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POSITION OF THE MIDDLE TRIASSIC TYROS-BEDS IN THE GAVROVO-TRIPOLIS UNIT (RHODES ISLAND, DODECANESE, GREECE)

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Abstract: We describe a Middle Triassic volcano-sedimentary sequence, which outcrops on Rhodes Island at the southeastern edge of the Aegean Arc. The sequence is tectonically overlain by the Mesozoic calcareous platform of the local Archangelos Unit. The latter is regarded as equivalent to the Gavrovo-Tripolis Unit of mainland Greece and Crete. We propose that the volcano-sedimentary sequence described here is homologue to the Tyros Beds of Peloponnesus or the Ravdoucha Beds of Crete, which mark the stratigraphic base of the Gavrovo-Tripolis calcareous platform. Consequently we suggest that Tyros Beds characterize the base of the Gavrovo-Tripolis Unit all along the southern Hellenic Arc, from Peloponnesus through Kythira and Crete to Rhodes Island.

Key words: Middle Triassic, Hellenides, Gavrovo-Tripolis Unit, Tyros Beds, volcanoclastic sedimentation.

Introduction

The Hellenic Arc is a multi-phase orogenic structure characterized mainly by extended nappes and thrust sheets. The present distribution of the various tectonic units (Hellenides) is the result of two successive orogenic phases, the eohellenic phase in the Late Jurassic–Early Cretaceous and the Alpine phase in Late Eocene–Early Miocene. The imprint of the eohellenic phase on some of the Hellenides has been used to distinguish them in Internal, which have been affected by that phase, and External, which have not been affected.

The paleogeographical distribution of the Hellenides has been for a long time and still is a matter of controversy among geologists, while the number of oceanic sutures still remains obscure (Robertson & Dixon 1984; Dercourt et al. 1986; Papanikolaou 1989). The correlation of the tectonic units, which outcrop in continental Greece with similar units outcropping on the Aegean islands, is another weak point in the geological interpretation of the Alpine structure. Recently new aspects on the paleogeographical organization of the Hellenides in the Late Paleozoic–Early Triassic came to light (Stampfli et al. 1998). The main question for that period is whether the various Triassic volcano-sedimentary sequences, which occur in the lower part of the lithostratigraphic columns of several tectonic units, represent passive margin volcanism and are related to the opening of Tethys or they are related to older consuming plate margins.

Rhodes Island is located at the southeastern edge of the Hellenic Arc (Fig. 1) and is characterized by a rather complicated Alpine geotectonic structure. Although numerous geologists have worked on the island since the beginning of the 20th century, fundamental aspects of the Alpine structure of Rhodes still remain obscure. The number and the origin of the Alpine units, the time span covered by their litho-stratigraphic columns, the tectonic relation between them as well as their correlation with similar units occurring in continental Greece and Crete are still a matter of debate. Consequently, the role of the Alpine units of Rhodes Island in the paleogeographical configuration of the Hellenides is not well understood.

In the present paper we describe a volcano-sedimentary sequence of Middle to Late Triassic age and we attempt to correlate it with known and geodynamically equivalent volcano-sedimentary sequences of the External Hellenides.

Geotectonic structure of Rhodes Island

Thick Neogene sedimentary sequences have been deposited in large, fault-controlled basins created during the postalpine period. The Alpine rocks built up mainly the mountainous areas of the island, which are surrounded by low relief areas covered by postalpine sediments (Fig. 2).

According to most of the researchers, the metamorphic Lindos Unit is the lowermost tectonic unit outcropping on Rhodes Island (Aubouin & Dercourt 1970) (Fig. 2). It is composed of dark bluish marbles, which develop upwards to thin-bedded marbles and ends with a metaflysch. The transition from calcareous sedimentation to flysch deposition occurs in late Eocene–Early Oligocene (Leboulenger & Matesco 1975). The geotectonic position of the Lindos Unit within the Hellenides is a matter of controversy among the various researchers. Some support its correlation either with the Ionian (or the Plattenkalk) Unit (Pozzi & Orombelli 1965; Leboulenger & Matesco 1975; Papanikolaou et al. 1995). Others, as Mutti et al. (1970) and Aubouin & Dercourt (1970) regard it as equivalent of the Preapulian Unit, because of its contents in shallow water fauna.

Lindos Unit is overlain by a mélange-type formation, which consists of pelites, clays, sandstones and bioclastic or conglomeratic limestone. Exotic blocks of volcanic rocks, pelagic

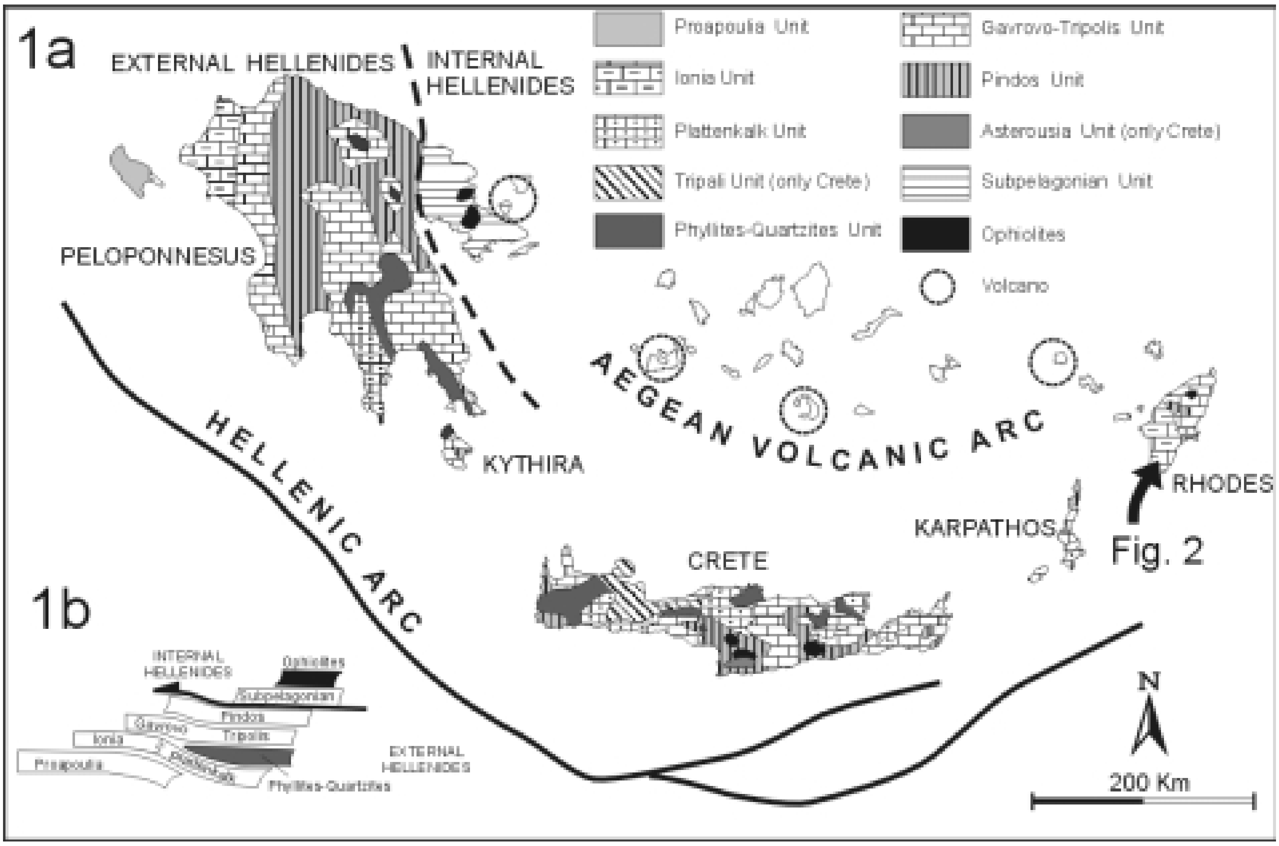

Fig. 1. a. Simplified geotectonic map of the Southern Aegean region (after Jacobshagen 1986) showing the geographical distribution of the main tectonic units of the External Hellenides. The Preapulian Unit constitutes the foreland of the Hellenides. Tripali and Asteroussia Units occur only in western and central Crete respectively. The Phyllite-Quartzite Unit is a Permo-Triassic sequence tectonically emplaced between the Plattenkalk and Tripolis Units, and is regarded by most authors as the metamorphic equivalent of the Tyros Beds. The tectonic relationship between the main Units is shown in Fig. 1b.

and brecciated limestones are included within this formation. The age of the formation, which is known as “Laerma wild flysch” (Papanikolaou et al. 1995), is Early Oligocene (Mutti et al. 1970).

Attavyros-Akramites Unit is the lowest among the allochthon units, which overlie the Laerma wild flysch (Fig. 2). The succession of the litho- and biofacies of this unit is very similar to those of the Ionian Unit in continental Greece and Crete Island (Renz 1929; Renz 1955; Orombelli & Pozzi 1967; Mutti et al. 1970; Aubouin & Dercourt 1970; Leboulenger & Matesco 1975). On the contrary, Harbury & Hall (1988) support a paleogeographical position of the Attavyros-Akramites Unit between the Gavrovo-Tripolis platform and the Pindos Basin.

The Archangelos Unit is constituted of a thick sequence of massive to thick-bedded limestone and dolomites of Late Triassic–Early Eocene age and Middle–Late Eocene flysch (Mutti et al. 1970; Leboulenger & Matesco 1975). Like the previous unit, the Archangelos Unit overlies tectonically the Laerma wild flysch (Papanikolaou et al. 1995) (Fig. 2). Renz (1929, 1955) considered that it corresponds to the Parnassos-Giona Unit of continental Greece, though Orombelli & Pozzi (1967) suggested a paleogeographical position near the Gavrovo Zone. On the contrary Aubouin & Dercourt (1970), Leboulenger & Matesco (1975) and Papanikolaou et al. (1995) correspond the Archangelos Unit with Gavrovo-Tripolis Unit, because of its tectonic position below the Profitis Ilias Unit (equivalent of the Pindos Unit), and the Eocene age of the uppermost horizons of its calcareous sequence.

The Profitis Ilias Unit is constituted exclusively of pelagic sediments, like thin-bedded limestones with silex, red marls and red radiolarites of Late Triassic–Early Cretaceous age (Mutti et al. 1970), and corresponds undoubtedly to the Pindos Unit.

The uppermost nappe on the island of Rhodes is constituted of ophiolite rocks. According to Aubouin & Dercourt (1970), Leboulenger & Matesco (1975) and Papanikolaou et al. (1995), they tectonically overlie the Profitis Ilias Unit. Mutti et al. (1970) on the contrary believe, that the ophiolites are tectonically intercalated between the Archangelos Unit below and the Profitis Ilias Unit above. These ophiolite outcrops have been interpreted as remnants either of the Vardar–Axios oceanic basin (Aubouin & Dercourt 1970), or of the Pindos oceanic basin (Papanikolaou et al. 1995).

As mentioned above, the dominant hypothesis in the existing literature favours the correlation of the Archangelos Unit with the Gavrovo-Tripolis Unit of continental Greece. The correlation of these two stratigraphically and tectonically similar units is strongly supported by the occurrence of a volcano-

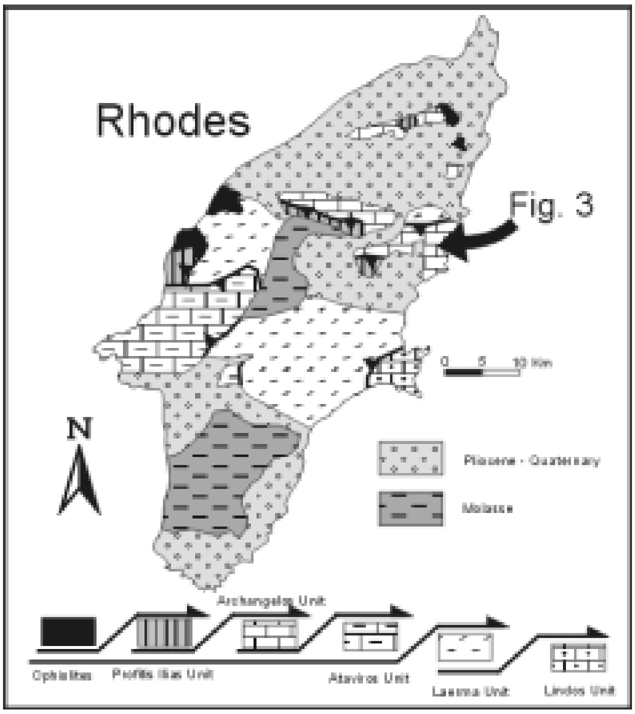

Fig. 2. Simplified geotectonic map of Rhodes Island according to Papanikolaou et al. (1995). See text for explanation and their correlation with the units of Fig. 1.

sedimentary sequence at the base of the platform of Archangelos Unit, which is very similar to the Tyros Beds.

Tectonic position and lithostratigraphy of the Archangelos volcano-sedimentary sequence

Although the outcrop of the Archangelos volcano-sedimentary sequence, southwest of the village with the same name, has been very early reported by Migliorini & Venzo (1934) and Mutti et al. (1970), its paleogeographical position and geodynamic significance remained obscure.

Mutti et al. (1970) mention the presence of limestone Beds alternating with brown-green pelites on the slopes of the Mt. Karavos near Archangelos village. The thickness of the formation is barely 20 m. The authors also note that the lower contact of the sequence to the calcareous Beds of the Archangelos Unit is faulted, while the upper one is characterized as normal stratigraphic contact. Within this formation they determine *Diplopora* sp., *Balanocidaris scrobiculata* (Bronn), *Stefaninia* cf. *ogilviae* (Bittn.) and *Mytilus* sp. and ascribe it to Carnian.

The stratigraphically lower horizons of the Archangelos Unit, which contain the volcano-sedimentary formation, outcrop on the eastern slope of Mt. Karavos, 500–600 m southwest of the Archangelos village, in the central eastern part of Rhodes Island (Figs. 3, 4a). They are tectonically emplaced in-between calcareous sediments of the Archangelos carbonate platform and are partly covered transgressionally by Quaternary coastal deposits (Fig. 3a,b). The profile presented below has been described and studied along the road climbing the eastern slope of Mt. Karavos (Fig. 4a).

The strata of the sequence strike NW-SE and dip SW-wards with 40°–70° (Fig. 4a,b). They lie tectonically on white to pinkish, thick bedded or massive, micritic to microbreccia and dolomitic limestones of the Archangelos Unit. The age of the calcareous sediments remains unknown, since no fossils were found but on the basis of their sedimentary character we ascribe them to the Upper Triassic–Lower Middle Jurassic.

The volcano-sedimentary formation itself is overlain tectonically by white to pinkish, 1–1.5 m thick-bedded, microbrecciated or endomicritic limestones, which contain angular and rounded limestone clasts and dip NE-wards. (Figs. 3a,b, 4a,c). Mutti et al. (1970) have found echinoid spines, bivalves, and Dasycladaceae within these calcareous sediments. Corals, *Cladocoropsis mirabilis* (Felix), echinoid spines, octracods, *Frondicularia* sp., *Trocholina* sp. and many other fossils have also been reported from younger horizons of the same formation located at a small distance to the east of the main outcrop.

Description of the profile

The volcano-sedimentary formation near Archangelos village has the following litho-stratigraphy from the stratigraphically lower to the higher levels (Fig. 3c).

a. The stratigraphically lower horizons are composed of alternations of pelites and tuffs with rare intercalations of sandstone and limestone horizons. Green and pink layers or rounded bodies of igneous rocks, as well as foliated and strongly altered pillow lavas are usually observed within the clastic sediments. Quartz, plagioclase, green amphibole, chlorite and opaque minerals have been observed in thin sections from the volcanoclastic, tuff layers. Mineralogical analysis of thin sections from the lava layers and rounded bodies revealed andesitic to diabasic composition with diopside phenocrystals flowing within microlithic matrix composed of plagioclase, chlorite, epidote, calcite and opaque minerals. The sandstone and limestone horizons become more abundant toward the higher stratigraphic levels. The calcareous layers are endobiomicritic to bioclastic limestones and contain fragments of algae, echinoderms and corals. Their thickness does not exceed 40 cm. The total thickness of this part of the sequence reaches 250–300 m. This formation overlies tectonically massive and thick-bedded dolomitic limestones of unknown age.

b. Upwards follows a 4–5 m thick sequence of yellowish sandstones and pelites within which greenish tuffs and grey, brecciated limestone Beds of 10–12 cm thickness are intercalated. The limestone Beds become thicker (up to 40–50 cm) upwards and contain fragments of algae and echinoid spines. Large calcareous clasts of up to 1.5 m in diameter have been deposited within the clastic sediments.

c. Alternations of thin green-grey pelites and yellow-greyish limestones of 15 m total thickness follow. The thickness of the limestone horizons increases towards the top of the sequence from 1–15 cm to 10–30 cm. They are microbrecciated and contain fragments of corals and bryozoa, unilinear foraminifers, algae and crinoides (*Encrinus liliiformis*) of Middle Triassic age. At the top of the sequence, a 30 cm thick microbreccia to bioclastic limestone horizon contains coral fragments, bryozoa, crinoides (*Encrinus liliiformis*), algae

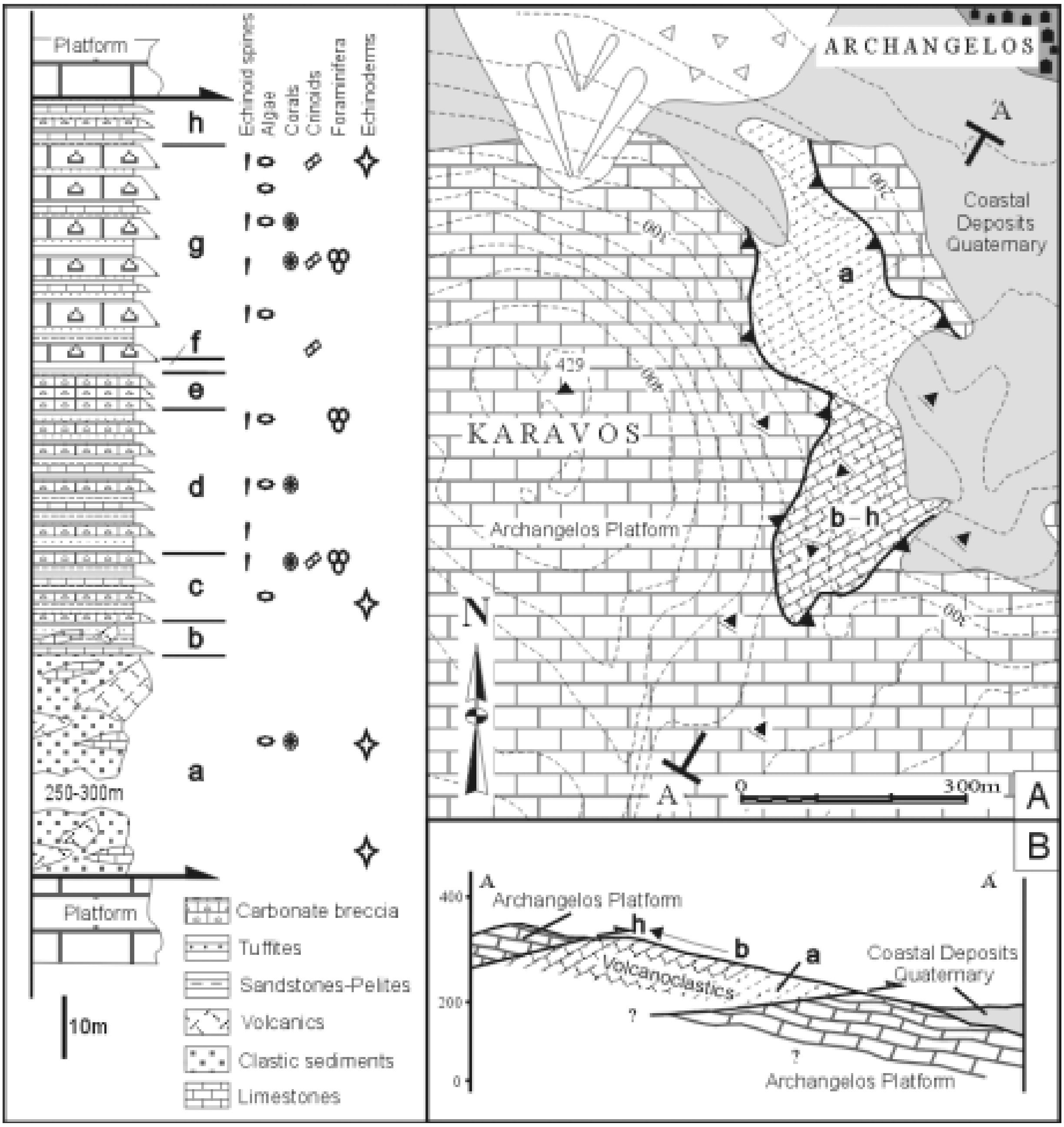

Fig. 3. A: Geological map of the area southwest of Archangelos village. See Fig. 2 for location. B: Geological cross-section A–A´. C: Stratigraphic column of the Archangelos volcano-sedimentary sequence. See "Description of the profile" for explanations on a–h.

(Diplopora sp.), foraminifers and echinoid spines of the Middle Triassic (Fig. 4d).

d. Thickness 30–32 m. Limestones and pelites with rare intercalations of 20–40 cm thick green tuffs and 12–15 cm thick yellow sandstones. Two facies of limestone horizons have been observed within this sequence. The first one corresponds to grey micritic limestones of 1–6 cm thickness, containing echinoid spines. The second facies corresponds to brecciated bioclastic limestone horizons of 10–40 cm thickness with some algae fragments and recrystalized coral fragments.

e. Thickness 5 m. Limestones with rare intercalations of green and yellow pelites. The thickness of the individual calcareous Beds reaches 60 cm.

f. 1 m thick green pelites and tuffs.

g. Thickness 45 m. Alternations of up to 1 m thick limestone Beds with up to 30–35 cm thick pelites and yellow to green tuffitic horizons with rare intercalations of sandstones. The brecciated limestone layers contain big fragments of crinoides (*Encrinus liliiformis*), recrystalized algae fragments, (*Diplopora* sp.), rounded and angular micritic pebbles and bryozoa. Their age is Middle Triassic.

h. Thickness 10 m. Alternations of 5–25 cm thick limestone Beds and 5–10 cm thick pelitic horizons. The micritic facies become more rare.

The upper contact of that series to the overlying limestones of the Archangelos platform is of tectonic origin. The contact

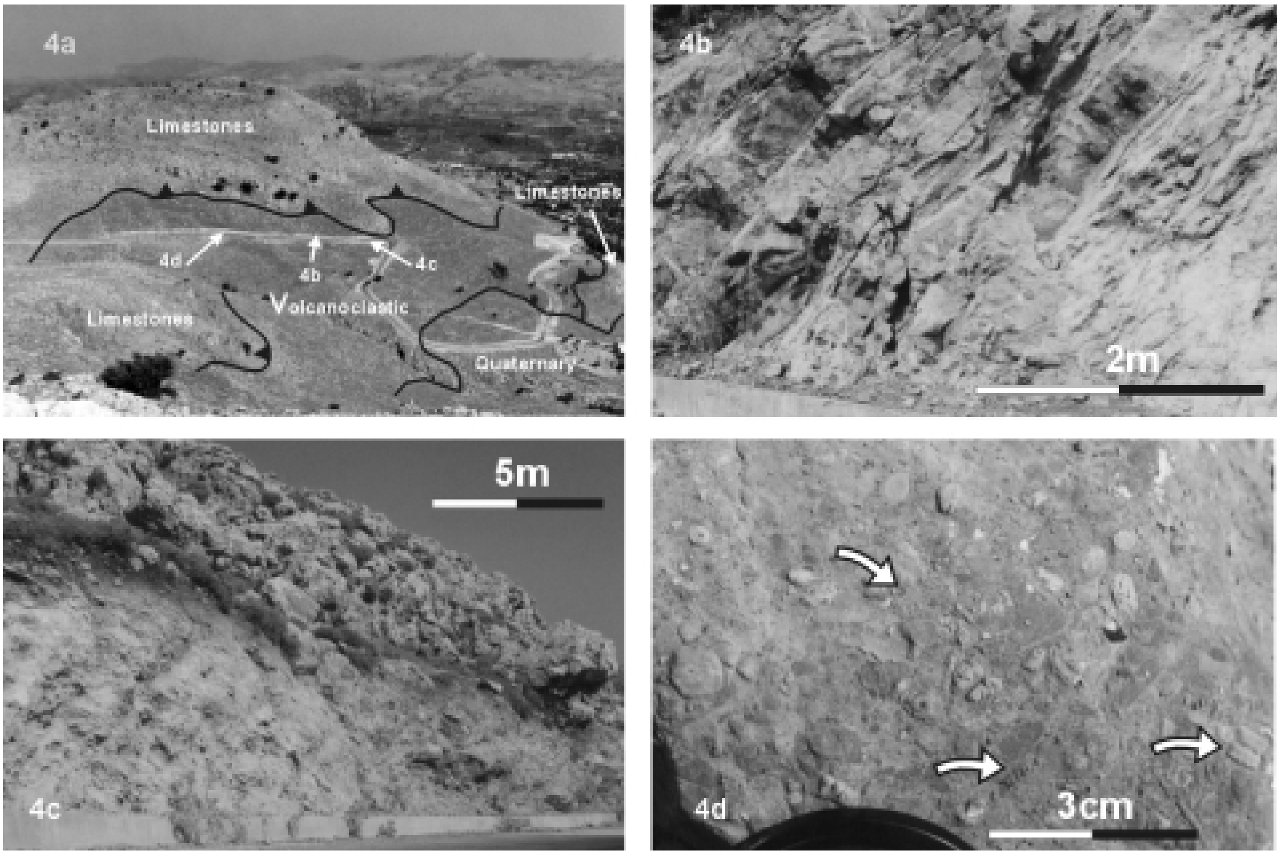

Fig. 4. a: View of the Archangelos volcano-sedimentary sequence outcrop from the east. b: Alternation of brecciated limestones, pelites, sandstones and tuff horizons. c: The tectonic contact between the Archangelos carbonate platform and the volcano-sedimentary sequence. d: *Encrinus lilliformis* within brecciated limestone. The location of the pictures of Fig. 4b, c and d are shown in Fig. 4a.

at the southern part of the outcrop dips relatively steeply while at the eastern and western part it becomes subhorizontal and crosscuts the stratigraphic horizons of the underlying volcano-sedimentary sequence (Figs. 3a,b, 4a).

Discussion

Up to now the Archangelos Unit was regarded by most researchers as equivalent to the Gavrovo-Tripolis Unit mainly because of the following two aspects: (*a*) the age of the Archangelos Unit calcareous sequence, which is compatible to the continuous Late Triassic–Upper Eocene calcareous sedimentation of the Gavrovo-Tripolis shallow water platform and (*b*) the tectonic position of the Archangelos Unit below the pelagic unit of Profitis Ilias, which is attributed by almost all researchers to the Pindos Unit.

The new data presented in this work support that hypothesis. We suggest, that the above-described volcano-sedimentary sequence of the Archanglos Unit is equivalent to the lower part of the litho-stratigraphic column of the Gavrovo-Tripolis Unit, meaning the Tyros Beds in the Peloponnesus or their equivalent Ravdoucha Beds in Crete Island.

Our hypothesis is supported by a) the lithological similarity between the Archangelos volcano-sedimentary sequence and the Tyros Beds; b) the age of the sequence, which has been also reported from several places in Peloponnesus and Crete for the upper part of the Tyros Beds and c) the tectonic position of the sequence below the Archangelos Unit carbonate platform, similar to the position of Tyros Beds below the Gavrovo-Tripolis platform.

The Upper Paleozoic–Lower Triassic volcano-sedimentary formation at the base of the Gavrovo-Tripolis shallow platform was recognized very early (Ktenas 1926) and repeatedly described since then. The Tyros Beds are characterized by a lower clastic formation and an upper volcano-sedimentary sequence (Fig. 5) (Skarpelis 1982). The lower part is constituted of pelites and sandstones, that often form turbite sequences within which calcareous lenses intercalate. Carboniferous, Permian and Early Triassic ages have been reported for the lower part of the Tyros Beds (Ktenas 1926; Lys & Thiebault 1971; Panagos et al. 1979; Thiebault 1982).

The majority of the Tyros Beds outcrops in the Peloponnesus and Crete are dominated by the upper volcano-sedimentary part. It is composed of lava horizons, pyroclastics, tuffs and clastic and calcareous sediments that intercalate within volcano-sedimentary deposits (Skarpelis 1982). Numerous fossils such as ostracods, echinoids, ammonites and conodonts, found within the calcareous Beds, are evidence of a Carnian–Norian and in some places also Rhaetian age for the upper part of Tyros Beds (Sannemann & Siedel 1976; Kopp & Ott 1977; Thiebault 1982; Brauer et al. 1980; Thorbecke 1987; Gerolymatos

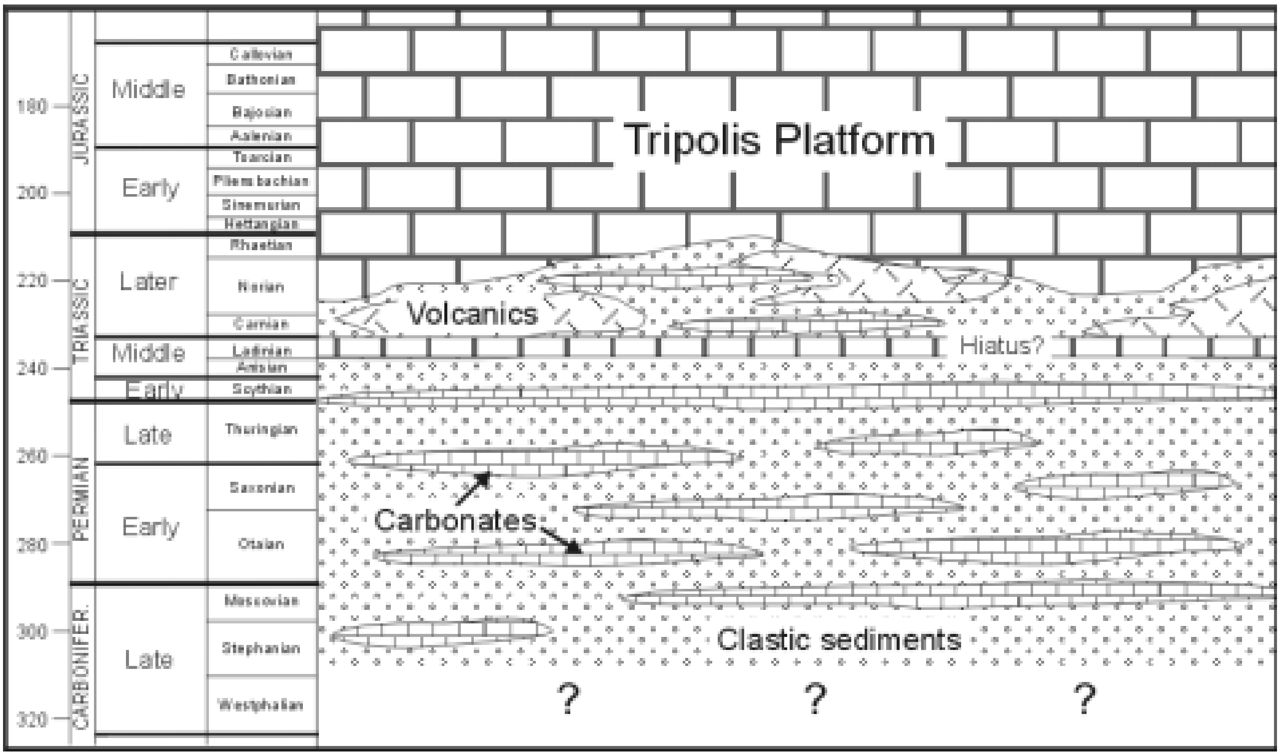

Fig. 5. Schematic presentation of the geological evolution of the Tripolis Unit in the Late Carboniferous–Early Jurassic.

1994). According to the synthetic litho-stratigraphic columns proposed by Gerolymatos (1994) and Dornsiepen & Manutsoglu (1994) for the Tyros Beds, a stratigraphic hiatus occurs in the Middle Triassic (Ladinian) (Fig. 5). It is possible that this hiatus represents the limit between the lower, clastic formation and the upper, volcano-sedimentary sequence of the Tyros Beds (Fig. 5).

The continuous transition from the volcano-clastic sediments of the "Tyros Beds" to the Gavrovo-Tripolis platform sedimentation has already been described from various places in the Peloponnesus (Tataris & Maragoudakis 1967; Fytrolakis 1971; Lekkas & Papanikolaou 1978; Thiebault 1982) and Crete (Kopp & Ott 1977; Bonneau & Karakitsios 1979; Fytrolakis 1980). This transition has usually been found to take place in the Late Carnian–Rhaetian, while Lias age is also reported by Alexopoulos (1990) in central Crete. Danamos (1991, 1992) and Gerolymatos (1994) report a tectonic relationship between the underlying Tyros Beds and the overlying shallow water carbonates. Consequently, we suggest that the volcano-sedimentary Archangelos sequence may easily be correlated with the upper part of the Tyros Beds.

There is a lot of incertitude regarding the origin of the Tyros Beds and the geotectonic setting of the Triassic volcanism. Thiebault (1982) & Thiebault et al. (1985) suggest that the shoshonitic composition of the Tyros volcanites is related to a rifting phase though Skarpelis (1982) and Pe-Piper (1982) favour an above subduction zone character for the Tyros volcanism. Pe-Piper (1983a,b) notes the presence of tholeiites and calcalkaline basalts, which may refer to an old subduction zone, but also describes also more alkaline types, which display within-plate character. Therefore she suggested that the Triassic volcanism occurred close to an old consuming plate boundary and is also related to the initial stage of a back-Arc rifting process. Later the same author (Pe-Piper 1998) suggested, on the basis of the geochemistry of Nd and Pb isotopes, that the Triassic volcanisms are related to a general extension, which affected the paleogeographical area of the Hellenides during that period. Recently Stampfli et al. (1998) proposed that Tyros-Beds represent an accretionary prism created in front of the subduction zone of the Paleotethys oceanic lithosphere below the southern Eurasian margin.

Up to now there are no data from the volcanic rocks of the Archangelos volcano-sedimentary sequence, which would allow us to support any of the proposed hypotheses regarding the geotectonic setting of the Triassic volcanism. The presence of pillow-lavas and the alternations described suggest a sequence rich in calcareous redeposits possibly deposited in deep water conditions.

It is obvious, that a widespread volcanic activity occurred in the Middle–Late Triassic within the palaeogeographical area of the Gavrovo-Tripolis Zone, before the onset of the shallow platform calcareous sedimentation. The deposition of the volcanic material was interfering with clastic and biochemical? sedimentation possibly in a shallow water environment. The end of that volcanic phase marks the onset of the calcareous sedimentation either in the Carnian–Norian or Rhaetian, or even in the Lias in central Crete. The shallow water platform sedimentation continued without any break until the Early Tertiary.

Conclusion

We propose that the Middle Triassic volcano-sedimentary sequence, which outcrops near Archangelos village in eastern Rhodes Island, is a homologue to the Tyros and Ravdoucha Beds, which represent the stratigraphic base of the Gavrovo-Tripolis carbonate platform in the Peloponnesus and Crete respectively.

The correlation of the Archangelos volcano-sedimentary formation with Tyros Beds indicates that the latter constitutes a significant characteristic of the entire palaeogeographical area of the External Hellenides carbonate platform, from the Peloponnesus through Kythira and Crete to Rhodes, before the onset of the shallow water sedimentation in the Middle–Upper Triassic.

The deposition of clastic sediments, accompanied by andesitic volcanism with lava flows and tuff layers, predates the onset of the shallow marine calcareous sedimentation of the Gavrovo-Tripolis Unit and is present throughout the entire paleogeographical area of the unit. It is noteworthy that the sedimentary facies and the lithological characteristics of the Upper Paleozoic–Upper Triassic volcano-sedimentary Tyros-Beds formation remain more or less constant all along the southern Hellenic Arc.

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