectonic evolution of the area has been described by Gökten (1983*a,b*, 1984) who considered that it represented an ensialic marginal basin.

Petrographically the lavas at the lowest levels of the sequence are augite andesites, whereas volcanics of more basaltic character become common towards the top (Gökten, 1983*a*). All the volcanics have been extensively altered, largely by reaction with seawater and subsequently during burial, up to the pumpellyite facies of metamorphism. Common alteration phases include albite

(replacing relict intermediate plagioclase), chlorite, actinolite, silica, iron oxides and leucoxene. Pumpellyite and also various zeolites are less common and appear to represent a later phase of alteration superimposed after the deformation of the initially degraded volcanics. Locally carbonate and kaolinite replace plagioclase and represent the final phase of secondary alteration.

Objectives and methods

This paper represents a preliminary study of the geochemistry of the volcanics with the object of determining their eruptive setting and thus constrain tectonic models for a segment of central Anatolia (e.g. Gorur *et al.*, 1984). Also, due to the degree of alteration, many of the primary petrographic features are obscured and their original lithological nature is difficult to interpret. In both cases, abundances and ratios of trace elements that are relatively stable during alteration processes can be employed to determine their rock type and tectonic environment (e.g. Pearce

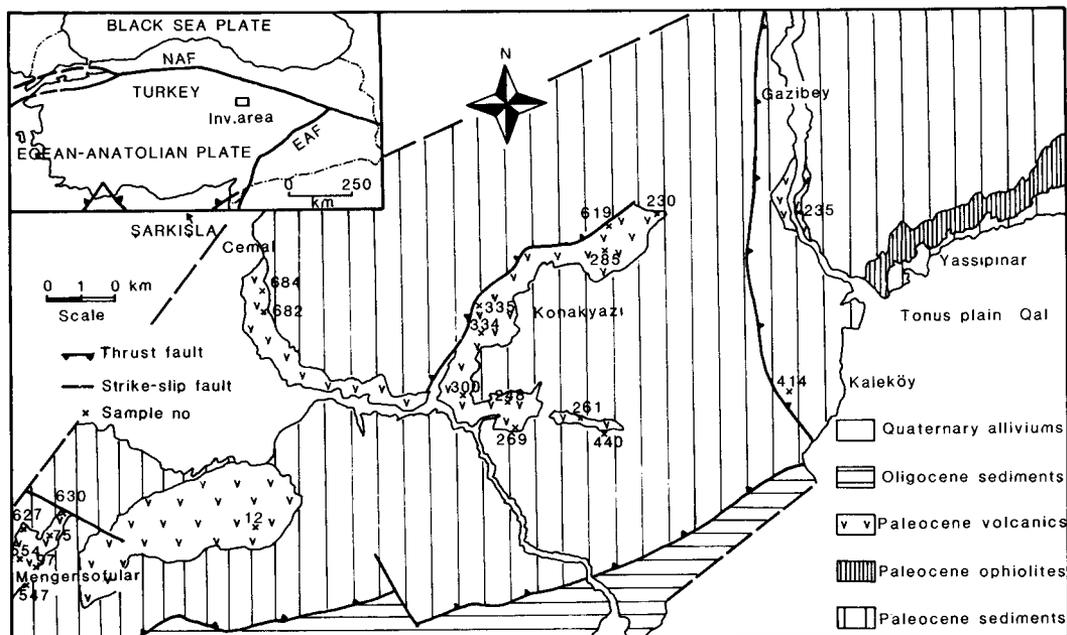


FIG. 1. Geological map of the Şarkışla area and location of volcanic samples. Inset shows position of investigated area in central Turkey.

and Cann, 1973; Floyd and Winchester, 1975; Winchester and Floyd, 1977).

Twenty-one volcanic samples were initially collected for this study from Upper Cretaceous–Palaeocene sequences throughout the area (localities in Fig. 1). As far as possible samples were selected that did not show visible signs of recent or present-day weathering and, in particular, all highly oxidized volcanics, strongly reddish or purple in colour, were rejected. However, petrographic examination showed that all analysed samples were variably oxidized, although in some cases it could be demonstrated that this represented post-consolidation alteration rather than recent weathering, being unrelated to microfractures and overprinted by late carbonate and zeolite veinlets.

Major and trace elements were analysed by XRF spectrometry on an ARL 8420 quantumeter at the Geochemical laboratories, University of Keele, using international and in-house standards of appropriate composition. Major elements were determined on a fused glass disc (method modified after Norrish and Hutton, 1969) and trace elements in a pressed powder pellet (method after Leake *et al.*, 1969). Loss-on-ignition (LOI) was determined in a furnace at 1200°C. Iron oxides

(FeO and Fe₂O₃) have been proportioned on the basis of an Fe₂O₃/FeO ratio of 0.15. Due to the altered nature of the samples, CIPW norms were computed (Kelsey, 1965) using this oxidation ratio and after recalculation to an anhydrous composition.

Geochemical characteristics

Geochemical data for the volcanics are presented in Table 1. The chemical effects of alteration are seen in the high LOI (and CO₂, when determined) and Na₂O contents, together with highly variable abundances of CaO, K₂O, Rb and Sr. These elements are often considered mobile during post-consolidation, low-grade alteration (e.g. Floyd and Winchester, 1975) and in this case display wide elemental variation and non-magmatic distributions relative to fresh rocks over the same compositional range. For example, the total alkali content is high and variable for a small SiO₂ range (Fig. 2a), and both K₂O and Rb show large coefficients of variation (52% and 74% respectively) relative to only 21% for a 'stable' oxide like TiO₂. Similarly, the disruption of typical covariant magmatic trends by alteration can be demonstrated by low correlation coefficients for mobile-

Table 1 Geochemical and normative data for Paleocene calc-alkali volcanics from the Şarkışla area, Turkey.

Major oxides in wt.%, trace elements in ppm; - = not determined, O = below detection limit (2-3 ppm for Rb, Nb, Pb and Th)

Oxides	EG12	EG75	EG97	EG230	EG235	EG248	EG261	EG269	EG285	EG300	EG334	EG335	EG414	EG440	EG547	EG554	EG619	EG627	EG630	EG682	EG684
SiO ₂	48.72	48.89	54.51	62.02	58.30	47.83	48.67	52.10	48.20	48.94	50.71	63.71	59.07	49.74	48.08	47.36	46.96	49.18	50.68	48.70	46.56
TiO ₂	0.94	0.94	0.64	0.59	0.58	0.92	1.00	0.82	0.69	0.80	0.65	0.55	0.72	0.73	1.19	1.22	0.79	1.21	0.87	1.02	0.70
Al ₂ O ₃	15.20	14.57	17.42	16.50	17.22	13.66	13.55	17.86	12.06	12.75	14.03	17.52	16.78	13.80	16.83	13.84	10.73	16.72	15.12	16.74	10.99
Fe ₂ O ₃	0.29	0.27	0.21	0.20	0.18	0.27	0.31	0.26	0.24	0.23	0.21	0.14	0.16	0.18	0.27	0.29	0.25	0.26	0.25	0.25	0.28
FeO	7.53	7.00	5.47	5.36	4.60	7.16	7.91	6.76	6.83	5.84	5.37	3.77	4.07	4.54	7.14	7.55	6.43	6.78	6.63	6.54	7.27
MnO	0.16	0.15	0.16	0.11	0.13	0.12	0.14	0.15	0.13	0.12	0.10	0.10	0.13	0.13	0.12	0.13	0.13	0.12	0.13	0.12	0.13
MgO	7.89	5.74	1.60	0.92	2.81	10.12	7.39	3.67	9.03	7.66	5.89	0.96	1.71	1.44	5.64	9.91	9.56	4.37	5.74	4.66	9.82
CaO	8.48	8.55	7.53	3.92	5.67	9.17	11.12	4.31	14.38	12.93	11.53	3.15	7.37	12.69	6.94	10.07	16.86	9.33	10.65	9.42	16.04
Na ₂ O	3.89	2.92	5.92	5.12	5.49	2.03	2.55	4.29	1.23	2.75	4.91	8.76	6.36	6.77	4.51	2.52	2.11	3.64	3.32	4.50	1.34
K ₂ O	1.99	5.02	1.81	2.64	0.46	2.59	2.03	4.38	2.87	2.57	1.04	0.17	0.65	0.60	3.34	2.14	1.16	2.99	2.85	1.80	2.09
P ₂ O ₅	0.46	0.41	0.16	0.23	0.21	0.28	0.42	0.85	0.37	0.62	0.30	0.13	0.17	0.34	0.38	0.62	0.23	0.51	0.43	0.50	0.30
LOI	3.76	5.38	5.30	2.36	3.77	4.87	3.99	4.69	4.16	1.67	2.11	1.54	3.14	0.50	5.32	3.82	4.09	4.39	3.08	4.98	3.87
CO ₂	n.f.	n.f.	n.f.	n.f.	n.f.	n.f.	n.f.	n.f.	n.f.	n.f.	2.40	3.55	n.f.	n.f.	8.27	n.f.	n.f.	n.f.	n.f.	n.f.	n.f.
SUM	99.31	99.84	100.73	99.97	99.42	99.04	99.09	100.11	100.22	99.28	100.39	100.50	100.33	99.73	99.76	99.52	99.30	99.50	99.75	99.23	99.39

Trace elements:

Rb	71	147	35	35	9	0	68	152	89	80	20	2	15	14	149	56	41	80	81	56	0
Sr	894	883	461	1020	1842	-	1667	1663	913	683	476	386	454	614	590	658	726	894	998	673	425
Y	27	23	18	23	22	-	18	25	25	24	20	26	27	22	26	25	19	29	26	27	21
Zr	175	189	83	129	150	150	170	228	118	294	163	186	162	164	157	392	92	216	167	207	96
Nb	10	15	2	7	3	-	7	15	9	15	12	5	6	9	10	19	0	13	8	11	0
Cr	244	293	66	54	-	-	-	-	-	285	304	54	112	286	84	540	634	84	245	60	465
Ni	110	140	25	26	-	-	-	-	-	148	218	16	20	36	85	229	155	56	114	47	231
Cu	60	89	78	42	-	-	-	-	-	57	22	48	40	37	50	386	174	92	68	81	158
Ga	17	16	15	15	-	-	-	-	-	16	15	13	14	13	15	21	10	20	17	18	12
Zn	79	71	42	41	-	-	-	-	-	65	51	55	62	36	67	99	49	73	68	78	77
V	200	140	144	91	-	-	-	-	-	173	118	101	148	148	174	203	199	194	194	213	455
Pb	28	56	11	11	-	-	-	-	-	32	34	11	10	25	43	85	1	37	36	28	0
Th	37	23	3	10	-	-	-	-	-	31	23	8	12	15	22	13	0	24	31	26	0

CFM Norms:

Qtz	0.00	0.00	0.00	10.60	7.48	0.00	0.00	0.00	0.00	0.00	0.00	3.44	3.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	12.30	31.39	11.20	15.97	2.84	16.24	12.60	27.11	17.64	15.19	6.15	1.01	3.95	3.55	20.88	13.20	7.19	18.56	17.41	11.28	9.06
Ab	24.36	7.83	45.00	44.36	48.55	18.11	20.31	34.97	3.42	21.29	40.97	74.88	55.35	57.28	18.82	17.21	2.02	21.30	19.92	26.29	0.00
An	18.97	12.51	16.35	14.58	21.93	21.77	20.52	16.58	19.67	14.86	13.17	8.06	15.75	5.49	18.54	21.38	18.62	16.73	21.02	17.19	21.49
Ne	5.45	9.92	4.04	0.00	0.00	0.07	1.28	1.65	4.01	1.07	0.31	0.00	0.00	0.00	11.68	2.74	9.06	5.99	4.94	7.63	6.43
Di(Mg)	12.11	15.18	6.79	0.84	2.76	14.71	18.50	0.00	30.44	17.01	10.49	2.02	8.20	0.92	8.80	15.97	41.74	11.39	17.36	12.22	36.77
Di(Fe)	5.64	8.94	11.55	2.42	2.22	5.05	9.62	0.00	11.53	7.33	5.49	3.80	9.07	1.59	5.14	5.70	13.73	8.04	9.69	8.03	13.68
En	0.00	0.00	0.00	1.96	6.04	0.00	0.00	0.00	0.00	0.00	0.00	1.48	0.58	2.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fs	0.00	0.00	0.00	6.49	5.58	0.00	0.00	0.00	0.00	0.00	0.00	3.19	0.74	5.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fo	10.47	5.67	0.72	0.00	0.00	13.97	7.54	6.71	6.51	7.85	6.86	0.00	0.00	0.31	4.72	4.65	5.98	7.56	12.87	3.95	4.31
FA	6.16	4.22	1.55	0.00	0.00	6.06	4.56	7.62	3.12	4.28	4.54	0.00	0.00	0.68	5.57	5.81	1.64	3.85	3.33	3.86	2.81
Hy	1.56	1.47	1.13	1.09	0.95	1.51	1.65	1.40	1.41	0.33	0.30	0.75	0.83	0.32	1.50	1.56	1.34	1.41	1.36	1.37	1.51
Il	1.87	1.89	1.27	1.15	1.15	1.83	2.00	1.63	1.36	1.52	1.23	1.05	1.41	1.39	2.39	2.42	1.57	2.41	1.71	2.05	1.39
Ap	1.14	1.03	0.40	0.56	0.52	0.73	1.05	2.11	0.91	1.47	0.71	0.31	0.41	0.81	0.95	1.53	0.57	1.27	1.05	1.25	0.74
Ca	-	-	-	-	-	-	-	-	-	5.46	8.07	-	-	-	18.81	-	-	-	-	-	-

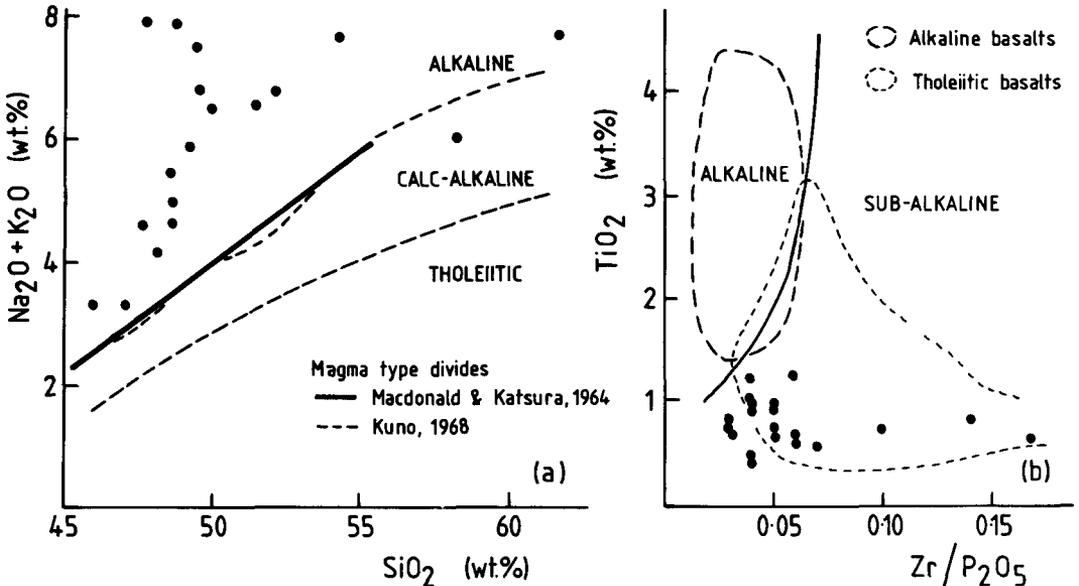


FIG. 2. Element plots that distinguish between alkaline and subalkaline magma types. Alkali metasomatism places the Şarkışla area volcanics in the alkaline field (diagram a), whereas using stable elements they are subalkaline in character (diagram b; magma type divide from Floyd and Winchester, 1975).

immobile incompatible element pairs (e.g. Rb-Zr, $r = 0.3$) relative to good correlations between pairs of immobile elements (e.g. TiO_2 -Zr, $r = 0.8$). The effects of alteration on the major elements is also discernable in the range of recalculated normative compositions and the often high computed contents of nepheline and calcite (Table 1).

If taken at face value, the SiO_2 contents (which range from about 46–64 wt. %), together with the abundance variation of stable elements (Ti, Zr, Y, Nb, and to a lesser extent, Cr, Ni, V) suggest that a range of lithological types are present. The elemental range is consistent with the petrographic evidence that both basaltic and andesitic lava types are present within the volcanics.

As seen in Fig. 2a the volcanic rocks would be classified as alkaline on the basis of their high total alkali content, although this is almost certainly due to post-consolidation metasomatism. Using stable elements and ratios (Fig. 2b) they are clearly sub-alkaline in character with high $\text{Zr}/\text{P}_2\text{O}_5$ values (~ 0.1), indicating that some of the volcanics have well-evolved non-basaltic compositions. The stable Zr/TiO_2 ratio (Winchester and Floyd, 1977) can be employed to determine the approximate proportions of basic and intermediate rocks within the sample set and is a more reliable first-order fractionation index than FeO^*/MgO (Miyashiro, 1975) which is liable to change with extreme alteration (Çapan and Floyd, 1985). On the basis of a Nb/Y ratio between 0.3 and 0.7 for the samples, lithological divisions have been drawn in Fig. 3 at specific Zr/TiO_2 ratios (taken from Winchester and Floyd, 1977, Fig. 6) and show that the majority of the samples are indeed andesitic, with minor basalts and dacites. Samples falling outside the envelope (Fig. 3) are highly altered mineralogically and chemically relative to the rest, a feature reflected in their apparently anomalous FeO^*/MgO ratios, together with low atypical K_2O and Rb contents.

The primary chemical features of the volcanics as a whole include: lack of marked Fe-enrichment (FeO^*/MgO is generally restricted for the less altered samples); low and restricted abundance distribution for TiO_2 , Y, Nb and V relative to Zr throughout the suite from basalts to dacites; generally low values for Zr even in the most evolved rocks (rarely being >250 ppm even in the dacites) and moderate levels of Cr and Ni (except for two basalt samples). These characteristics are more typical of calc-alkali rocks than tholeiitic and indicate that the samples studied here are a metamorphosed andesite-dominated suite of calc-alkali volcanics. Some of the above chemical

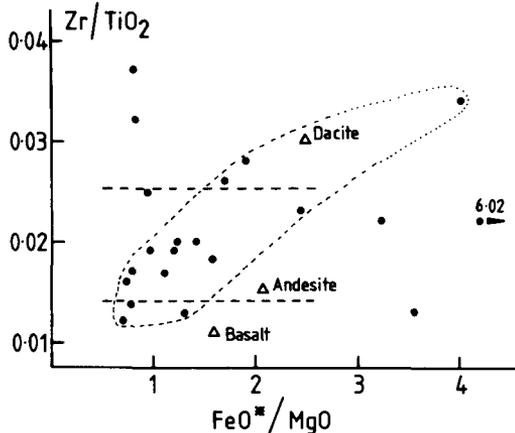


Fig. 3. Characterization of volcanic lithologies using stable (Zr/TiO_2) and less stable (FeO^*/MgO) fractionation indices—after Winchester and Floyd (1977) and Miyashiro (1975) respectively. Average values for calc-alkali basalts, andesites and dacites calculated from data by Le Maitre (1976) and Winchester and Floyd (1977).

features are shown in Fig. 4 together with average values for calc-alkali basalts, andesites and dacite which are not dissimilar to the corresponding rocks identified in the Şarkışla area volcanics. As seen in the Cr-Zr plot (Fig. 4) no negative correlation is developed between these elements as might be expected if the three volcanic lithologies were related via some progressive crystal fractionation process involving pyroxene or amphibole. Although the disruption of a fractionation trend could be a feature of the alteration, stable element plots of TiO_2 and Nb versus Zr (Fig. 4) suggest that each lithology defines its own positive trend unrelated to the others. This feature of the chemistry displayed by some incompatible elements implies that the basalts, andesites and dacites are not cogenetic and could have been developed independently, for example, by variable partial melting. However, this suggestion can only be considered tentative at this stage in view of the small sample set used.

One further point of interest is the apparent enrichment of a dacite (sample EG554, Table 1) in Cu, Zn, Pb, and to a lesser extent Cr and Ni. Dacitic rocks are often the host lithology for porphyry-type copper deposits (Davenport and Nichol, 1973) and the high levels of base metals recorded in this sample relative to the rest of the volcanics indicates limited, localized mineralization, although no economic deposits are known in the adjacent area.

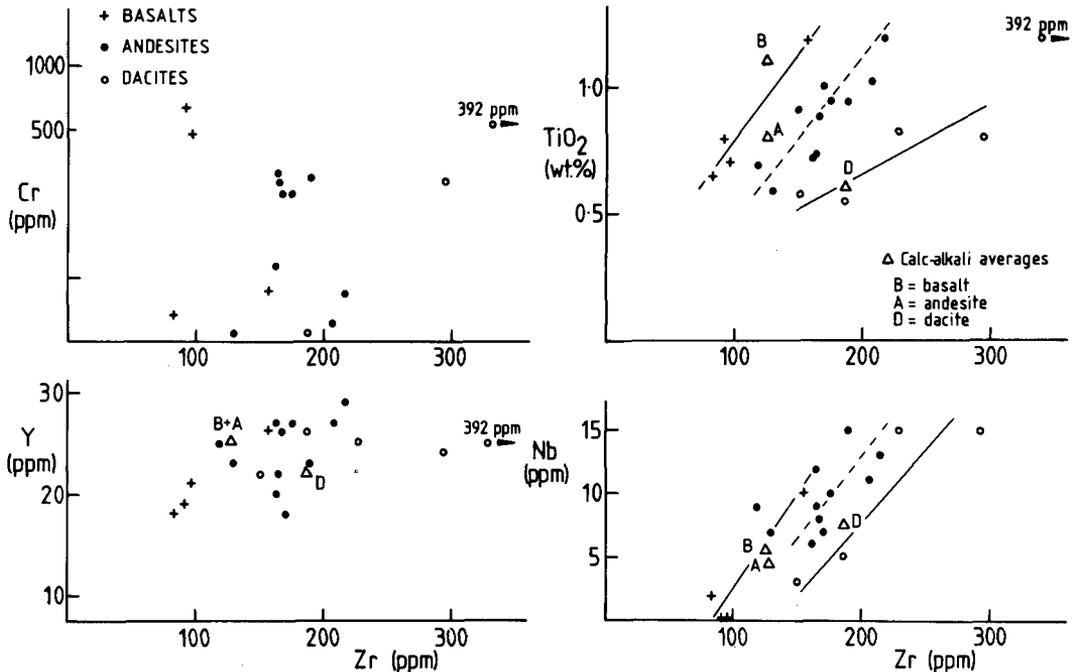


FIG. 4. Plots of Cr and incompatible elements relative to Zr as a stable fractionation index. Tentative trend lines connect samples of the same lithology in the TiO_2 and Nb diagrams. Average calc-alkali compositions from Winchester and Floyd (1977).

Chemical discrimination of tectonic environment

As seen in Fig. 5 the volcanics plot in the calc-alkali arc field in three of the discrimination diagrams, although high Zr/Y ratios (generally ~ 5 – 10) imply a within-plate eruptive setting. Although the majority of the volcanics are of andesitic composition and not basaltic, the diagrams can be employed with caution as (a) calc-alkali basalts and andesites have relatively similar concentrations of elements such as Ti, Y, Zr, and thus plot in roughly the same area of the diagram, and (b) non-basaltic differentiates of the calc-alkali suite produce an observed trend away from and out of calc-alkali arc space in the diagrams towards relatively higher Zr contents and not into any other environmental field. The high and variable Zr/Y ratio and apparently within-plate feature indicated by the (Zr/Y) –Zr plot (Fig. 5) is a characteristic of calc-alkali volcanics formed in a continental arc (margin) environment (Pearce, 1983; Çapan and Floyd, 1985). As arc volcanism is subduction-related, dehydration of the downgoing oceanic slab enriches the overlying mantle wedge (and subsequently magmas generated here) in large-ion-lithophile (LIL) elements

(Saunders and Tarney, 1979). Thus, one chemical feature of subduction-related volcanics is an enrichment in LIL elements relative to high field strength (HSF) elements such that high LIL/HFS ratios are typical of this eruptive setting (Pearce, 1983; Saunders and Tarney, 1984). The Th/Nb ratio can be used as an example of a stable element LIL/HFS ratio and is generally between 1.4 and 2.4 for the volcanics studied here and indicative of subduction enrichment relative to the much lower values of about 0.07 for MORB (Bougault *et al.*, 1979).

Discussion and conclusions

In summary, geochemical characterization and tectonic environment discrimination indicates that the volcanics of the Şarkışla area are an andesite-dominated non-comagmatic suite of calc-alkali arc lavas developed on continental crust. However, their limited stratigraphic extent and intimate association with a thick pile of turbidites, deep-water shales and volcanoclastics suggests they do not represent the main arc structure, but possibly minor related activity in an adjacent basinal area. In terms of their regional setting this

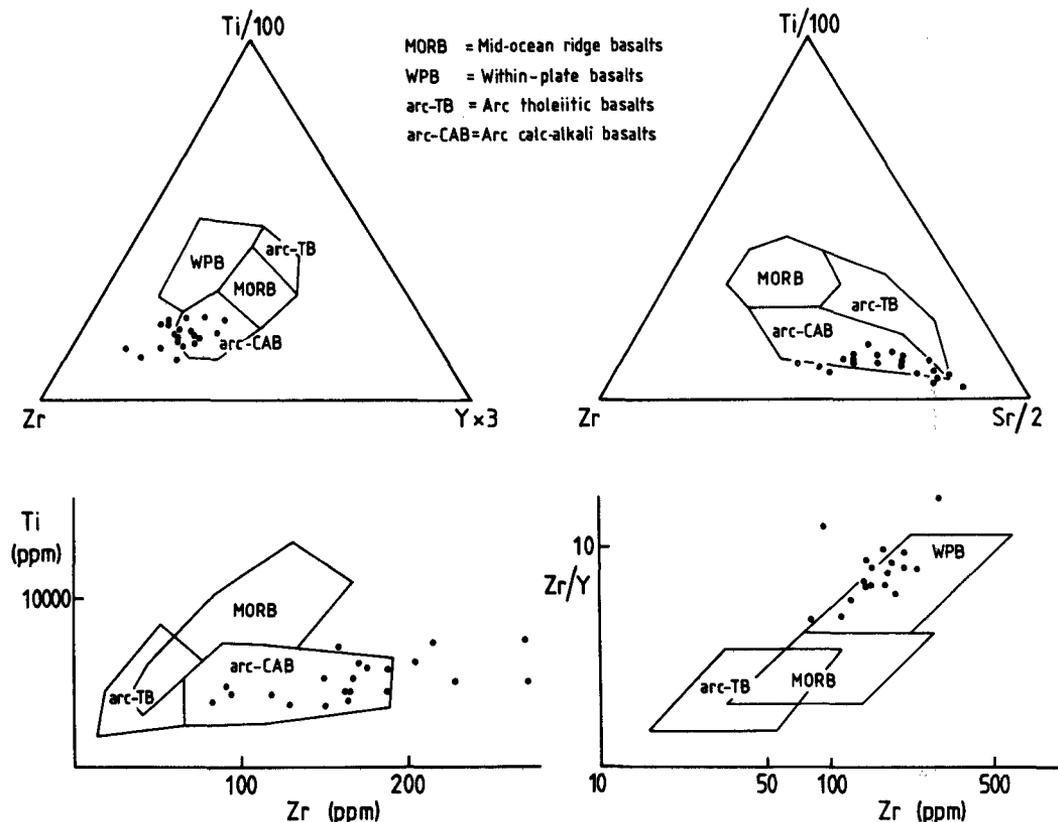


FIG. 5. Tectonic environment discrimination diagrams. Field boundaries from Pearce and Cann (1973) and Pearce and Norry (1979). The more-evolved rocks plot outside the drawn fields towards high Zr values. Although mobile, Sr, has not caused any change in the designated eruptive setting relative to the other plots.

was probably the southern part of the Anatolide-Tauride platform of Şengör and Yılmaz (1981) during the Upper Cretaceous-Palaeocene. Also, during this time period, Gorur *et al.* (1984) envisage northwards subduction below a magmatic arc that would be just to the south of the study area. The volcanics of the Şarkışla region may thus be related to the postulated arc of Gorur *et al.* (1984). Further evidence for Eocene calc-alkali arc volcanism is also seen well to the south in the Malatya district (Aktas and Robertson, 1984).

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