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The Triassic Volcanic Rocks of Tyros, Zarouhla, Kalamae, and Epidavros, Peloponnese, Greece

by *Georgia Pe-Piper*[1]

Abstract

Mid Triassic volcanic rocks occur in several inliers in the nappe sequence in the Peloponnese, Greece. They form part of the Tyros Beds of the Phyllite Series. The petrography and geochemistry of rocks from Tyros, Zarzouhla, Kalamae and Epidavros are described and compared with the previously studied volcanic sequence of Lakonia. The rocks at Tyros are principally coarse pyroclastics with rare andesite flows; at Epidavros are acid air-fall tuffs and pyroclastics. Mostly lavas have been sampled at Zarouhla and Kalamae.

Although there has been considerable mobility of some major elements, major and trace element chemistry suggest that the rocks from Kalamae and Zarouhla are subduction related tholeiites, while those at Tyros are generally calc-alkaline with some alkaline characteristics.

All the volcanic rocks, except those at Epidavros, have experienced low-grade greenschist facies metamorphism during the alpine metamorphism of the Phyllite Series. The volcanic rocks and metamorphism of the Tyros Beds is similar to that observed in the Phyllite-Quartzite Series of central and eastern Crete, including the Ravdoucha beds. The two areas have probably had a similar geological history.

Keywords: metavolcanic rocks, geochemistry, greenschist facies, triassic, Peloponnese

Introduction

Volcanic rocks of late Paleozoic to early Mesozoic age are preserved in small inliers over a wide area of Greece. Many are demonstrably of mid-Triassic age (Brauer et al., 1980; Pe-Piper, 1982). The best known outcrops in the external Hellenides are in the Lakmon Mountains of N.W. Greece (Pe-Piper, 1983) and the Stefania region of Lakonia (Panagos et al. 1979; Pe-Piper et al., 1982; Pe-Piper & Kotopouli, 1981). This paper describes the other inliers of volcanic rocks in the external Hellenides of the Peloponnese: at Tyros, Zarouhla, Kalamae and Epidavros (Fig 1).

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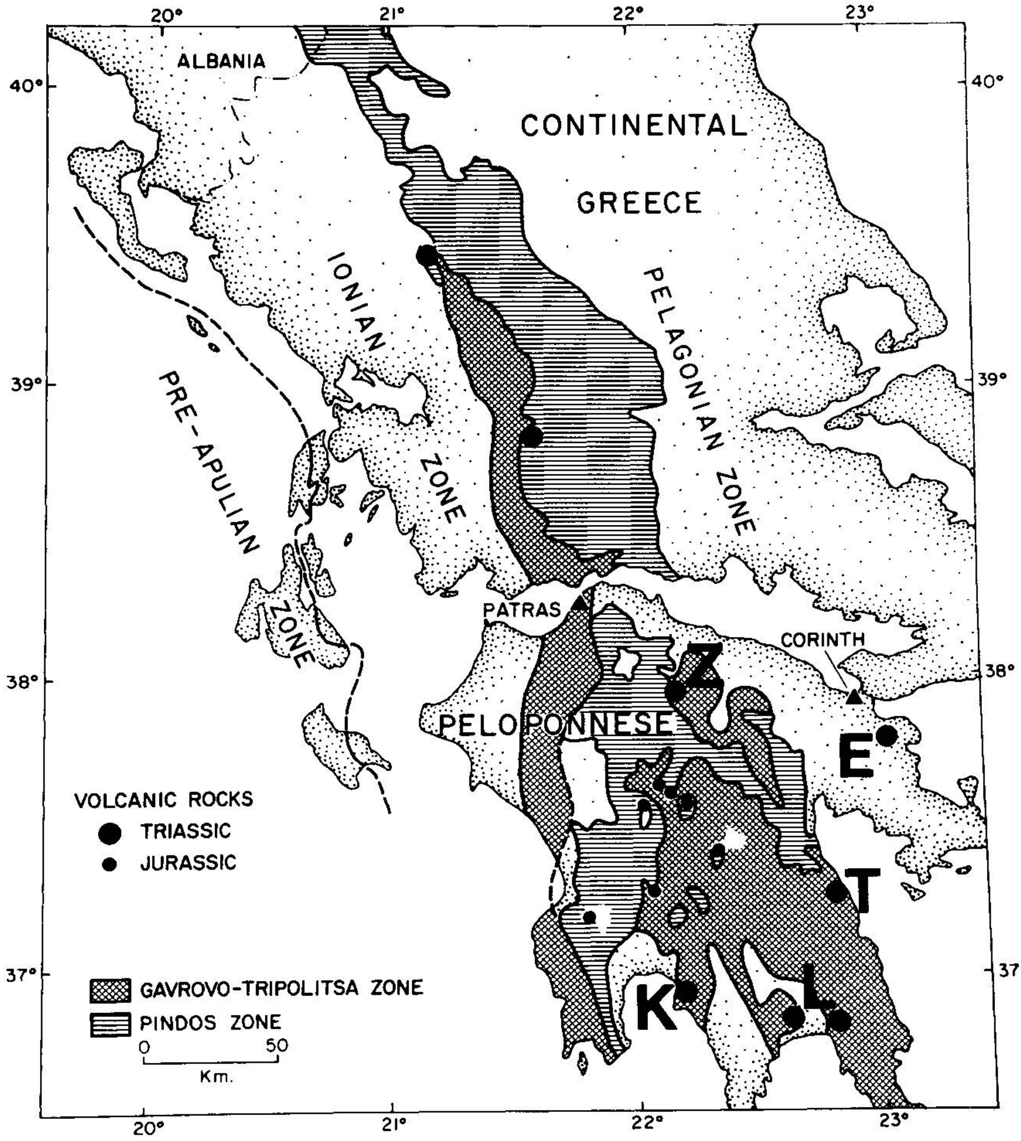

Fig. 1 Generalized geological map of western Greece showing distribution of probable Triassic volcanic rocks. E = Epidavros, K = Kalamae, L = Lakonia (Pe-Piper et al., 1982), T = Tyros, Z = Zarouhla.

The external Hellenides of western Greece (Fig. 1) comprise a stack of nappes of mostly Mesozoic sediments resting on an autochthonous foreland (Aubouin, 1959; Smith & Moores, 1974; Jacobshagen et al., 1978). The term "isopic zone" has been widely used to refer to each successive nappe with a distinctive facies succession. The autochthonous foreland is termed the pre-Apulian isopic zone. It is succeeded westwards by the Ionian and Gavrovo-Tripolitsa isopic zones of the Western Hellenic nappes, and the Pindos, Parnassos and Pelagonian isopic zones of the Central Hellenic nappes. The Carboniferous-Triassic Phyllite Series of the Peloponnese at the base of the West Hellenic nappes may form an additional isopic zone, or may be the basement of the Gavrovo-Tripolitsa zone.

There is no direct evidence for the age of the volcanic rocks at Zarouhla, Kalamae and Tyros. They are believed to be of mid-Triassic age on the basis of their association with the Phyllite Series and similarity with the Phyllite Series volcanic rocks of Lakonia, which rest unconformably on Permian sediments (PANAGOS et al., 1979) and may be interbedded with mid-Triassic sediments (BRAUER et al., 1980).

The Phyllite Series in the Peloponnese shows varying grades of both blueschist and greenschist facies metamorphism. Higher grade rocks include glaucophane-garnet-chloritoid schists (KATAGAS, 1980; SEIDEL et al., 1982) and chlorite-muscovite-chloritoid-paragonite schists (PANAGOS et al., 1979). The rocks of lower grade of metamorphism are referred to as the Tyros Beds (LEKKAS & PAPANIKOLAOU, 1978) and include the volcanic rocks at Tyros and Lakonia in which the dominant metamorphic phases include chlorite, pumpellyite and epidote. The metamorphism is apparently entirely of alpine age, on the basis of radiometric dating (PANAGOS et al., 1979; SEIDEL et al., 1982). (The rocks which PANAGOS et al. (1979) interpreted as Hercynian basement appear on the basis of their metamorphic assemblage to be rocks of the Phyllite Series with normal alpine metamorphism that are in tectonic contact with Tyros Beds.)

The Phyllite-Quartzite Series of Crete (SEIDEL et al., 1982) appears to be correlative with the Phyllite Series of Lakonia. It shows a similar range of metamorphic facies, and appears to be of similar age. The Ravdoucha sequence (SANNEMANN & SEIDEL, 1976) is similar to the less metamorphosed parts of the Tyros Beds.

The volcanic rocks of the Tyros Beds of Lakonia are a subaerial suite of andesitic pyroclastics, with less common acid pyroclastics and basic lavas and hypabyssal intrusions (PE-PIPER et al., 1982). Most have a metamorphic mineral assemblage of chlorite + epidote + quartz + hematite + albite + K-mica, with pumpellyite in some samples. A rare chlorite-clinozoisite-actinolite assemblage also occurs (PE-PIPER & KOTOPOULI, 1981).

In a previous study (PE-PIPER, 1982), selected trace element abundances were used to infer the regional tectonic setting of the mid-Triassic volcanism. It was concluded that the volcanism was related to a north-eastward dipping subduction zone and associated back-arc basin in the Pindos Zone. In this paper, the volcanic history and primary geochemistry and mineralogy, of the four inliers are described and interpreted in more detail.

Field Occurrence

TYROS

Volcanic rocks occur in a narrow coastal strip some 7 km long and 1 km wide between Tyros and Leonidion. They outcrop along the main highway, on the coast, and in stream sections.

The volcanic rocks are predominantly pyroclastics with minor andesite flows. The dominant lithology (55%) is agglomerate, with a range of basic and intermediate clasts up to 80 cm in size. Most are greenish in colour, but some are purplish. Well bedded air-fall dacitic tuffs and ashes (35%) are associated with the agglomerates. Most are purple; the remainder are greenish. Very rare (1%) clast-supported volcaniclastic cobble conglomerate has also been seen. Andesites and rarer basalts occur in flows up to 16 m thick. They are often porphyritic, and occasionally are amygdaloidal. The tops of flows are generally reddened.

The more competent lithologies occur in regularly dipping sequences cut by normal faults. However, some pyroclastics show isoclinal folding. Similar folding, with a poorly developed axial planar cleavage, occurs in psammites and semipelites of the Tyros Beds that outcrop in the same area, and contain rare volcanic clasts.

Because of the complex structure and discontinuous character of the outcrops, total stratigraphic thickness is unknown: it exceeds 200 m, and may be much greater.

ZAROUHLA

Metavolcanic rocks outcrop within the Zarouhla or Feneos window in the Pindos nappe of the Northern Peloponnese, in the area immediately south of the village of Zarouhla. They interbed with schists and psammites of the Phyllite Series (DERCOURT et al., 1978), and are overlain by upper Triassic sediments of the Gavrovo-Tripolitsa zone (DERCOURT, 1964). Outcrops of the metavolcanites are tectonised, and the rocks are cleaved, so that their original nature is uncertain: petrographically, they consist of basalts and andesites.

KALAMAE

Metabasalts occur as abundant float over an area of about one square kilometer at Verga, near Kalamae (FYTROLAKIS, 1970). They are associated with low grade metamorphic rocks of the Phyllite Series, and thus are probably similar to the rocks of Zarouhla and Tyros.

EPIDAVROS

Acid pyroclastic rocks at least 10 m thick outcrop in the cores of two anticlines near Epidavros (Argolis), at the theatre at Ancient Epidavros and east of Adhami. The rocks are almost undeformed, and are conformably overlain by limestone of late Skythian age (BANNERT & BENDER, 1968). The Phyllite Series is not known from Argolis; the stratigraphic position of these volcanic rocks suggests that they may be the same age as the mid-Triassic volcanic rocks of the Tyros Beds (PE-PIPER, 1982). Outcrops are poor: bedded air-fall tuffs predominate at Adhami, ignimbrites are seen at Ancient Epidavros.

Petrography

TYROS

The Tyros section comprises lavas, hypabyssal rocks, and pyroclastics (tuffs, ashes and agglomerates). Primary textures and minerals are often difficult to distinguish due to advanced metamorphism. Metamorphic mineral assemblages are summarised in Fig. 2. The lavas and hypabyssal rocks can be further divided into basalts, andesites and dacites.

Basaltic lavas

All are porphyritic and a very few are vesicular. The proportion of phenocrysts to groundmass is very variable. Feldspar (probably plagioclase) is the

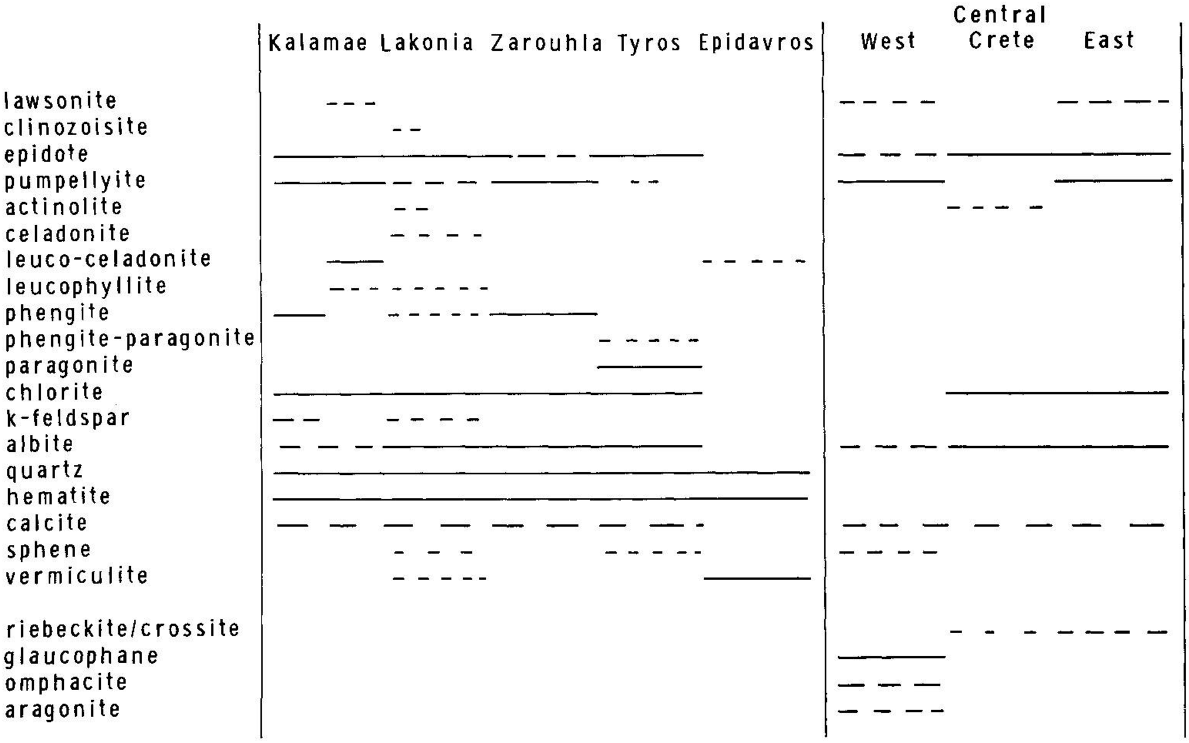

Fig. 2 Geographic distribution of metamorphic minerals in metavolcanic rocks of Peloponnese and Crete. (Data from Crete from SEIDEL et al., 1982, and references cited therein.)

dominant phenocrystal phase. The rare cavities of the basalts are filled with chlorite + quartz ± epidote.

Some rocks contain abundant phenocrysts with crystal outlines similar to pyroxene, that are altered to a dusty, brown, anisotropic mass and appear to have been gradually replaced completely by chlorite, quartz and abundant epidote prisms. Fresh clinopyroxene crystals up to 2 mm size occur in only a few samples. They have altered to green, pleochroic, yellow to colourless pleochroic epidote, quartz and some ?mica. In these samples the feldspar crystals have altered to a dusty microcrystalline assemblage of epidote, quartz, and chlorite. Rare small crystals of pumpellyite have been found only in one sample.

Andesites and dacites

The andesites and dacites are chemically different but show similar petrography. Texturally the following groups can be established.

a) Rocks with 95% of fine grained groundmass and only a few phenocrysts. The identified assemblage is:
chlorite + epidote + quartz + ?feldspar + hematite + mica.

b) Porphyritic rocks with the assemblage:
chlorite + epidote + feldspar + quartz + hematite + sphene + mica.

c) Hypabyssal rocks with a very high proportion of phenocrysts and abundant quartz in the groundmass. Most of these phenocrysts have pyroxene-like crystal outlines. They have been converted to a dusty, brownish, anisotropic mass (?epidote) and (in more altered rocks) they are progressively replaced by abundant epidote prisms, quartz and calcite. In the same samples there are some other phenocrysts altered to quartz and calcite. Thus, the identified assemblage is:
epidote + calcite + quartz + albite + hematite + chlorite + mica.

Pyroclastics

The ashes contain some quartz crystals and some fine grained rock fragments in a very fine grained matrix. The identified minerals are: chlorite + epidote + quartz + mica + ?feldspar. The tuffs are crystal tuffs, lithic tuffs or a mixture of the two, and some contain vesicles filled with mica and epidote. The minerals present are epidote, chlorite, quartz, mica and calcite. Fine grained basaltic crystal tuffs contain abundant quartz as pseudomorphs after dolomite, in addition to chlorite, epidote and hematite. The clasts of the agglomerates are of lithologies generally similar to those found as lavas, hypabyssal rocks, tuffs or ashes.

ZAROUHLA

The volcanic rocks of Zarouhla are either porphyritic or vesicular basalts and andesites. No highly porphyritic rocks similar to those from Tyros or Lakonia (PE-PIPER & KOTOPOULI, 1981) are found. The preserved primary mineral phases are plagioclase and clinopyroxene. The metamorphic assemblage is: pumpellyite + chlorite + phengite ± epidote + albite + quartz + hematite.

Pumpellyite occurs as green pleochroic prisms or as massive patches. Chlorite is green; epidote is colourless or brown; and phengite is colourless, usually on small crystals in phenocrysts pseudomorphs, in cavities or in sheaflike dusty masses in feldspar phenocrysts. In the tectonised samples fractures are filled by calcite and quartz. In such samples some primary phenocrysts are replaced by carbonate.

KALAMAE

All the samples examined from Kalamae are porphyritic metabasalts, often with very large pseudomorphs after feldspar. No primary phases are preserved. On the basis of their metamorphic mineral assemblages they are classified into two groups:

Group 1

These rocks contain leuco-celadonite, leucophyllite and lawsonite in addition to chlorite, pumpellyite, epidote, albite, quartz and hematite. The leuco-celadonite (PE-PIPER, 1983) is greenish to bluish and often carries dusty to colourness zones of leucophyllite. The lawsonite occurs as prisms associated with the K-micas, as crystals enclosed in albitized feldspars or as independent crystals. The chlorite is green or colourless and occurs either as independent crystals or in association with the K-micas and lawsonite. The epidote is in small grains usually in association with the K-micas. The rare pumpellyite occurs as a few independent colourless crystals. The large (2 mm) feldspar crystals have been replaced by albite ± lawsonite + quartz ± leuco-celadonite ± very small amount of chlorite.

Group 2

These rocks contain phengite and K-feldspar in addition to pumpellyite, epidote, chlorite, quartz and hematite, and in some rocks calcite and albite. Pumpellyite and chlorite are the main mineral phases. The pumpellyite is pleochroic yellowish to brown. The chlorite is greenish and the epidote colourless. The feldspar crystals are now replaced by phengite + K-feldspar + epidote ± minor chlorite.

EPIDAVROS

The Triassic volcanic rocks of Argolis are ignimbrites and fine grained tuffs. The ignimbrites consist of glass shards and feldspar, quartz, rare clinopyroxene and rare mica crystals, all set in a greenish matrix. The glass shards are yellowish, brown or colourless, and only some are flattened. The freshest glass shards have a dacitic composition. With increasing alteration, SiO_2, Na_2O and K_2O decrease, whereas Al_2O_3 and CaO increase. In many individual samples, there is a bimodal distribution of the chemical composition of the analysed shards, which is believed to be due to the alteration, since the more altered samples contain only one mode. The feldspar crystals have a composition of $An_{48}Ab_{50}Or_2$ – $An_{39}Ab_{59}Or_2$. Quartz is abundant and it occurs both as independent crystals or in veins. Colourless augite crystals are very rare. The rare K-mica is a greenish leuco-celadonite, occurring in small crystals or veins. The greenish matrix is K_2O rich, which suggests the presence of further K-mica.

PYROXENES

Representative pyroxene analyses are given in Table 1. Most pyroxenes are augites or diopsides, showing calc-alkali chracteristics in the discriminant function analysis of both LE BAS (1962) and NISBET & PEARCE (1977) (see PE-PIPER, 1982, Fig. 12).

TiO_2 contents are less than 0.7%, and Na_2O less than 0.5%. Salites, which are characteristic of some shoshonites, do not occur even at Tyros, although rare pyroxenes from Zarouhla are somewhat aluminous. No systematic variations in pyroxene geochemistry have been observed from one outcrop area to another.

SUMMARY

Only rarely are primary igneous minerals preserved in the metavolcanic rocks studied. Feldspar and clinopyroxene are the only minerals identified in the basalts and andesites, while more acid rocks contain in addition quartz.

Almost all the rocks fall within the lower greenschist metamorphic facies. The predominant mineral assemblage at Tyros is chlorite, epidote and micas. At Zarouhla, the assemblage is chlorite + pumpellyite ± epidote + phengite. At Kalamae, the rocks are similar, containing chlorite + epidote ± pumpellyite with leuco-celadonite, leucophyllite and phengite; however, lawsonite is pres-

Table 1 Representative electron microprobe analyses of primary clinopyroxenes

	TYROS			ZAROUHLA			EPIDAVROS
	1	2	3	4	5	6	7
SiO_2	51.06	51.58	50.92	51.47	49.04	49.87	51.57
TiO_2	0.58	0.45	0.56	0.27	0.70	0.41	0.29
Al_2O_3	2.43	2.21	2.42	2.07	4.24	3.46	0.98
FeO_t	11.10	9.73	13.91	9.60	12.04	10.15	12.92
MnO	0.29	0.23	0.29	0.27	0.33	0.10	0.75
MgO	15.86	16.36	15.73	16.30	13.75	15.72	13.48
CaO	17.72	18.55	15.53	19.40	19.63	19.57	19.76
Na_2O	0.10	0.07	0.20	0.39	0.51	0.35	-
Cr_2O_3	0.12	0.10	0.12	0.06	-	0.10	n.d.
Total	99.26	99.36	99.68	99.83	100.23	99.72	99.75

ent in one sample. Epidavros has a lower grade metamorphic assemblage, with vermiculite and leuco-celadonite.

Whole Rock Geochemistry

Representative whole rock chemical analyses are given in Table 1. Si, Ti, Al, Fe^{+3}_{t}, Mn, Mg, Ca, Na, K have been determined by atomic absorption, P by colorimetry, CO_2 and FeO by titration and H_2O by Penfield tube. The table included an electron micropobe chemical analysis of fresh interstitial glass. In order to calculate CIPW norms, analyses have first been recalculated on a CO_2 and total H_2O-free basis, with IRVINE & BARAGAR'S (1971) correction for iron oxidation.

Most of the rocks from all four localities have been altered, by the addition of significant H_2O (up to 6%) and CO_2 (up to 1%). Only a few samples are relatively unaltered. Plots of major elements against either SiO_2 (Fig. 3) or a differentiation index, show a broad scatter of data points for Ca, K and Na, with only FeO and MgO showing weak linear trends. This suggests there has been considerable mobility of Ca, Na and K as recognized by PE-PIPER et al. (1982) in Lakonia. The Tyros rocks, which comprise basic, intermediate and acid mem-

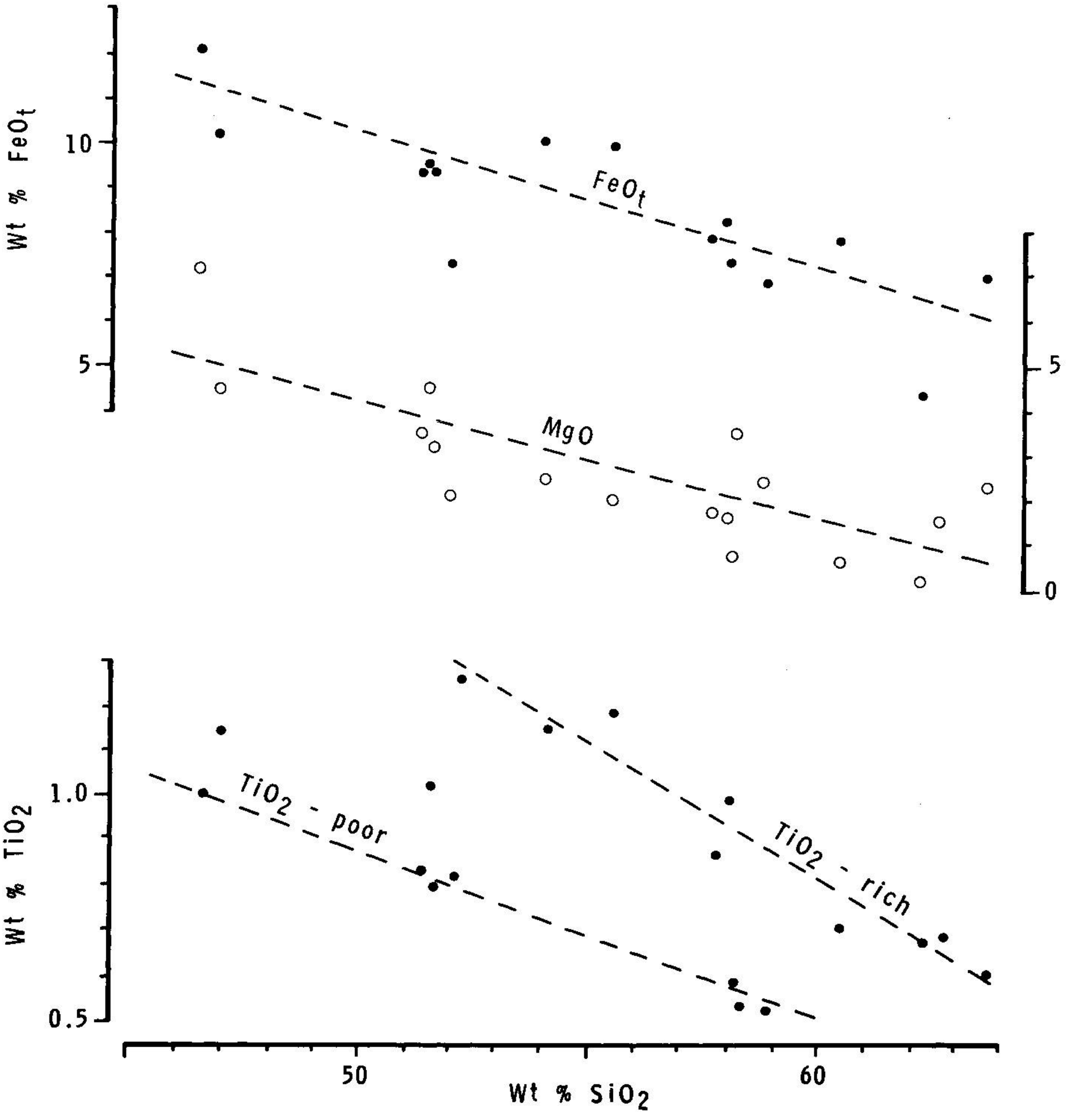

Fig. 3 Plot of FeO$_t$, MgO and TiO$_2$ against SiO$_2$ for analysed rocks from Tyros. Dashed lines are regression lines showing general uniformity of FeO$_t$ and MgO content, but the occurrence of two groups of rocks based on TiO$_2$ content.

bers, show a bimodal distribution of TiO$_2$ against SiO$_2$ (Fig. 3) that appears almost independent of silica content. On a plot of TiO$_2$ against FeO$_t$/MgO (Fig. 4), analyses from Zarouhla and Kalamae cluster together, whereas the Tyros analyses are scattered. The lack of scatter in FeO$_t$ or MgO plotted against SiO$_2$ (Fig. 3) suggests that it is TiO$_2$ which has an anomalous distribution.

Pe-Piper (1982) showed that REE and stable trace elements such as Hf, Y, Ta, Th, Ce, and Zr appear relative immobile and show systematic patterns (Fig. 5). Using criteria summarized by Pearce (1982), these distributions suggest that all the rocks are calc-alkali in character. Those at Kalamae and Zar-

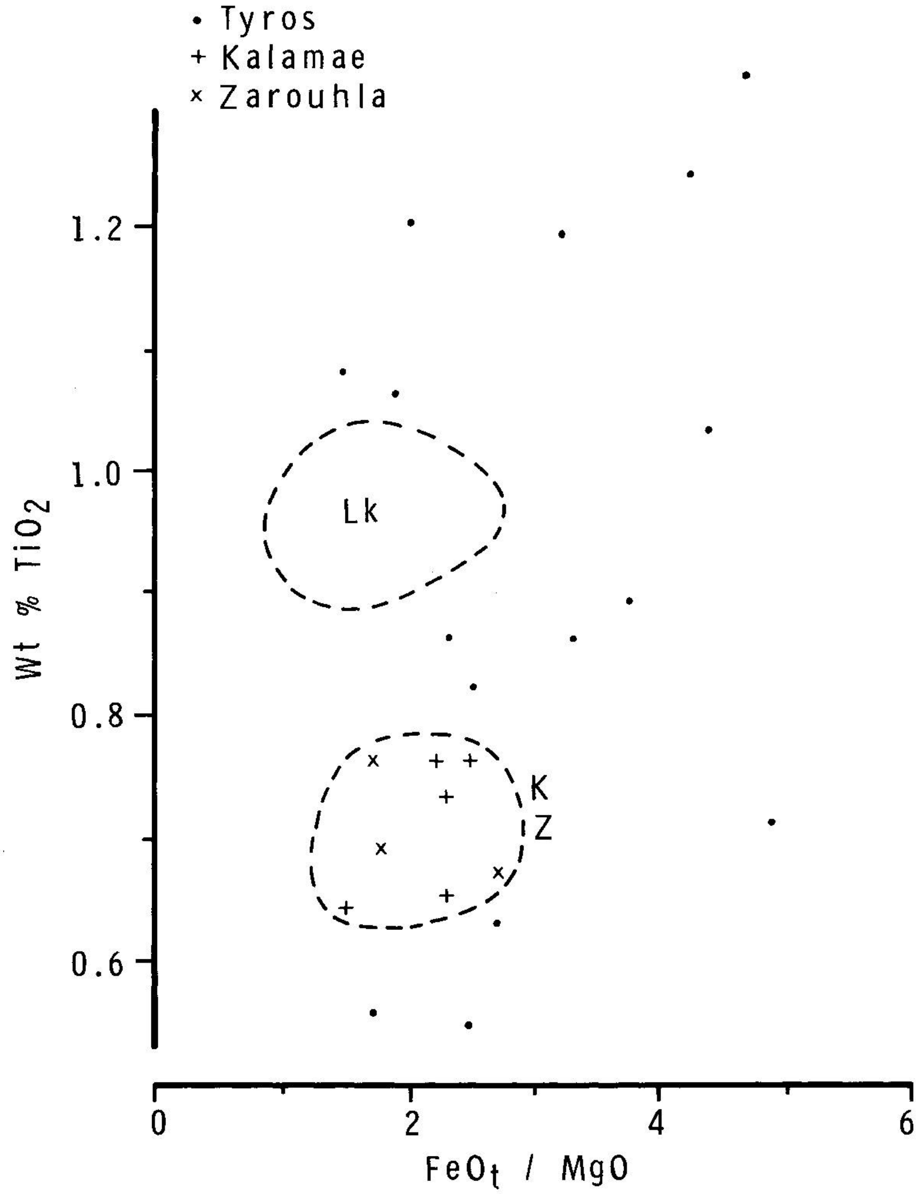

Fig. 4 Plot of TiO_2 against FeO_t/MgO for the volcanic rocks analysed, illustrating scatter of analyses from Tyros (dots), but clustering of Kalamae (K) and Zarouhla (Z) analyses, and those from Lakonia (Lk – PE-PIPER et al., 1982).

ouhla are the most tholeiitic, while the most alkaline are at Epidavros (PE-PIPER 1982, Figs. 3–12; Table 2, this paper).

Discussion

Interpretation of the primary geochemistry and tectonic setting of the volcanic rocks studied is hindered by their metamorphism (PE-PIPER et al., 1982). In rocks from Lakonia, Kalamae und Zarouhla, TiO_2 varies in a systematic

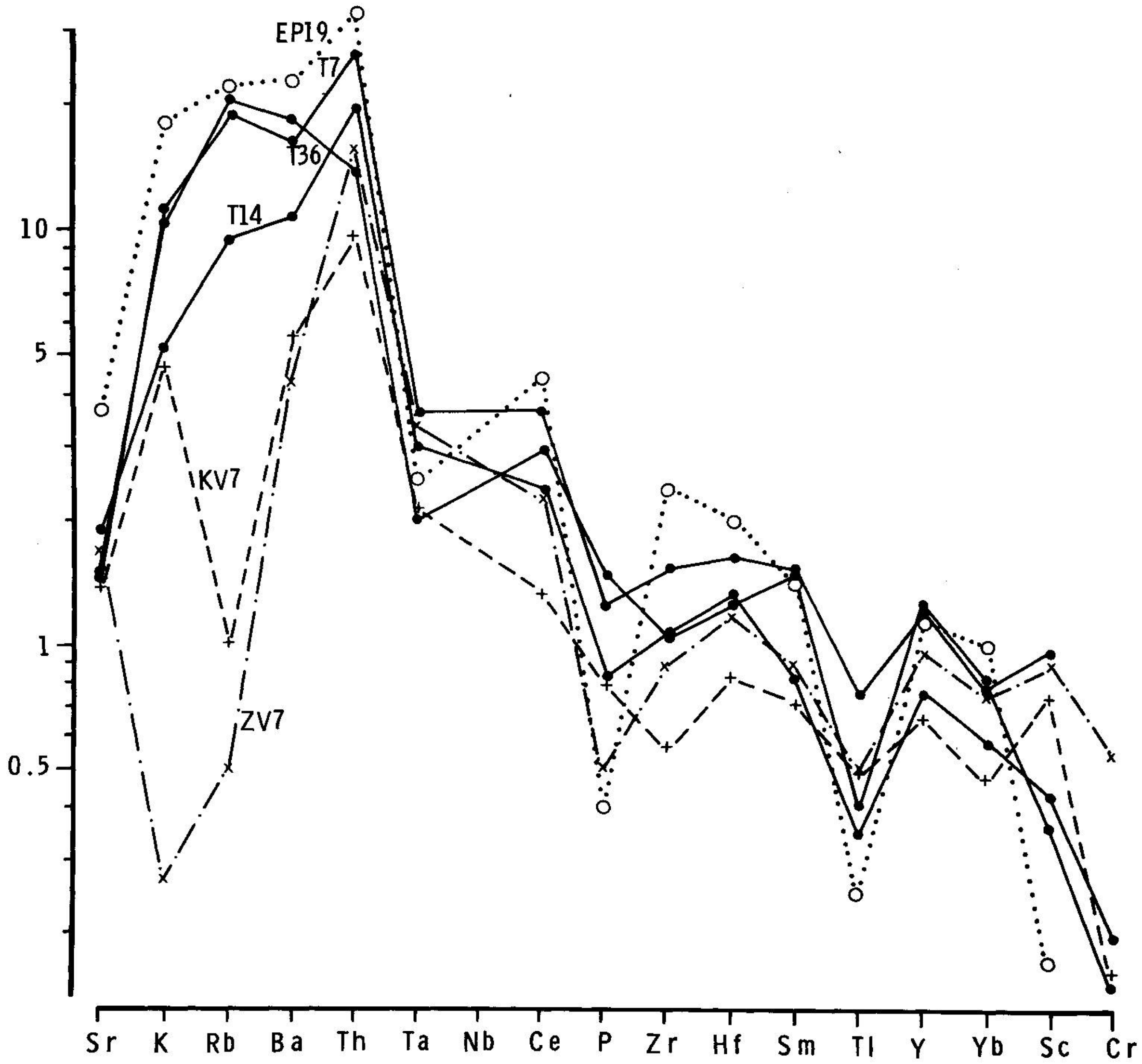

Fig. 5 MORB-normalised trace-element distribution of analysed volcanic rocks. Normalising values from PEARCE (1982).

fashion with SiO_2, and is probably relatively immobile. At Tyros, there is a weak bimodal pattern of TiO_2 distribution (Fig. 2). The content of TiO_2 in basic rocks increase from around 0.7% at Kalamae and Zarouhla to 1.0% in Lakonia and around 1.2% for Ti-rich rocks at Tyros (Fig. 4).

Trace element abundances are conveniently compared when normalised to MORB composition (PEARCE 1982). Samples from Kalamae and Zarouhla are enriched in elements from Sr to Ce, but are depleted in elements of P and higher atomic number (Fig. 5) which is an island-arc tholeiitic character (PEARCE 1982, Fig. 1c). The sample from Tyros is enriched in all elements to Sm, and close to MORB values for most higher elements, thus showing characteristics of both subduction and within-plate alkali volcanism. This is consistent with the Ti-enrichment seen in major element analyses. PE-PIPER (1982) describes several other trace-element patterns that indicate a similar interpretation. The highly fractionated acid rocks at Epidavros cannot readily be compared with the more basic rocks at Tyros, Zarouhla and Kalamae.

The metabasalts at Kalamae and Zarouhla thus appear to be subduction-related tholeiites. The rocks at Tyros are more alkaline in character, showing some within-plate alkaline characteristics, such as enrichment in some samples in Zr, Hf, Sm and Ti relative to MORB (Figs. 4, 5).

SEIDEL et al. (1982) recognize two types of metavolcanite in the Phyllite Series (their PQ unit) of Crete: calc-alkaline andesites and latites, and alkali basalts. The alkali basalts contain titanaugite and kaersutite, and fall within the alkali basalt field on the TiO_2 versus Zr/P_2O_5 plot of WINCHESTER & FLOYD (1976) (SEIDEL et al., 1982). They are thus much more alkaline than any of the Tyros rocks. All the metavolcanics from the Phyllite Series of the Peloponnese appear to be equivalent to the calc-alkaline rocks of Crete; and the stratigraphic evidence in Lakonia suggests they are younger than the alkali basalts which have been dated as late Permian (250 Ma) by SEIDEL et al. (1982).

The metamorphism of the Phyllite Series of the Peloponnese has been compared with that of Crete by SEIDEL et al. (1982). In Crete, metavolcanic rocks show a grade of metamorphism similar to that of the Permo-Triassic sediments in which they occur. SEIDEL et al. (1982) estimate pressure-temperature conditions of 7–9 kb and 300–400° C in western Crete and 3–4 kb and 200–300° C in eastern Crete (SEIDEL, 1981). Lawsonite and pumpellyite are common in metavolcanic rocks in eastern Crete; in addition, glaucophane and omphacite occur in metavolcanics in western Crete.

SEIDEL et al (1982) do not regard the Tyros Beds, in which the metavolcanic rocks are intercalated, as part of the Phyllite Series because they lack high P/T metamorphic minerals. The juxtaposition of almost unmetamorphosed shales (Tyros Beds) and mica-schists in the Phyllite Series (PANAGOS et all., 1979) suggests substantial tectonic complexity.

The metavolcanites at Tyros contain a mineral assemblage similar to that recognized in central Crete (Fig. 2), while those of Kalamae, Zarouhla and Lakonia are more similar to rocks in eastern Crete (Fig. 2; see also Fig. 8 of SEIDEL et al., 1982). The most distinctive differences are the rareity of lawsonite and absence of riebeckite in the Peloponnese. Comparison with Crete provides no basis for the exclusion of the Peloponnese metavolcanites from the Phyllite Series (PQ series of SEIDEL et al., 1982). The metavolcanites are in probable tectonic contact with metasediments of substantially higher metamorphic grade equivalent to that achieved in western Crete. It is thus impractical to follow SEIDEL et al. (1982) in defining the Phyllite Series to exclude the Tyros (and probably also the Ravdoucha) beds on the basis of metamorphic grade, because of the lithologic similarity throughout the entire sequence, and the continuum of metamorphic grades that are observed.

Table 2 Chemical analyses and CIPW norms of representative rock samples from Tyros (T), Zarouhla (ZV), Kalamae (KV) and Epidavros (EP)

	T38	T36	T12	T24	T19	T22	T8	T9a	T23	T31	T1	T16I	T14
SiO_2	46.56	47.01	51.34	51.62	51.73	52.08	52.27	54.16	55.59	57.83	58.07	58.15	58.28
TiO_2	1.00	1.14	0.83	1.01	0.79	0.82	1.26	1.14	1.18	0.87	0.99	0.58	0.53
Al_2O_3	18.70	21.75	18.82	16.95	18.76	19.56	20.10	18.48	18.59	17.81	16.26	15.70	17.45
Fe_2O_3	5.47	4.66	5.97	4.53	5.44	2.33	5.28	5.25	6.59	5.64	5.84	6.02	4.00
FeO	6.01	4.98	2.63	4.42	3.20	4.70	3.73	4.13	2.54	1.30	1.72	0.59	2.86
MnO	0.14	0.14	0.14	0.12	0.13	0.13	0.12	0.12	0.07	0.14	0.13	0.12	0.11
MgO	7.18	4.47	3.46	4.49	3.22	2.07	1.79	2.53	1.99	1.68	1.58	0.67	3.53
CaO	4.18	6.74	11.80	7.02	11.54	11.17	7.04	6.74	2.52	9.26	8.48	12.82	5.07
Na_2O	1.81	2.68	1.77	2.30	1.96	2.59	2.43	2.50	1.36	3.11	2.19	1.52	2.46
K_2O	1.92	1.57	0.16	2.93	0.34	0.26	1.57	0.81	5.33	0.37	1.17	0.30	0.78
P_2O_5	0.14	0.18	0.13	0.16	0.13	0.17	0.23	0.20	0.17	0.17	0.23	0.13	0.10
CO_2	0.05	0.10	0.08	0.08	0.16	0.07	0.06	0.11	0.10	0.31	0.13	1.14	0.05
H_2O+	5.18	4.29	2.94	3.32	2.71	3.31	3.44	3.21	2.75	1.97	2.26	1.70	3.69
H_2O-	1.07	0.63	0.45	0.48	0.26	0.23	0.28	0.61	0.58	0.39	0.48	0.36	0.59
Total	99.41	100.34	100.52	99.43	100.37	99.49	99.60	99.99	99.36	100.85	99.53	99.80	99.50
CIPW NORMS													
Qz	4.79	0.88	10.32	3.72	9.72	10.23	12.45	15.84	16.93	17.13	21.48	24.60	23.53
Or	12.31	9.76	1.01	18.16	2.07	1.60	9.70	5.03	33.00	2.25	7.16	1.83	4.85
Ab	16.58	23.85	15.48	20.39	17.09	22.84	21.49	22.08	12.01	26.91	19.21	13.37	21.91
An	21.45	33.92	44.38	28.62	42.73	42.74	34.99	33.54	11.92	34.27	32.30	36.52	25.77
Wo	-	-	-	-	-	-	-	-	-	-	-	5.24	-
Di	-	-	12.56	5.55	12.84	11.51	-	-	-	9.59	8.18	13.84	-
Hy	31.63	20.83	10.80	17.34	10.27	5.52	11.86	14.98	12.58	4.26	5.41	-	15.75
Ol	-	-	-	-	-	-	-	-	-	-	-	-	-
Mt	3.92	4.03	3.49	3.81	3.42	3.51	4.19	4.00	4.07	3.51	3.76	3.13	3.10
Il	2.06	2.28	1.63	2.01	1.56	1.63	2.51	2.26	2.35	1.69	1.96	1.14	1.06
Ap	0.35	0.44	0.32	0.39	0.30	0.42	0.56	0.49	0.42	0.39	0.56	0.32	0.26
C	6.91	4.01	-	-	-	-	2.25	1.78	6.71	-	-	-	3.78

Table 2 Continued

	T18	T33	T32I	T4	T7	ZV7	ZV6	ZV8	KV7	KV4	KV3	KV1	KV5
SiO_2	58.88	60.51	62.30	62.66	63.68	50.97	53.13	56.67	49.27	49.81	50.61	53.93	55.80
TiO_2	0.52	0.71	0.67	0.68	0.60	0.72	0.67	0.64	0.72	0.62	0.70	0.72	0.60
Al_2O_3	16.18	16.39	17.43	15.31	14.40	17.36	18.07	18.25	20.42	19.92	20.58	18.40	15.74
Fe_2O_3	4.62	6.49	3.79	7.62	3.50	2.30	1.71	2.87	4.17	3.54	2.78	5.90	4.03
FeO	1.70	0.54	0.38	0.48	2.97	6.86	5.99	2.20	4.33	4.70	5.34	3.74	4.86
MnO	0.12	0.08	0.09	0.06	0.09	0.16	0.15	0.10	0.14	0.14	0.14	0.09	0.11
MgO	2.40	0.61	0.18	1.50	2.29	5.08	4.19	1.74	3.66	3.40	3.42	3.67	5.71
CaO	8.99	8.99	7.81	3.44	4.73	6.43	7.75	8.36	7.58	8.70	6.84	3.05	3.00
Na_2O	2.31	2.06	3.62	2.95	1.40	4.78	5.01	4.43	4.51	3.17	4.27	4.77	1.67
K_2O	0.19	0.83	0.43	1.79	1.66	0.04	0.09	0.70	0.15	0.91	1.02	1.31	1.88
P_2O_5	0.09	0.15	0.15	0.19	0.15	0.06	0.06	0.12	0.10	0.09	0.09	0.14	0.08
CO_2	0.56	0.05	0.13	0.06	0.49	0.00	0.08	0.10	0.20	0.03	0.05	0.14	0.72
H_2O+	2.46	2.22	2.15	2.12	3.18	4.48	3.01	2.88	3.64	4.62	4.15	3.57	5.02
H_2O-	0.45	0.32	0.34	0.94	0.46	0.40	0.19	0.42	0.57	0.52	0.38	0.38	0.89
Total	99.47	99.95	99.47	99.80	99.60	99.64	100.10	99.48	99.46	100.17	100.37	99.83	100.11
CIPW NORMS													
Qz	23.11	26.28	25.22	27.42	35.34	-	-	10.07	-	1.80	-	5.25	21.20
Or	1.18	5.09	2.66	11.00	10.29	0.24	0.53	4.32	0.95	5.68	6.51	8.10	11.95
Ab	20.39	18.02	31.64	25.97	12.44	42.73	43.82	39.00	40.18	28.26	37.73	42.30	15.14
An	34.71	34.03	31.08	26.45	23.56	27.21	27.40	29.02	36.95	39.47	34.83	14.89	15.38
Wo	-	-	2.19	-	-	-	-	-	-	-	-	-	-
Di	9.29	9.42	2.27	-	-	5.00	9.82	10.86	1.62	4.44	-	-	-
Hy	7.03	2.10	-	11.23	11.44	15.49	12.79	1.93	8.31	15.64	11.62	20.15	25.55
Ol	-	-	-	-	-	4.36	1.62	-	6.89	-	4.18	-	-
Mt	3.06	3.31	3.25	3.29	3.19	3.39	2.57	3.23	3.39	3.25	3.33	3.38	3.26
Il	1.03	1.39	1.31	1.35	1.20	1.44	1.31	1.27	1.44	1.23	1.39	1.44	1.22
Ap	0.21	0.37	0.37	0.46	0.37	0.14	0.14	0.30	0.26	0.23	0.21	0.35	0.21
C	-	-	-	2.84	2.17	-	-	-	-	-	0.20	4.13	6.10

Table 2 Continued

	EP19d	EP19b	EP19c	EP20	EP27	EP19c+
SiO_2	68.55	69.33	70.58	71.81	82.51	65.82
TiO_2	0.52	0.41	0.38	0.44	0.33	-
Al_2O_3	12.70	11.32	10.37	9.69	6.64	12.48
Fe_2O_3	3.41*	2.83*	2.86*	2.88*	2.24*	n.d.
FeO	n.d.	n.d.	n.d.	n.d.	n.d.	2.89++
MnO	0.05	0.04	0.05	0.03	0.03	-
MgO	0.99	1.00	0.92	0.80	0.96	1.25
CaO	3.20	2.50	2.59	2.00	1.21	2.49
Na_2O	2.09	1.55	1.37	1.47	0.76	0.64
K_2O	2.35	3.16	2.69	2.31	2.07	4.07
P_2O_5	0.09	0.05	0.05	0.04	0.05	n.d.
CO_2	0.04	0.04	n.d.	0.02	n.d.	n.d.
H_2O+	3.13	3.86	4.07	4.78	2.18	n.d.
H_2O-	2.44	3.10	2.86	3.19	1.12	n.d.
Total	99.56	99.19	98.79	99.46	100.01	89.64
CIPW NORMS						
Qz	41.91	45.06	49.61	53.67	68.50	43.18
Or	14.82	20.29	17.34	14.95	12.65	26.86
Ab	18.85	14.24	12.63	13.61	6.65	6.04
An	16.30	13.11	13.65	10.57	5.87	13.78
Wo	-	-	-	-	-	-
Di	-	-	-	-	-	-
Hy	2.63	2.70	2.50	2.18	2.47	4.94
Ol	-	-	-	-	-	-
Mt	2.82	1.76	2.07	1.71	0.35	2.43
Il	1.05	0.85	0.79	0.91	0.65	-
Ap	0.22	0.13	0.13	0.10	0.12	-
C	1.19	1.00	0.67	1.34	1.10	2.78

* Total iron determined as Fe_2O_3

\+ Electron-microprobe analysis of glass shard

++ Total iron determined as FeO

Conclusions

1. The mid-Triassic volcanites of Kalamae, Zarouhla, Lakonia and Tyros are among the lower grade metamorphic rocks (Tyros Beds) of the Phyllite Series of the Peloponnese. Almost unmetamorphosed acid volcanic rocks from Epidavros are of similar age.
2. The metavolcanites at Kalamae and Zarouhla are subduction related tholeiites. In Lakonia and Tyros there is a more varied suite of basic, intermediate and some acid rocks, generally calc-alkaline in character. Some rocks at Tyros show alkaline charcteristics, perhaps related to a back-arc basin setting.
3. Metamorphic assemblages are dominated by chlorite, epidote, K-mica and albite. High pressure minerals are absent, but in places the metavolcanites are in tectonic contact with rocks containing glaucophane and aragonite. The metamorphism is similar to that in the Phyllite-Quartzite Series of Crete.

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